Analysis and Recommendations on the Exhaustion of IPv4 Address Space

This document is the translation of the original report in Japanese available at:

http://www.nic.ad.jp/ja/research/ipv4exhaustion/ipv4exh-report.pdf

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Expert Research Team on Number Resources Utilization

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1. Introduction

The development of the Internet is inextricably linked with the expansion in the consumption of IPv4 address space. The Internet has rapidly developed throughout the world for almost a decade, and 32-bit IPv4 address space limitations have become severe.

The shortage of IPv4 address space had been projected as early as 1990. Since around last year when the actual allocatable IPv4 address space became less than one fourth of the total space, the exhaustion of IPv4 address space has become a real possibility. Moreover, some experts have brought forward their projections for the date of IPv4 address space exhaustion; if the pace of allocation over the last 3 to 5 years continues, it is predicted that IPv4 address space will be exhausted at a relatively early stage.

This report summarizes the current state, events that may arise, and preparations required for the eventual exhaustion, with reference to projections for the date of IPv4 address exhaustion. The objective is to enable the smooth operations and usage of the Internet even at the time of IPv4 address space exhaustion.

Chapter 2 analyzes in detail projections for when IPv4 address space will be exhausted, the basis of this report. The eventual exhaustion of IPv4 address space has been predicted by several experts. In this report, we study each projection as well as its basis, and the predicted exhaustion point. The projections are also analyzed statistically and objectively.

Chapter 3 looks at the utilization state of IPv4 address space in Japan, the Asia-Pacific region, as well as throughout all regions globally. In the history of IPv4 address space, which had been used in various forms since 1980, there was a time when the address space was not managed in an orderly manner as in today, and large volumes of address space had been given out as a result. With this and other factors in mind, we shall look at the utilization state of IPv4 address space from a technical perspective.

In Chapter 4, we compile and classify the phenomena related to the exhaustion of IPv4 address space into several phases based on issues raised so far. The events that may occur for each phase are examined, such as a surge in demand just before the exhaustion and appearance of the black-market of IPv4 address space after the exhaustion. Furthermore, the co-existing network during migration from IPv4 Internet to IPv6 Internet is discussed and its influence is examined.

In Chapter 5, some recommendations are offered based on the discussions for ensuring usage of the current IPv4 Internet and new IPv6 Internet without difficulty as IPv4 address space is exhausted and during the final phase of allocations of IPv4 address space.

Recommendations are offered for six types of organizations and the Internet users: Internet Registries, Internet service providers, IP engineers including vendors, service providers using the Internet, corporate users, and end users.

We consider it the highest priority that Internet service providers prepare for IPv6 network services to enable IPv6 Internet connectivity for their customers. We propose IP engineers, such as developers and vendors to improve their IPv6 products to ensure the safe and convenient usage of the Internet.

This report does not focus on exactly when IPv4 address space will be exhausted as the speed of depletion may change according to future demand for address space. Rather, it offers various recommendations in order to draw attention to the issue and encourage preparations for the recommended measures with a rough time frame in mind.

The recommendations contained in this report are intended to serve merely as a reference. Events may turn out very differently from the recommendations or projections studied here. By referring to the recommendations offered, the authors merely wish to encourage the stakeholders to consider what actions should be taken when IPv4 address space is exhausted.

2. Global consumption trends of IPv4 address space and future projections

From 2003 to 2005, industry experts throughout the world have provided numerous projections and reports on when IPv4 address space would be exhausted.

Due to differences in the definition and concept of exhaustion, projections varied widely, ranging from January 2009 to 2028.

Among these projections, in this chapter we look into three reports issued in 2005 and one virtual meeting.

2.1. Reports on IPv4 address consumption

In this chapter, the following reports and a virtual meeting concerning the exhaustion of IPv4 address space are introduced.

- "IP Address Space Report"

  Author Geoff Huston (APNIC[1])
  Date Data is automatically updated daily.
  URL http://bgp.potaroo.net/ipv4/
  *The original document was updated in January 2006, but this document is based on the content before the update to provide the background for previous issues raised.

- "A Pragmatic Report on IPv4 Address Space Consumption"

  Author Tony Hain (Cisco Systems)
  Date September 2005
  URL First half of
  http://www.cisco.com/application/pdf/en/us/guest/about/about/c644/ccmigration_09186a00805320df.pdf

[1] APNIC: Asia Pacific Network Information Centre
One of the regional Internet registries that performs IP address management in the Asia-Pacific area http://www.apnic.net/

- "A Virtual Roundtable Meeting" (Virtual meeting by Email)

Participants	Tony Hain	(Cisco Systems)
	Geoff Huston	(APNIC)
	John Klensin	(Independent Consultant)
	Fred Baker	(Cisco Systems)
Date	October 2005	
URL	Latter half of http://www.cisco.com/application/pdf/en/us/guest/about/about/c644/ccmigration_09186a00805320df.pdf	

- "IPv4 - How long have we got?"

Author	Geoff Huston	(APNIC)
Issuance date	November, 2005	
URL	http://www.potaroo.net/ispcol/2005-11/numerology.html	

The next section summarizes the predicted date of exhaustion in each report, and the subsequent sections examine each report in detail.

2.2. Summary of each report on the exhaustion of IPv4 address space

Table 2-1 shows a summary of each report.

Table 2-1 Summary of each report

Document	Issued	Author	Characteristics	IANA pool	RIR pool	BGP
The ISP Column (How long have we got?)	Jul. 2003	Geoff Huston	- Estimated using trends over the last 10 years - Considering advertised routes	2021	2022	2029
IPv4 Address Report (Potaroo)	Dec. 28 2005 (*1)	Geoff Huston	- Estimated using trends over the last 10 years - Considering advertised routes	Jan. 2013 (*)	Jan. 2016 (*)	Aug. 2022
Internet Protocol Journal (A Pragmatic Report on IPv4 Address Space Consumption)	Sep. 2005	Tony Hain	- Estimated using trends over the last 5 years	2009 --- 2016		-
The ISP Column (Numerology)	Nov. 2005	Geoff Huston	- Estimated using trends over the last 3 years - Considering advertised routes	Jan. 24 2012	Mar. 23 2013	Jan. 16 2027

(*) The estimated exhaustion date is updated daily on the web.

The terms used in the table have the following meanings:

- "IANA[2] pool" indicates the date of exhaustion for the pool of address space retained by IANA.
- "RIR[3] pool" indicates the date of exhaustion for the pool of address space retained by each RIR.
- "BGP[4]" indicates the time when all allocatable IPv4 address blocks have been allocated and all of those blocks are incorporated in the routing table of BGP[5].

2.3. Research on projections for exhaustion of IPv4 address space

This section briefly describes the main thrust and conclusions of each report. Details are given in Appendix A.

2.3.1. IP Address Space Report by Geoff Huston

Geoff Huston conducted his analysis in the report using a large amount of relevant data for projecting IPv4 address consumption such as historical BGP routing tables, allocation statistics of each RIR and the state of allocations by IANA to RIR.

Moreover, he classifies in detail the different categories of IPv4 address space, investigates the characteristics of each category and uses the space normally allocated to LIRs[6] and end users within those categories to predict the date of IPv4 address exhaustion.

The key feature of this report is those future projections based on the data over the past 10 years to observe the state of allocations of IPv4 address space.

Note that the future trend projections for the exhaustion date widely vary depending on at which point in the past the data for the projections is based on. .. In this report, the projection is based on a trend of approximately 10 years since implementation of CIDR[7]. As a result, the RIR pool is predicted to run out

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[2] IANA: Internet Assigned Number Authority (http://www.iana.org/)
An organization that coordinates various resources of the Internet worldwide

[3] RIR: Regional Internet Registry
A generic name for a registry that allocates IP address space in a specified area

[4] BGP: Border Gateway Protocol (RFC4271)
One of the protocols used to exchange routing information between networks

[5] Essentially, this indicates the time when all address spaces are completely exhausted. Strictly speaking, it is not when those appearing in the routing table of BGP are used up, although this definition is used for convenience to "observe consumption"

[6] LIR: Local Internet Registry
An organization that assigns address space to a network that it mainly provides itself

[7] CIDR: Classless Inter-Domain Routing
A type of technology that uses IP address space effectively with eliminating former concepts of classes of IPv4 address space

in January 2016.

However, this report is updated daily taking into account the state of allocations and assignments, therefore this projection may have changed by the time this report is read.

2.3.2. A Pragmatic Report on IPv4 Address Space Consumption by Tony Hain

In this report, Tony Hain added some new parameters to the projection made by Huston.

While Huston used a period of approximately 10 years to observe the trends, Hain made his projection using data over the past 5 years, which is the key feature of his report. He used a period of 5 years because after plotting the consumption of IPv4 address space on a graph, he found that consumption from 10 to 5 years ago showed a different curve to that from 5 years ago to the present, with the rate of consumption being faster over the last 5 years.

He also examined the curves of future projections by using exponential functions as well as N polynomials.

From these studies, Hain predicts that the IANA and RIR pools will run out between 2009 to 2016.

2.3.3. A Virtual Round Table discussion between IP address experts

This Virtual Round Table, which was conducted by email, discussed what may happen when IPv4 address space is exhausted, rather than predicting when it will be exhausted.

Four experts participated in this discussion: Tony Hain of Cisco Systems, Geoff Huston, the Internet research scientist in APNIC, Fred Baker, a consultant, and Jon Klensin from the Technical Advisory Board of FCC[8].

Five major topics were discussed:

- When will it be exhausted?
- Is it true that IPv4 address space will not be exhausted in the U.S.?
- Does NAT[9] solve the problem of exhaustion?
- Support of IPv6 by the US government and GOSIP[10]
- One closing thought

In the sections “When will they be exhausted?” and “One closing thought”, it

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8 FCC: Federal Communications Commission

9 NAT: Network Address Translation
A function to translate a private address to a global address one-on-one

10 GOSIP: Government Open Systems Interconnection Profile

was the opinion of all experts at the Table that IPv4 address space would be exhausted in a few years and that migration to IPv6 will take place. Furthermore, concerns were express over the black market of address space at the time of IPv4 exhaustion and calls for calm handling of the situation as well as sufficient preparations from this point.

2.3.4. ISP column by Geoff Huston

In this report by Geoff Huston, he changed the predicted exhaustion date mentioned in his former report "IP Address Space Report".

The major difference is that he used a period of approximately 3 years (1,200 days) in his new report rather than the 10-year period used for the projections in the former report; other factors are basically unchanged.

This report states that the RIR pool will be exhausted on March 23, 2013. However, as in the case of the "IP Address Space Report", the report is updated daily according to the allocation and assignment state of IP address space, and as a result, this projection may have changed by the time this report is read.

2.4. Statistical evaluation regarding demand projection

This section introduces comments from Dr. Hiroyuki Minami, an associate professor of Hokkaido University from a statistical perspective.

In his comments, Dr. Minami evaluated two of Huston's projections; "IP Address Space Report" is referred to as "Potaroo" and "IPv4 - How long have we got?" is referred to as "Huston". Although there are rooms for different interpretations on the following comments from Dr. Minami, it will not be discussed here.

According to Dr. Minami, the major interest is in the validity of the projection model represented by the above-mentioned two examples, however, as described, it is difficult to give theoretical validity to setting the period of data, which becomes the basis for extension of the curve, to 3 years.

> When measuring the validity of a model, information criteria such as AIC (Akaike Information Criterion) are generally used. In this case, the target is a discrete value. Therefore, an intuitive approach to a simple curve fitting is acceptable, which is to make a projection for the following year (for which data is actually being measured) based on data for 2 to 3 years starting from a less significant year (1 year is not enough to identify secular changes) and using a model that has the minimum difference from the actual measurement value (however, it is difficult to draw theoretical implications from this).
>
> Some may be convinced by the method, which is to use each of the above techniques for the three kinds of curves mentioned in Potaroo

(linear regression, exponential function, quadratic curve) and choose the model considered most valid.

However, as described in "Uncertainties" section at the end of Huston's report, the approach of "predicting the future based on the forecasting curve" (called extrapolating) is valid only if it is assumed that a similar external situation will continue in the future as well. It is obvious that when there is a notable trend, the utility value of data until then will decrease dramatically.

This is only my personal view, states Dr. Minami: If it is accepted that the consumption of IP address space is based on various external triggers, it is likely to be weak to argue that numbers of announced BGP routes are independent factors, as long as the key factor is the IP address consumption. (It is difficult to believe that the consumption of IP address space will decline, even if routing information is aggregated.)

For example, another approach uses an analytical method to confirm such a correlation, taking into account other actual measurement data related to the Internet such as the number of customers or the number of acquired domain names based on the hypothesis that "the total number of subscribers (or number of domain names obtained) and the size of IP address consumption are reasonably correlated" and consequently works out the size of IP address consumption. This approach seems to have less of an information bias.

Considering the current global situation, the Internet population is likely to continue its growth, therefore this approach is reasonable for making a safer (negative) projection. If we assume that growth in the Internet population will level off, then the assignment of IP address space will not grow either. The three curves used for Potaroo will all continue to increase, and as a result, it is necessary to consider using some other function (which can reach a plateau).

However, most of these other factors use "time t" as an input variable, therefore they are linked to time change (which means that everything depends on "t"). To examine this further, we need to investigate the mutual relationship such as the existence of hidden factors, but it is not practical to collect such data, and as a result, we must look carefully at how far we should proceed in further examination.

In this section, we requested Dr. Minami to statistically evaluate the projection model of Huston. However, no evaluation was performed to determine if his exhaustion date was correct. Our objective was to evaluate the validity of Huston's projection model.

3. IPv4 address consumption and demand projection in Japan

This chapter analyzes IPv4 address consumption in Japan based on data registered in JPNIC database and future demand is projected. The actual consumption of address space is also examined and a report on this is included.

Section 3.1 looks at IPv4 address consumption over the last few years, and describes forms of IPv4 address consumption, IPv4 address space registration details and demand projections in Japan.

Section 3.2 looks at the consumption of IPv4 address space managed by JPNIC, the situation in the Asia-Pacific region as a whole as well as in each economies in the region, including Japan.

3.1. IPv4 address consumption in Japan

This section examines the demand and utilization ratio of IPv4 address space based on actual numerical data, focusing on trends in Japan.

3.1.1. Japanese IPv4 address consumption from a global perspective

Table 3-1 shows the country- and region-specific assignment of IPv4 address space. The number of assigned IPv4 address spaces in Japan is ranked second behind the United States.

Table 3-1 Country- and region-specific assignment state of IPv4 address space

Country	Percentage
United States of America (US)	59.50%
Japan (JP)	6.43%
Europe (EU)	5.14%

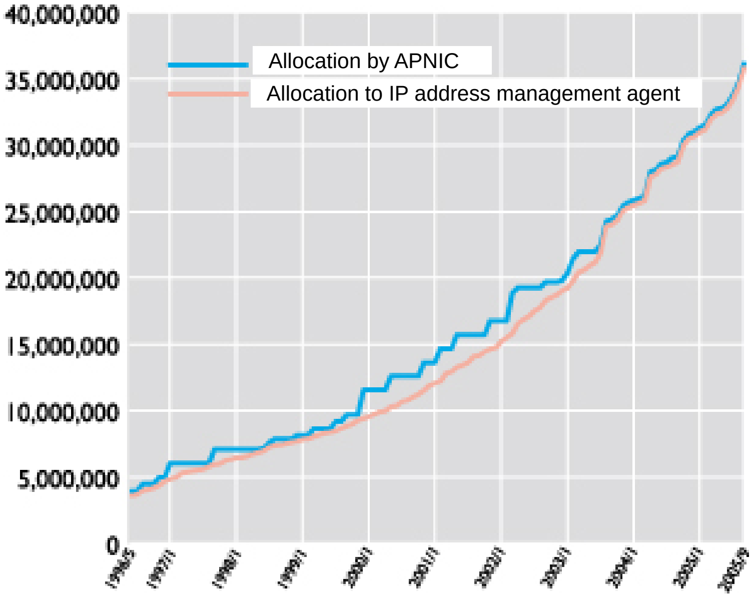
Source: BGP Routing Table Analysis Reports[11] (End of 2005)

3.1.2. IPv4 address consumption in Japan

Fig. 3-1 shows monthly data for IPv4 address space allocated by JPNIC. As shown in August 2003, April 2004 and October 2004, large-scale allocations of IPv4 address spaces were made several times in the past. These were presumably made to multiple organizations rather than providing some specific services.

[11] BGP Routing Table Analysis Reports
http://bgp.potaroo.net/ipv4/stats/allocated-all.html

If these large allocations are considered as regular events, there is no remarkable trend overall and the volume of IPv4 address space allocations has been increasing constantly since 2000. However, comparing the current allocation of IPv4 address space with that of the past, there is a trend toward growth in recent allocations.



Source: JPNIC Newsletter No.31
http://www.nic.ad.jp/ja/newsletter/No31/090.html

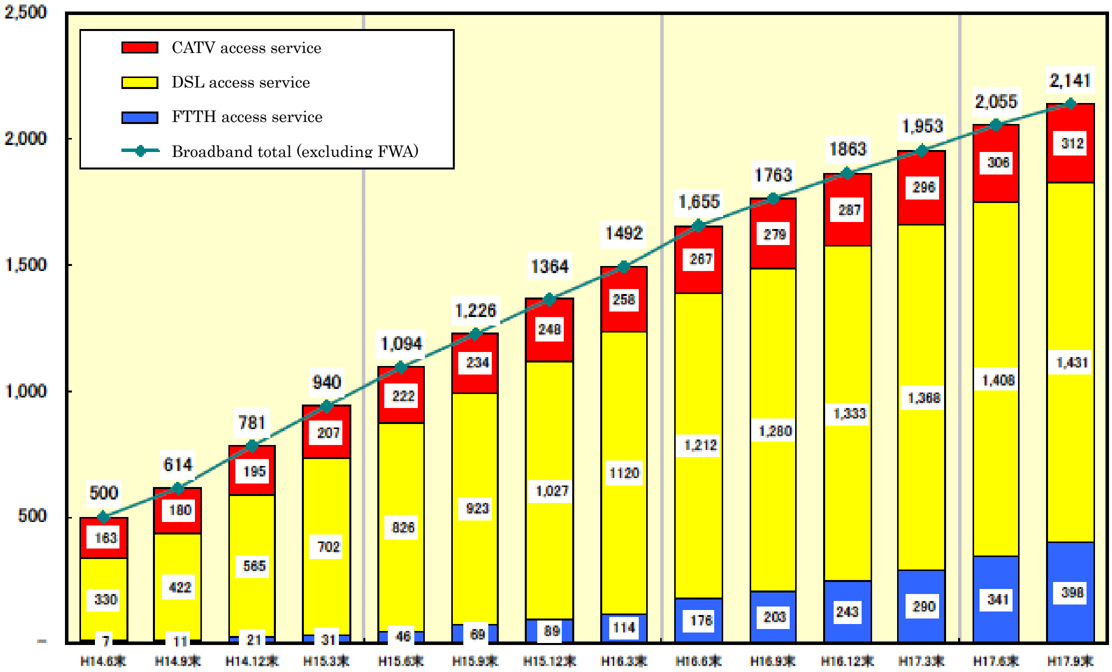
Fig. 3-1 Change in the cumulative number of allocated IPv4 address space

3.1.3. Validation of IPv4 address consumption

As described in the previous section on consumption of IPv4 address space, IPv4 address space was allocated in bulk several times in the past up to around 2004. These were subsequent allocations to several organizations, at which time no services for assigning multiple addresses to a single subscriber had started. Consequently, it is understood that IPv4 address space was allocated in bulk as demand had accelerated solely as a result of rapid growth in the number of broadband users. Hence, it was not caused by growth of a single specific service, but rather in response to the general high demand at that period.

3.1.4. Relationship between consumption forms of IPv4 address space and address demand trends

The change in the number of broadband subscribers in Japan in Fig. 3-2 shows that the migration from ADSL[12] to FTTH[13] is accelerating, but the overall expansion in the number of subscribers has slowed down since 2005.



Change in the number of broadband contracts, etc.（chart）[14] (Ministry of Internal Affairs and Communications)

Fig. 3-2　Number of subscribers by broadband service

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[12] ADSL: Asymmetric Digital Subscriber Line
A type of digital technology that enables data to be transmitted at high speed using a telephone line

[13] FTTH: Fiber To The Home
An optical fiber capable of high-speed communication linked to each home

[14] Change, etc. in the number of broadband service contracts (chart):
http://www.soumu.go.jp/s-news/2005/pdf/051129_3_1.pdf

On the other hand, the consumption of IPv4 address space shows an upward trend, contrary to the change in the number of broadband subscribers; that is, the expansion of the number of broadband subscribers is slowing down as the consumption of IP address space moves steadily upward.

Possible factors contributing to this acceleration of IPv4 address consumption are growth in the number of services assigning multiple IPv4 address spaces to a single subscriber and the shift from services utilizing private address space to those utilizing global address space.

The broadband market is mature today, with the growth in numbers of subscribers starting to slow down from around 2004. However, services where a single subscriber consumes multiple IPv4 address space started in 2004, and such services are expanding. As more global addresses are assigned to a single terminal, the demand for IPv4 address space accelerates. Put simply, the demand for global address space is increasing, and as shown in Table 3-2, consumption is increasing in more environments, boosting demand for address space even further.

Table 3-2 Internet users

	H12	H13	H14	H15	H16	H17
	2000	2001	2002	2003	2004	2005
Internet users:	1,937.7	3,263.6	4,619.6	5,645.3	6,559.4	7,007.2
From equipment at home	821.5	1,152.4	1,785.6	2,196.1	2,364.1	2,447.9
Users of both equipment at home, work and school	746.8	893.1	1,336.7	1,766.7	2,134.1	2,360.3
Users of equipment at work or school	366.4	565.6	819.9	946.9	1,115.7	1,255.8
Users of only mobile phone and PHS	3.0	652.5	677.4	735.6	945.5	943.1

Unit: 10,000 persons

2004 Internet survey statistic report [15] (Ministry of Internal Affairs and Communications)

3.1.5. Projection of demand in Japan

As described in the previous section, address space will continue to be consumed and demand for IPv4 address space will increase. However, as shown by the expansion of broadband subscribers, after a certain point, the environment surrounding Internet connection services will be saturated and consumption will start to slow down.

However, if services assigning multiple IPv4 addresses to a single subscriber by major telecommunications carriers accelerate suddenly, then the acceleration rate will likely rise further.

The demand for address space in the future will shift to IPv6. When IPv4 address space runs low, the demand for new services using IPv4 address space will decrease and the expansion in demand for IPv4 address space will slow down. Thus, demand will shift from IPv4 address space to IPv6 address space

[15] Internet survey statistical report: http://www.soumu.go.jp/s-news/2006/pdf/060130_2_bt1.pdf

in a few years.

3.2. Actual IPv4 address utilization state based on routing information

In this section, we look at how much address space is actually consumed based on routing information advertised on the Internet.

Routing information advertised on the Internet is generally used for route control of the Internet and is exchanged with BGP, while research is conducted using this routing information. In this section, the term “address” means an IPv4 address unless stated otherwise.

3.2.1. Definition of IPv4 address utilization state

The address utilization state discussed in the following sections is determined in accordance with how much of the allocated IPv4 address space (prefix) is advertised on the Internet, and is defined as "utilized" if it is visible in the routing table on the Internet, and as "not utilized" if it is not included in the routing information.

Even if not actually visible on the Internet routing table, address space may be utilized internally; however, such address space is regarded as not utilized in this study.

3.2.2. Utilization state in Japan

This section focuses on the consumption of IPv4 address space in Japan by screening routing information and matching it with allocations made by JPNIC.

3.2.2.1 Outline of research and purpose

We matched the provider aggregatable address (PA address[16]) and provider independent address (PI address[17]) managed by JPNIC with BGP routing information to determine to what extent they are appear on the routing table.

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[16] PA address: Provider Aggregatable Address
IP address assigned to LIR

[17] PI address: Provider Independent Address
IP address assigned by other than LIR. Refer to the following page for details:
http://www.nic.ad.jp/ja/ip/hr/index.html#id000101 (Japanese Only)

Based on an assumption that IPv4 address space will eventually run low, we shall analyze the current situation by studying in detail the address space held by Japan. If there is a substantial volume of unutilized address space, we shall examine whether the return of unutilized address spaces would effectively extend their lifetime or whether new countermeasures can be applied based on this research.

3.2.2.2 Research method

We matched all PA address space and PI address space managed by JPNIC with BGP routing table. It is of AS2914[18] operated by NTT Communications.

In principle, an IP address block is to be advertised on the Internet once allocations are made from RIR or NIR to an ISP. The state in which the advertised address range is identical with the allocated range is called "Exact Match". However, we can see cases other than Exact Match on the real-life Internet.

We have taken the following points into consideration in our data collection.

- Multiple split routes are advertised from a single allocated address block

  For instance, even if prefix information registered in the database is /16, in some cases the routing information actually advertised is two continuous /17.

- An allocated address block is aggregated with adjacent blocks to be advertised

  For instance, when prefix information registered in the database is two continuous /16, in some cases the routing information actually advertised is /15.

- Multiple overlapped routes are advertised from an allocated block

  For instance, even if prefix information registered in the database is /16, in some cases the routing information is actually advertised by duplicating /16 and two /17 including /16 or more fine /18.

Based on these cases, we found the most practical and appropriate approach was to split all prefix information registered in the database into /24s and observe whether it was covered by advertised BGP routes in order to determine the utilization state. Routing information longer than /25 is disregarded in this report because it is not generally advertised, and there are not many with such routes advertised on the Internet.

3.2.2.3 Research subjects

We conducted the research based on the following lists of IP address as of

[18] AS2914 is the AS number used for BGP and is to be assigned to the network that operates BGP. AS2914 is the number assigned to Verio. (http://www.verio.com/)

December 28, 2005:

- PA address space managed by JPNIC (= 1937 prefix)
- PI address space managed by JPNIC (=2906 prefix)

3.2.2.4 Results

Outlined below are the results of our research and observations.

(1) PA address

Table 3-3 Address consumption research results

	PA		PI	
Number of surveyed prefixes	1,937	100.00%	2,906	100.00%
(size by number of /24 blocks)	134,140	100.00%	151,414	100.00%
Number of prefixes of exact match	1,060	54.72%	931	32.94%
(size by number of /24 blocks)	100,508	74.93%	93,957	62.05%
Advertised prefixes (by /24 blocks)	130,446	97.25%	95,551	63.11%
Not advertised prefixes (by /24 blocks)	3,694	2.75%	55,863	36.89%

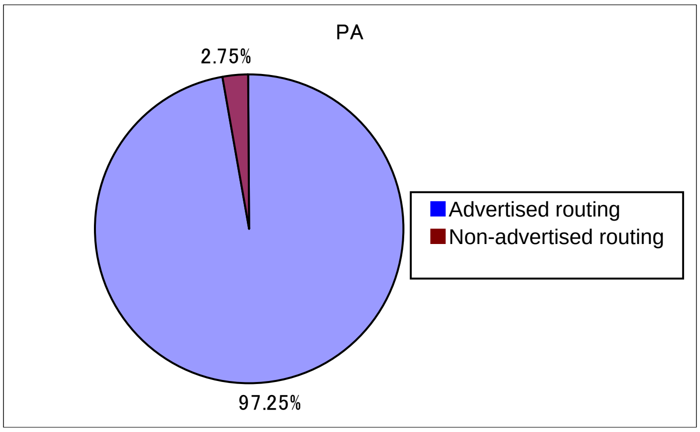


Fig. 3-3 Advertised state of PA address space

As shown in Table 3-3 and Fig. 3-3, the utilization ratio of PA address space has reached 97.25% and almost all of the address spaces are advertised on the Internet. Although a few address prefixes are not advertised, it seems that some do not exist, while others are being prepared for advertising. Therefore, the actual utilization ratio would certainly be higher than this figure.

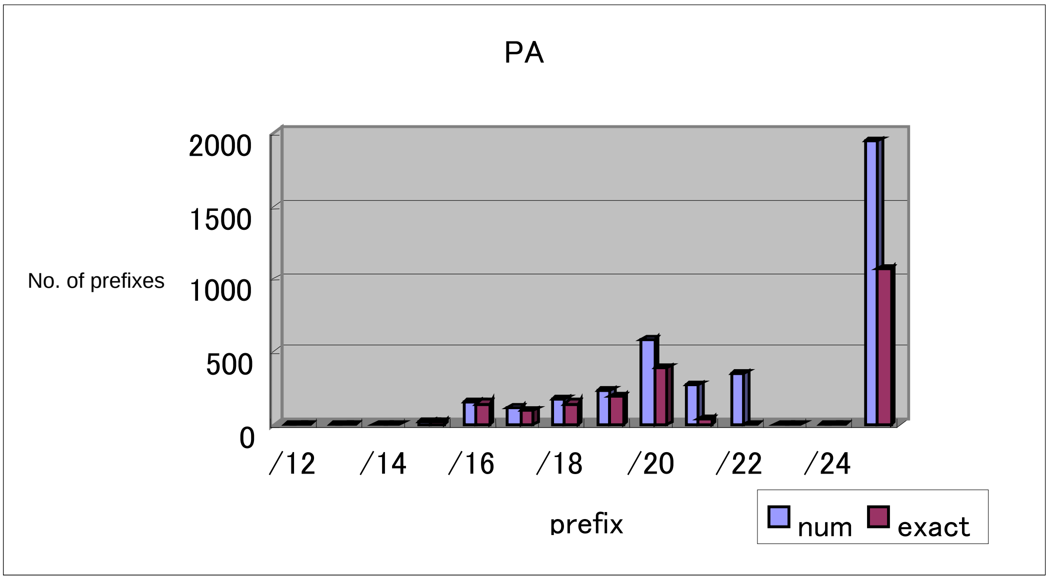


Fig. 3-4　State of PA address space for each prefix

A detailed examination of each prefix shown in Fig. 3-4 and Table 3-4 reveals some unexpected results.

As mentioned previously, the overall advertised rate of PA address space is high. It was also revealed that approximately 90% of advertised routes were "Exact Match" from /16 to /19, while many of the /21 and /22 prefixes on the routing table with a different prefix length.

This is likely due to the address allocation policy applied by JPNIC in the past.

When /22 had been allocated by JPNIC in the past, address space of /19 or /20, which contains /22, was considered as reserve space. Therefore, it was actually possible to advertise /19 or /20 without advertising /22. Among 356 prefixes of /22, 205 were /20 and 123 were /19. It was found that a total of 328 prefixes, which was more than 90% of the 356, were advertised as/20 or /19, thus reducing the "Exact Match" ratio.

Table 3-4 Detailed results of PA address for each prefix

	No. of prefixes	exact match	Percent-age
/12	3	2	66.67%
/13	6	3	50.00%
/14	9	6	66.67%
/15	25	14	56.00%
/16	162	145	89.51%
/17	116	104	89.66%
/18	171	147	85.96%
/19	229	199	86.90%
/20	587	394	67.12%
/21	266	41	15.41%
/22	356	5	1.40%
/23	5	0	0.00%
/24	2	0	0.00%
sum	1,937	1,060	54.72%

(2) PI address space

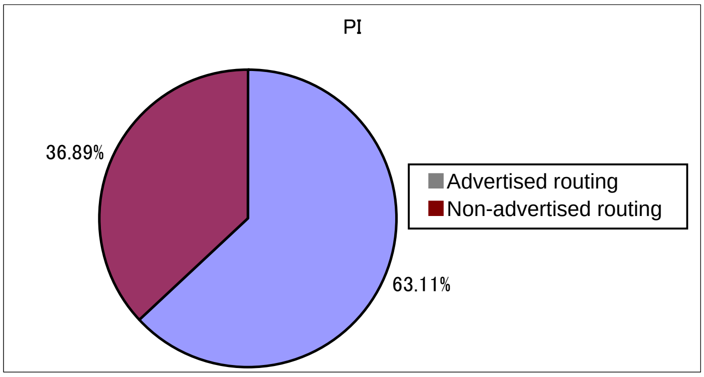


Fig. 3-5 Advertised state of PI address space

According to Fig. 3-5 and Table 3-5, the utilization ratio of PI address space is approximately 60%, which is an extremely low utilization ratio. 62.05% were an "Exact Match", which was extremely close to the overall advertised ratio for PI address space (63.11%).

This result shows that address blocks registered in the JPNIC's database are not split up when advertised, but are advertised with the actual prefix length as is, or is not advertised at all. Hence, much is unutilized.

In the case of /16 in particular, the ratio is almost the same as the overall advertised ratio, and the advertised ratio of /16s may have a significant impact on the result for PI address space overall. When adding up 202 unadvertised prefixes of /16 and converting them into address space, it resulted in approximately 80% address space of a /8 block, which is an extremely high ratio.

Table 3-5 Detailed results of PI address space for each prefix

	No. of prefixes	exact match	Percent-age	Advertis-ed ratio
/12				
/13				
/14				
/15	1	0	0.00%	0.00%
/16	560	356	63.57%	63.88%
/17	0	0	-	-
/18	10	7	70.00%	70.63%
/19	24	15	62.50%	62.89%
/20	60	32	53.33%	56.77%
/21	124	71	57.26%	60.28%
/22	216	93	43.06%	45.02%
/23	262	84	32.06%	36.07%
/24	1569	273	17.40%	17.40%
sum	2826	931	32.94%	63.11%

3.2.3. Utilization state in the APNIC region

In this section, the utilization of IPv4 address space in the Asia Pacific region will be studied and discussed by comparing address blocks registered in APNIC database[20] and routes advertised.

3.2.3.1. Research outline and objectives

A study was conducted of the utilization state of the whole APNIC region, focusing on major economies within the region. This study clarified the

[20] APNIC IPv4 resource guide
http://www.apnic.net/services/ipv4_guide.html

deviation existing in each economy and the state in Japan under these circumstances.

Any examination of just the address space managed by JPNIC would exclude the address space assigned to Japanese organizations that acquire address space directly from APNIC. Moreover, referring merely to the results of the previous section would be insufficient in properly monitoring the utilization state of all address space consumed in Japan. Therefore, it became necessary to group address spaces managed throughout the APNIC region country by country, and then study the utilization state in Japan.

3.2.3.2. Research method

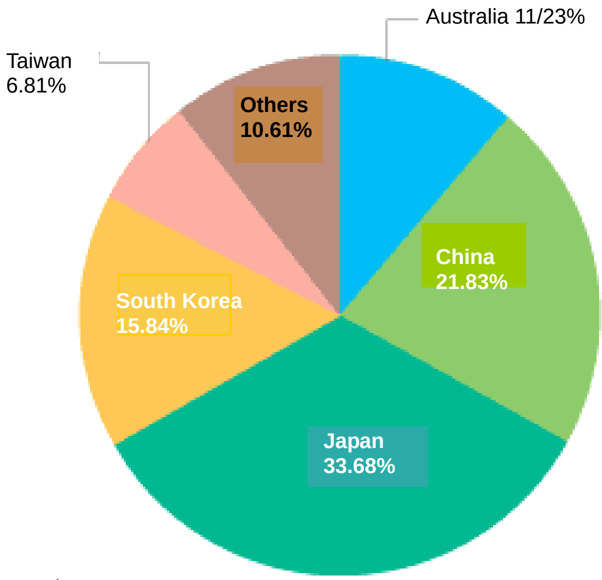
Similar to the approach described in section 3.2.2.2, we split all prefix information registered in the database into /24 blocks and tried to identify the utilization state by determining whether it is covered by advertised BGP routes or not. Routing information prefixes longer than /25 were excluded from the scope of this study.

3.2.3.3. Research subjects

This study was conducted using statistics[22] published by APNIC. We created a list covering address spaces for the entire address list and country-specific address list grouped country by country, and based on those lists, studied the entire region managed by APNIC and the five major economies.

[22] APNIC allocation and assignment reports
http://ftp.apnic.net/stats/apnic/

Fig. 3-6 shows the allocation state of IPv4 address space in the five major countries in the region managed by APNIC.



(Source: http://www.nic.ad.jp/ja/newsletter/No26/080.html)

Fig. 3-6 IPv4 address allocation state by country in the region managed by APNIC

3.2.3.4. Study results

Table 3-6 Utilization state in the entire region and by country managed by APNIC

	Number of study subjects (/24 conversion number)	Rough estimate number	Advertised routing number (/24 conversion)	Percentage
AP	1169025	~=/4	953872	81.6%
JP	427277	/5~/6	306160	71.7%
CN	289167	~=/6	249054	86.1%
KR	163381	/6~/7	157144	96.2%
AU	104929	/7~/8	78935	75.2%
TW	63594	~=/8	62592	98.4%

From Table 3-6, it is concluded that more than 80% of address spaces are actually consumed in the entire region managed by APNIC. This result shows that the advertised ratio of Taiwan and South Korea is high. In these two economies, the allocations before CIDR was relatively small, and the assigned PA address spaces are properly advertised and utilized on the Internet. This result for utilization state is similar to the advertised ratio of PA address space in Japan found by previous research. China, Australia and Japan follow Taiwan and South Korea. Some negative factors contributing to the poor utilization state in Japan are as follows.

One factor is that Internet was used in Japan longer than other economies in the region and it resulted in holding much more PI addresses, so the low advertised ratio for PI address space probably affects the utilization state. As previously described, only 60% of PI address space is utilized and this may be a major reason for this result. Moreover, one /8 address space that was assigned recently exerts an extremely large influence. For this /8 block, all address spaces were once allocated, but according to the utilization state we researched, only 7.5% of the entire space is advertised, thus reducing the utilization ratio. If all of this address space was advertised, the advertised ratio for the whole of Japan would be 85.8%, which is very different from the actual 71.7% found in this study.

We conducted the study based on the statistics list of APNIC, but when verifying consistency with the address space managed by JPNIC, we found that some of the PI address space managed by JPNIC was not covered. We therefore conducted further studies of the utilization state of Japan as a whole, including not only Japanese address space extracted from APNIC statistical data, but also Japanese address space not covered, and found that the utilization ratio fell to 70.7%. The cause of this low ratio is clear: the added PI address blocks were old with low usage rate, and as a result, the overall utilization ratio declines.

3.3. Conclusion

This chapter outlines trends in demand and the state of utilization of IPv4 address space in Japan.

The demand for address space will continue to grow in Japan, and global address space will be consumed within a certain period. It was found that the consumption of PA address spaces in Japan is similar to that in major Asian economies. However, in the case of PI address spaces, many of them assigned in the past are not actually utilized.

When available IPv4 address spaces run low globally and Japan continues to hold unutilized IPv4 address space as as found in this research, it may be possible depending on circumstances, to be pointed to either return or reuse such space before applying for additional address space. To prevent this situation and utilize address resources effectively, it is desirable to monitor the consumption of PI address space in the future and actively reclaim unconsumed address spaces; in the case of /6 in particular, if all 200 prefixes were reclaimed, this would be equivalent to 80% of /8. This may not lead to the reuse of the entire IPv4 address space, but it is important for Japan to tackle this problem seriously and exercise leadership in the effective utilization of address resources.

4. Phenomena Anticipated in the Exhaustion Period

As indicated by the projections in Chapter 2, all allocatable IPv4 address space will become completely assigned, or will be exhausted in the near future.

When there was sufficient IPv4 address space available, users were simply requested to demonstrate how much IPv4 address spaces were needed in order to use that amount.

However, if IPv4 address space is exhausted, then even if an organization is able to demonstrate a requirement for a certain volume of address space, there will be no IPv4 address space remaining and as a result, it will be unable to receive an allocation.

This exhaustion of IPv4 address space will not occur abruptly. As shown in previous chapters on the projections for exhaustion of IPv4 address space that have been widely made available, there is sufficient time within the range of these projections to examine this phenomenon of exhaustion. While time remains, due consideration must be given to what will occur and what measures must be adopted. When it is realized that IPv4 address space will indeed be exhausted in the near future, those concerned may then act very differently.

In this chapter, we define “exhaustion” and categorize the time up to exhaustion into certain phases. We then consider and summarize what may happen in each phase.

We offer some suppositions in this chapter based on thorough investigations by the authors and provide supporting materials where possible.

4.1. Definition of period

Some new phenomena will occur as IPv4 address space is exhausted. The exhaustion itself may occur very quickly, but the new phenomena will occur over a long time centered on this extremely short period. Phenomena occurring over the long term are not constant, but will differ depending on the quantity of IPv4 address spaces remaining.

In this chapter, we divide this flow into three phases and call the point when IPv4 address space is exhausted the "exhaustion point", and the periods before and after this point, "before exhaustion" and "after exhaustion". These concepts are shown in Fig. 4-1.

Each phase is initially defined and then discussed.

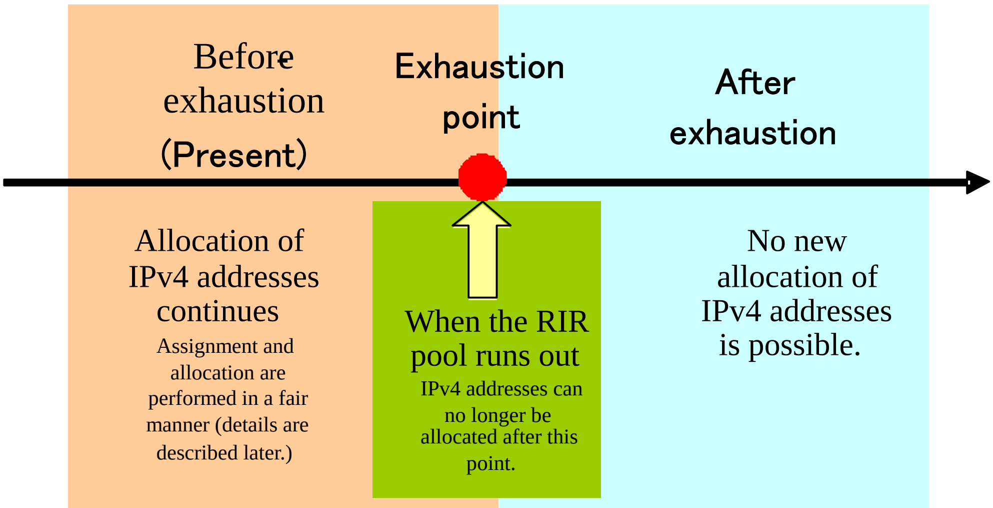


Fig. 4-1 Definition of Exhaustion point

4.1.1. Exhaustion point

IPv4 Internet address space is allocated by IANA, the central registry for RIRs and from RIRs to NIRs[23] or LIRs according to the hierarchical structure of the registry, and then assigned to end users.

Due to this structure, there can be several definitions of exhaustion:

- "Exhaustion" is when the IANA pool is completely exhausted.

  The exhaustion point is the point in time when the IANA has allocated all the IPv4 address space in the pool it retains. In this state, the RIRs are not able to receive a new allocation from IANA.
  However, there may be IPv4 address space in the pool retained by RIRs, therefore allocation from RIR to NIR or LIR may continue.

- "Exhaustion" is when the RIR pool is completely exhausted.

  The exhaustion point is the point in time when the RIRs have allocated all the IPv4 address space retained in its pool to the LIRs. Under current APNIC policies, when the NIR makes an allocation to the LIR, the release comes directly from APNIC, in other words, the address pool of RIR, and NIRs do not hold address pool of its own, therefore, only the LIR are considered as the target of allocations by RIRs for the convenience.
  At this point, the IANA pool is already exhausted, therefore no new allocation can be received from IANA or allocations to be made to LIRs.
  However, there may be a few remaining address spaces in the IPv4 address pool retained by the LIRs, therefore the LIRs are able to continue assignments to end users for some period of time.

- "Exhaustion" is when the LIR pool is completely exhausted.

  The exhaustion point is the point in time when the IPv4 address space in the pool retained by the LIRs is completely assigned to end users.
  At this stage, all IPv4 address space managed by registries is distributed and the registries can no longer assign new IPv4 address space.

After due consideration of these various exhaustion points, we regard the point when the entire RIR pool is exhausted as the exhaustion point in this report. This is due to the fact that the impact is greatest when the IPv4 address space allocated by the RIRs, which are nonprofit organizations performing public address allocations to LIRs including service providers, is exhausted.

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[23] NIR: National Internet Registry
Internet registry organized for each economy

4.1.2. Pre-Exhaustion Period

The exhaustion point is a fixed point in time; we define the period before this point as "pre-exhaustion period".

It is not possible to clearly define the starting point of "pre-exhaustion period," but this would be the point when it becomes clear that exhaustion will take place in the near future. Such awareness may change the trend in IPv4 address consumption.

In addition, we are already aware at the time of writing this report that IPv4 address space will run out in the near future; that is, we have actually already entered the "before exhaustion" period.

The "before exhaustion" period concludes immediately prior to the "exhaustion point." The main characteristic of "before exhaustion" is that new IPv4 address space continues to be allocated.

4.1.3. Post-Exhaustion Period

We define the period after the exhaustion point as "post-exhaustion period." The starting point of "post-exhaustion period" is just after the exhaustion point.

It is not possible to define precisely when the post-exhaustion period will be over, but this is the time when a new form of the Internet becomes the standard as an alternative to the existing IPv4 Internet.

The main characteristic of "post-exhaustion period" is that new IPv4 address space is no longer allocated. However, this simply means that new IPv4 address space is not allocated; it does not mean that the IPv4 Internet no longer exists. Even after the exhaustion, the IPv4 Internet will continue to be used until an alternative form of the Internet is widely deployed.

4.2. Trends in policy changes regarding IPv4 address space

In this section, we introduce the address policy currently defined in the APNIC region and changes in address policy that are currently under consideration, and discuss their impact on the exhaustion date of IPv4 address space.

The following policy areas may have an impact on the consumption of IPv4 address space in the APNIC region as of now. Documents published by APNIC are available at:

Policy Archives
http://ftp.apnic.net/apnic/archive/

Policy Proposals
http://www.apnic.net/docs/policy/proposals/archive.html

The numbered Proposals listed below can be referred to within the above-mentioned group of Policy Proposals.

● prop-006-v001: “Supporting historical resource transfers”

The method of migrating IPv4 address space registered based on the early registry policy from the current assignees to an LIR was proposed and endorseed in July 2003. As it is left up to each organization whether to make use of this policy, the possibility of unused IPv4 address space being recovered is low.

● prop-008-v001: “IANA IPv4 resource request procedures”

Criteria for subsequent allocations from IANA to RIRs was proposed and was endorsed in July 2003. IPv4 address space is to be allocated according to a defined criteria, and as a result, this may affect the date when IANA terminates allocations of IPv4 address space

● prop-014-v001: “A proposal to lower the IPv4 minimum allocation size and initial allocation criteria in the Asia Pacific region”

A proposal was made to change the minimum allocation size on subsequent allocations from RIR or NIR to LIR, and was implemented from January 2004. Thereafter, the allocation of longer prefix began, which may affect the date of termination of IPv4 address allocation by RIR or NIR to LIR.

● prop-017-v001: “Recovery of unused address space”

A proposal was made to recover historical IP address space that are considered unused in order to prevent unauthorized use of address space and was endorsed in January 2004. Such effective utilization of address space has been taken into account for the future considerations, and may affect the date of termination of IPv4 address allocations by RIR or NIR to LIR.

● prop-020-v001: “Application of the HD ratio to IPv4”

A proposal was made to apply a utilization ratio calculated from a formula called the HD-ratio instead of the uniform utilization ratio of subsequent allocations for IPv4 address space in August 2004 and continues to be discussed. If this policy were implemented, the time of termination of IPv4 address allocation by RIR or NIR to LIR may be accelerated.

Additional note for the translated document:
Prop-020-v001 was abandoned in 18 April 2006.

4.3. Anticipated phenomena before exhaustion

In the "before exhaustion" period, LIR will receive allocations of an adequate volume of IPv4 address space from RIR or NIR based on estimated demand, as in the current procedure.

Such allocations will continue to be conducted up to the exhaustion point when all available IPv4 address space is allocated.

However, as the exhaustion point approaches, various phenomena will occur, such as surges in allocation requests to secure sufficient IPv4 address space before exhaustion, discontinued consumption of IPv4 itself, or the development of technologies to extend the lifetime of IPv4.

This section examines these possible phenomena before exhaustion.

4.3.1. Demand surge

As the exhaustion point draws closer and the date of exhaustion becomes clear, some organizations that use IPv4 address space for their major business infrastructure may wish to secure more IPv4 address space than others in order to continue operating. This phenomenon will appear in the number of requests submitted and in the size of allocations requested for IPv4 address space in order to receive as much IPv4 address space as possible. This may accelerate the consumption of IPv4 address space and hasten the exhaustion point.

We call this phenomenon “demand surge”.

Demand surge will certainly occur even before exhaustion, with the peak possibly occurring a few years before the actual exhaustion point, for the following reasons.

Under the current allocation procedures, demand for up to one year's requirement can be allocated in advance. Network facilities are often used to demonstrate this one year requirement of IP address space. Therefore, a surge in application submissions may occur after organizations have actually prepared their facilities.

For instance, when building facilities for an IPv4 network, organizations take into account their investment plans and the operating lifetime of the facilities. Considerations are rarely given in project investment-related cost-recouping plans or the working lifetime of equipment to continuing beyond the exhaustion point. Investment which anticipates such exhaustion points often leads to demand surges, and such demand surges will peak a few years before the exhaustion point, not immediately prior to it.

Moreover, after this peak, surges in demand to secure IPv4 address space in advance in order to incorporate it into existing services as well as facilities in the future will continue up to the exhaustion point, although the size of demand will be very small compared to the peak.

Business plans evaluating networks after exhaustion will have already been drawn up immediately prior to the exhaustion point. Therefore, demand for new address space will concentrate on the IP address space required for networks after exhaustion. Consequently, during the period after the demand surge and before exhaustion, demand for IPv4 address space will fall as the exhaustion point approaches.

4.3.2. Avoidance of consumption of IPv4 address space

As the exhaustion point approaches, some organizations may consider it difficult to secure the necessary IPv4 address space in the future to build new services and networks, and as a result, will abandon developing new services or networks using IPv4 address space. This will slow down the consumption of IPv4 address space and consequently delay the exhaustion point.

The following measures may be adopted as alternatives to abandoning the development of new services or networks using IPv4 address space.

Firstly, there may be efforts to use IPv6 address space to build networks.

Secondly, there may be efforts to secure connections to the Internet using a small number of global address spaces only for that part concerned with connection to the Internet by utilizing NATs and private IPv4 address space for the former IPv4 network.

In both cases, mutual communication is established with the existing Internet that uses global IPv4 address space, so an address translation gateway, or other means will be required and services will be restricted.

4.3.3. Efforts to delay the exhaustion point

For those who wish to use the existing IPv4 Internet as long as possible, measures may be adopted to extend the lifetime of IPv4 address space in order to delay the exhaustion point.

In order to avoid exhaustion of IPv4 address space, cutting back the allocations from registries may achieve the maximum result. Therefore, users may try to extend the lifetime of IPv4 address space by proposing to change the address policy, such as tightening the allocation criterion for IPv4 address space to Internet Registries.

Moreover, in order to postpone exhaustion, proposals may be made to change the address policy to recover unused IPv4 address space, by a rule or using economic incentives, and making IPv4 address space re-allocatable.

There are two broad directions for changing address policy as the exhaustion point approaches. One is a change of address policy in order to extend the IPv4 address lifetime and the other is to terminate the allocation of IPv4 address space in a fair manner. Both of these approaches involve a change of address policy and may seem similar, however it is necessary to distinguish between the two.

The reclamation of unused IPv4 address space was mentioned in Chapter 2, but would incur substantial expenses and efforts.

Nevertheless, as it takes considerable time for a policy proposal to be adopted, it is likely to be handled as an urgent case if the proposal is made, and we cannot remove the possibility that this may cause confusions to address allocations.

4.3.4. Reaching the exhaustion point without disruption

As described in the previous section, there are two methods of changing address policy, one of which is to terminate allocations in a fair manner.

Some disruption is likely to occur just before the exhaustion point. One form of disruption is due to regional differences, the second is caused by a sense of unfairness arising from differences in size of networks submitting the requests, and the last is the result of disruption from timeline unfairness.

For IP address allocation, the world is split into several regions to be managed by each RIR in charge. At present, each RIR holds a unique address pool and allocates address space from their own pool in order to carry out allocations smoothly within their respective region. Since address pool is secured for each region, the exhaustion point varies slightly depending on how many IP address spaces the RIR in charge of the region has released from the address pool it holds. That is, the exhaustion point may vary according to each RIR.

Differences in exhaustion point indicate differences between regions making applications for allocations, so a sense of unfairness may arise because a company that provides a network service on a global scale is free to change the RIR to which they make applications.

Moreover, when making additional allocations of IP address space, the address utilization ratio (a percentage of the allocation block is assigned from the total allocation) needs to comply with the criteria (80% at present). Some companies provide small-scale network services while others provide large-scale services, but the application timing of IP address space and application quantity may vary according to the policy of the company providing the network service. However, this does not mean that the importance of the network service of a company varies according to the application quantity. This matter should be judged in a fair manner, but if a regular allocations request is made by a certain large-scale network and the requested large address block is allocated as it has been, the exhaustion point will be reached in one step. If a small-scale network makes a regular allocation request at the same point in time, it may not be able to receive an allocation.

At present, applications can be made based on estimated consumption for the coming year and the allocation quantity is determined accordingly. Hence, unfairness may occur depending on the scale of the network, therefore it may be necessary to reduce this unfairness by limiting the estimation period to 6 months for example, or by reducing the minimum allocation unit.

Moreover, when final requests are about to be made, it may be necessary to verify the application time in order to clarify which organization has made the final application.

The above three possible types of disruption are not certain to occur and countermeasures have not yet been clarified. However, as Chapter 2 describes and the authors of this report have discussed, such disruption is likely to take place, so an address policy to avoid such disruption is likely to be proposed.

4.4. Anticipated phenomenon at the exhaustion point

When all allocatable IPv4 address space has been allocated by RIRs, each RIR will announce that allocation of IPv4 address space has terminated. This indicates the approach of the exhaustion point. The period after exhaustion then begins.

As described in the previous section, under the current hierarchical allocation, each RIR retains independent address pools of their own, and from this address pool they distribute IP address space to those who have submitted a request to each RIR. Therefore, the timing of the exhaustion point varies slightly between RIRs.

Therefore, some organizations in a region where IPv4 address space is already exhausted may temporarily apply for allocations of IPv4 address space to another RIR where address space is not yet exhausted.

During regular operation of an RIR, when a request for IP address allocation is submitted from another region, it is suggested to apply to the appropriate RIR by introducing RIRs in the relevant region. However, if an organization has its bases throughout the world, they will be able to make this type of request more easily.

In order to avoid this situation, there may be to be efforts to unify the exhaustion point of each region by reallocating the remaining IPv4 address space between RIRs.

4.5. Anticipated phenomena after exhaustion

In the period after exhaustion, allocations of IPv4 address space from registries has already terminated and as a result, no new IPv4 address space will be allocated. However, the IPv4 Internet is unlikely to fall out of use immediately simply because no more IPv4 address space can be allocated.

The existing IPv4 Internet will continue to operate using IPv4 address space, and in addition, it is likely that the new Internet will become widely used.

In this section, we look at activities after exhaustion, which were projected in the report mentioned in Chapter 2:

- System for trading IPv4 address space
- Migration to IPv6 Internet
- Maintenance of IPv4 Internet

4.5.1. Trading of IPv4 address space

After exhaustion, no new IP address space will be allocated from RIRs. However, just after the exhaustion point, demand for IPv4 address space for urgent expansion of networks will continue. This demand can be covered only by IPv4 address space that has already been allocated and is no longer used, so it is possible to think that some type of system for trading IPv4 address space will be created.

At present, Internet registries are prohibited from carrying out any type of address transfers such as selling or purchasing allocated IP address space[24]. However, under the tight situation just after exhaustion, public institutions such as RIRs may need to create a suitable distribution structure, for example, for the securities market. If such a structure is not adequate, as mentioned in section 2.2.3, a black market may develop.

It is impossible to predict how much demand there will be for IPv4 address space on the black market or how long such a situation will last. However, if such a black market develops just after the exhaustion point, then the price of IPv4 address space will soar.

4.5.2. Migration to IPv6 Internet

Even if such a black market develops after exhaustion, the volume of IPv4 address space available on the market is likely to be very small compared with the actual demand for IPv4 address space required.

Address space on this black market will come from areas that are not address spaces allocated according to actual demand, that is, the surplus part of space allocated before RIRs were formed. The volume of such address space flowing in

[24] For instance, APNIC Address Policy (Policies for IPv4 address space management in the Asia Pacific region) Item 9.9
http://www.apnic.net/docs/policy/add-manage-policy.html

will not be as large as expected, and will probably satisfy the demand for only a few years at most, as mentioned in Chapter 2.

If the volume of address space flowing into the market is small, the price of IPv4 address space is likely to become extremely high. Therefore, many organizations will need to find an alternative to IPv4 address space.

The adoption of IPv6 is the prevailing alternative to IPv4. Many technologies related to IPv6 have been verified in the last few years, and can operate without difficulty in various scenarios. Therefore, we expect that new services will be created using IPv6 address space, and as a result, many organizations will start the deployment of IPv6.

When the IPv6 Internet has grown sufficiently and replaces the existing IPv4 Internet, the IPv4 Internet will belong to the past and demand for IPv4 address space will decrease.

4.5.3. Maintenance of IPv4 Internet

The new IPv6 Internet network will likely replace the current IPv4 Internet, but is not the only means of maintaining the current Internet.

The main alternative for maintaining the current IPv4 Internet other than IPv6 is address translation technology such as NAT. When address translation technology such as NAT is upgraded and becomes more user-friendly, users may choose to use address translation technology rather than IPv6.

However, because new IPv4 address space will no longer be provided, IPv4 address space will be repeatedly generated and recycled, which will foster a black market.

However, if the amount of IP address space used continues to increase, IPv4 address space will run out completely, even on the black market. It is impossible to anticipate when this will happen, but assuming it does, an alternative technology to IPv4 Internet will be needed.

4.6. Impact of co-existence of IPv6 Internet and IPv4 Internet

This section discusses what sort of situation will occur on the Internet when allocation of IPv4 address spaces has terminated and only IPv6 address spaces are available.

4.6.1. Basic operation of the Internet

First, a review of the basic operation of the Internet.

The Internet is a global public network that interconnects networks using the TCP/IP[25] protocol. Computers are generally connected to it and communication occurs among them. An essential condition of each network service is that equipment to be connected must be able to be identified by a unique identifier, and with the TCP/IP protocol, the identifier is an IP address.

However, IP address space is not normally used directly by computer users except in special cases; rather, the communication destination is specified using a host name and communication is established by reference to the IP address using the host name by means of the DNS[26] system. This system is expressed as a conceptual diagram in Fig. 4-2.

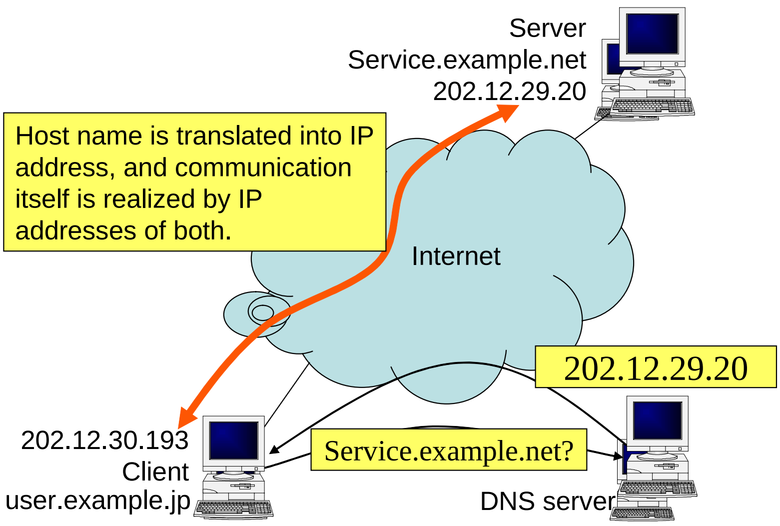

Fig. 4-2 Concept of the Internet

[25] TCP/IP: Transmission Control Protocol/Internet Protocol
The generic name of protocols used for the Internet

[26] DNS: Domain Name System
The system used to provide information on computers connected to the Internet

4.6.2. Differences between IPv4 and IPv6 for the Internet user

Users of computers connected to the Internet discover its convenience when accessing to various services and information residing on the servers of service providers. Without doubt, the convenience of the Internet for users applies to these services on other servers.

In such cases, host names used for URI[27] become the index to access various services. Users obtain various services by inputting a host name into a WWW[28] browser or mail software; users are rarely aware of IP address space.

As the names indicate, IPv4 and IPv6 are two different versions of an Internet protocol, and they often run simultaneously on the same computers or routers and share physical facilities (a state called “dual stack”). However, IPv4 and IPv6 as protocols are not compatible and cannot communicate directly with each other. Therefore, the Internet constructed with IPv4 and the Internet constructed with IPv6 should be considered as two independent networks, though they share some of the same facilities. Fig. 4-3 is a conceptual diagram re-drawn from Fig. 4-2 from this perspective.

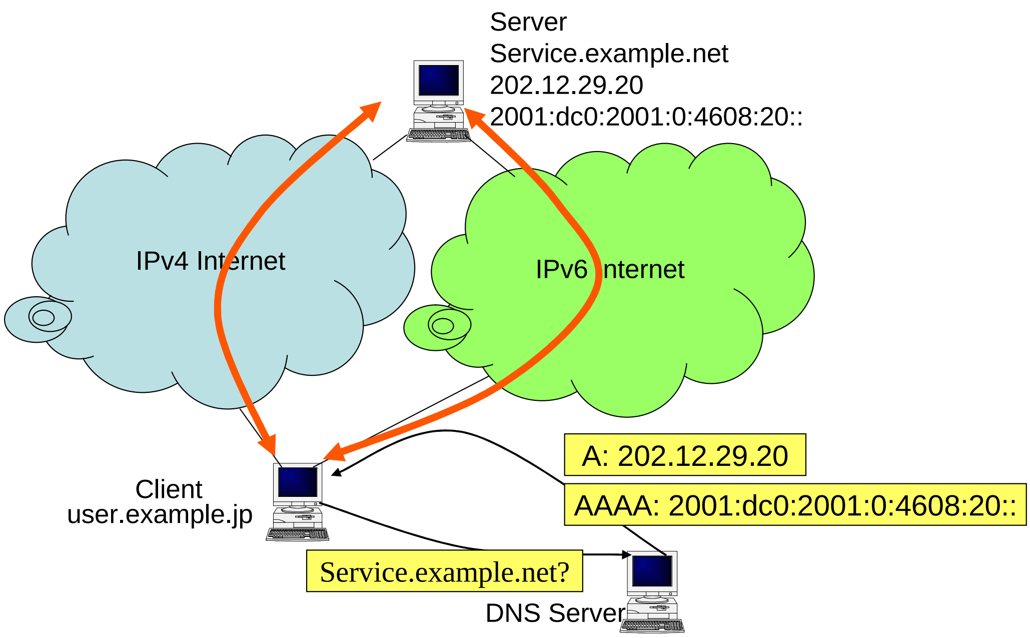

Fig. 4-3 Dual stack Internet

[27] URI: Uniform Resource Identifier
A method to indicate the location of information on the Internet

[28] WWW: World Wide Web
A document system normally used on the Internet

In Fig. 4-3, the name server is described separately from the network for convenience, but the name server referred to by a computer for resolving the host name resolves the same contents via both IPv4 and IPv6; different DNSs are not constructed separately for IPv4 and IPv6. For one host name, either "A" resource record, which is the IPv4 address or "AAAA (quad A)" resource record, which is the IPv6 address, or both of them, are resolved.

At present when users talk about the Internet, they mean the IPv4 Internet. IPv4 exclusively provides information and services sought by users of the Internet, thus raising the value of the Internet.

The IPv6 Internet is provided commercially, but both providers and users still consider it as experimental. However, the IPv6 Internet already exists, and dual stack clients and servers connected to both IPv4 and IPv6 Internet exist though the number is small, and there are already a few IPv6 single stack client servers. This is illustrated in Fig. 4-4.

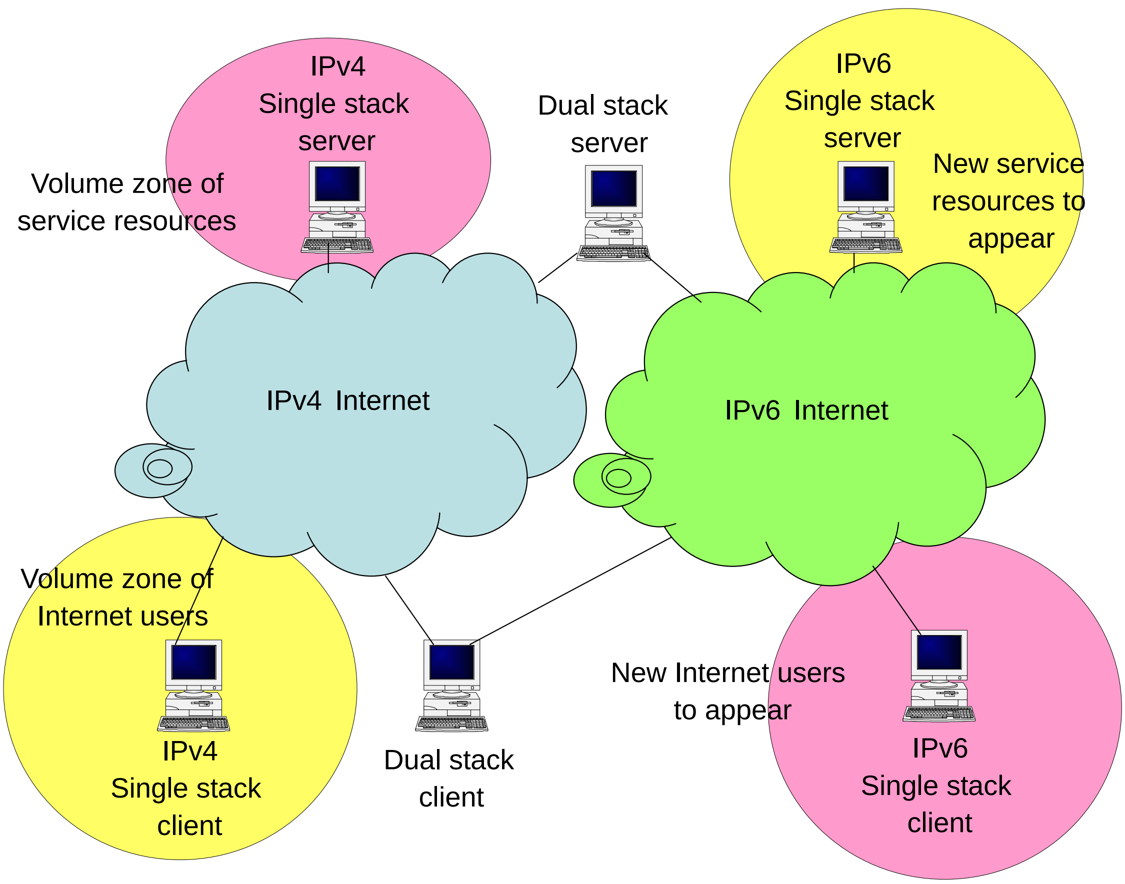

Fig. 4-4 Various servers and clients connected to the Internet

4.6.3. Problems and solutions after IPv4 address space is exhausted

When the assignment of IPv4 address space terminates and only IPv6 address space can be assigned, service providers and users which are newly connecting to the Internet can use the Internet only by IPv6 single stacks. The following two problems will then occur.

1. New Internet users (client side) can use only the IPv6 Internet, and cannot access the IPv4 single stack servers that have a wealth of information and services. As described previously, the convenience of the Internet for users is provided via the servers, so new Internet users will not be able to enjoy the convenience of the Internet. In other words, users will not connect to an Internet that does not offer any convenience.

2. New service providers (server side) can use only the IPv6 Internet and cannot provide services for users of IPv4 single stacks that form a volume zone. Consequently it has no importance for business, and their business will not develop.

It is extremely important to resolve these problems to ensure smooth development of the IPv6 Internet when IPv4 address space allocations are terminated. How can this be resolved? Two possible measures when IPv4 address space can no longer be secured are as follows.

a. Measures to allow a client of IPv6 single stacks to access an IPv4 single stack server, such as:
   (A) the server side perfects IPv6 to form a dual stack, or
   (B) to develop and set up a middle system to allow a session to be established from IPv6 to IPv4.

b. Measures to allow a client of IPv4 single stacks to access the IPv6 single stack server, such as:
   (A) to develop and set up a middle system that enables a session to be established from IPv4 to IPv6, or
   (B) the client side perfects IPv6 to form a dual stack.

These two approaches are illustrated in Fig. 4-5 and Fig. 4-6. (A) is performed on the server side (by the network provider on the server side), and (B) is performed on the client side (by the network provider on the client side).

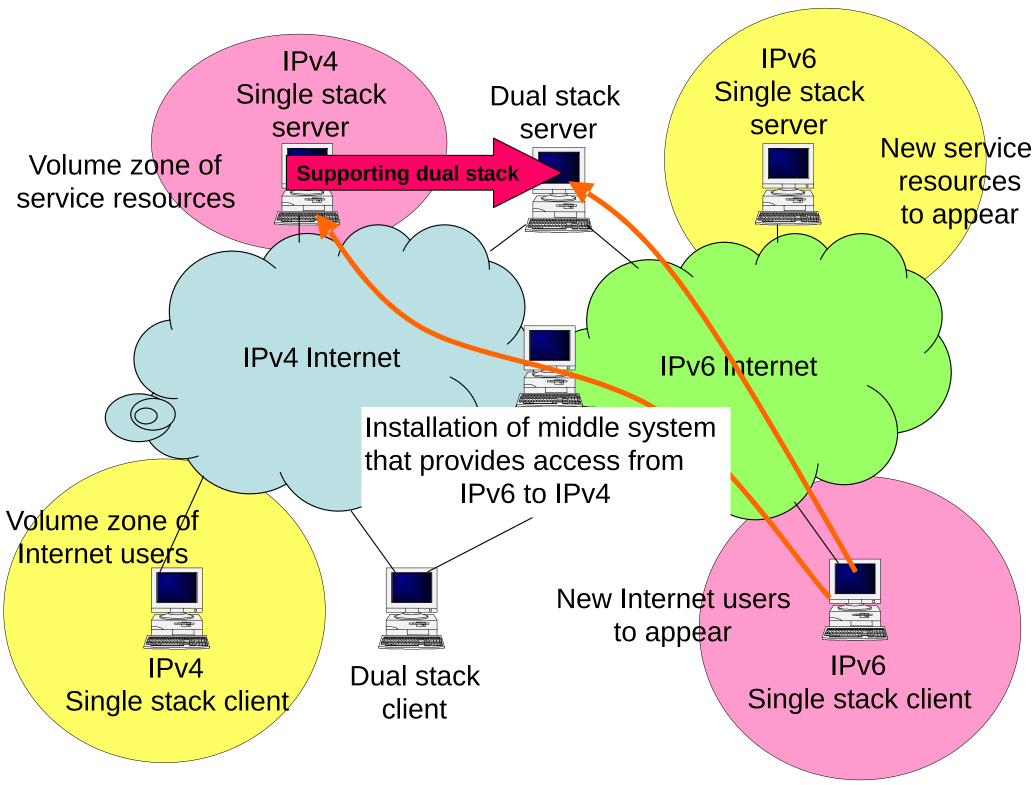

Fig. 4-5 Measure for IPv6 single stack client

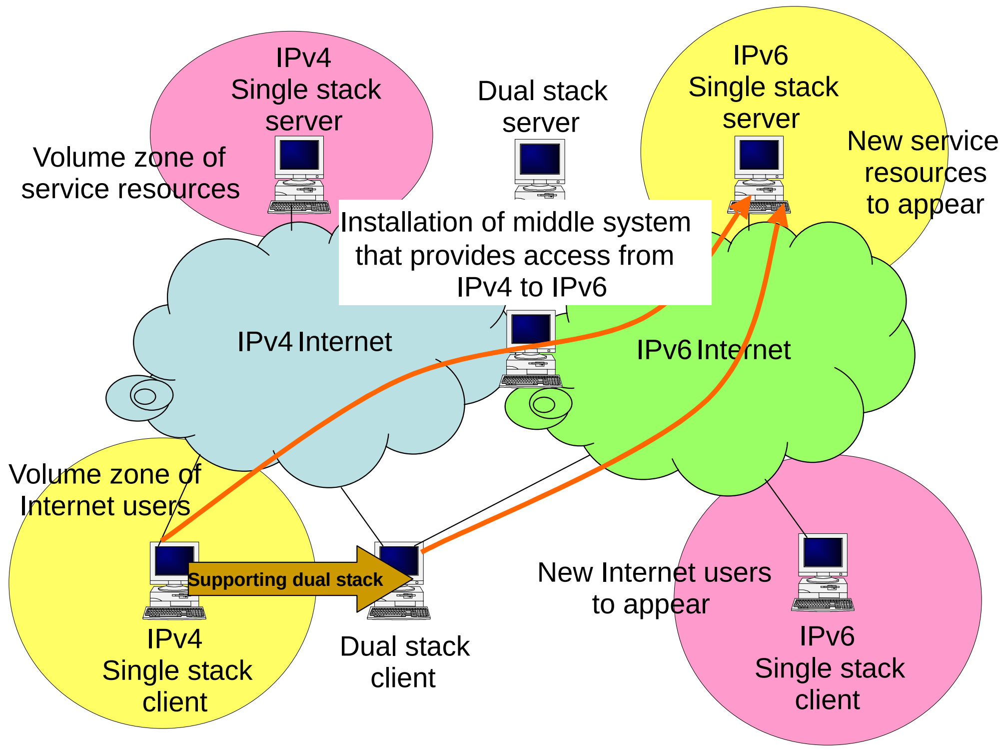

Fig. 4-6 Measure for IPv6 single stack server

It is difficult to imagine that a host administrator or network provider, which has taken the required measures by perfecting IPv6 for an IPv4 single stack host to form a dual stack, to take further measures to allow communication between an IPv4 single stack host on its side and another IPv6 single stack host. Instead, the host administrator or network provider on the IPv6 single stack side should take measures to enable communication with the IPv4 single stack. This is illustrated in Fig. 4-7.

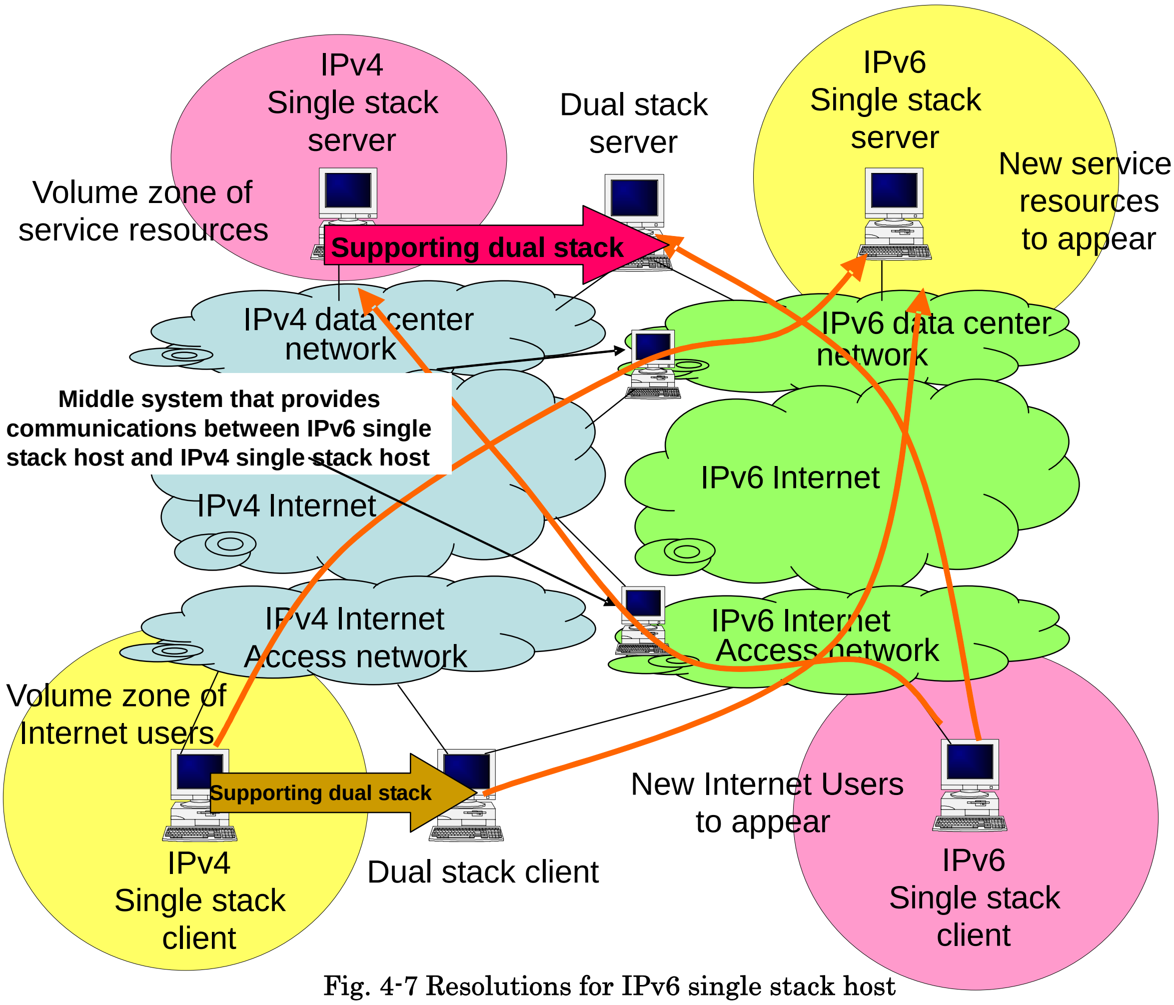

Fig. 4-7 Resolutions for IPv6 single stack host

When setting up a middle system, new IPv4 address space will be needed, but the volume of the required IPv4 address will largely depend on the specifications of the middle system. Measures are needed to secure IPv4 address space for this middle system.

4.6.4. Organizing the problems in a coexisting environment

The following is a re-examination, from the perspective of the network provider, of countermeasures for the IPv6 single stack host, which become crucial after assignment of IPv4 terminates, as discussed so far.

i) to promote support for dual stacks with IPv6 for the existing IPv4 clients to allow communication with the IPv4 single stack servers,

ii) to promote support for dual stacks with IPv6 for the existing IPv4 servers to allow communication from an IPv6 single stack clients,

iii) to set up a middle system to secure convenient access for new IPv6 single stack clients to the IPv4 single stack server on an Internet that does not support dual stacks.

iv) to set up a middle system to secure convenient access for new IPv6 single stack servers from an IPv4 single stack client on an Internet that does not support dual stacks.

These measures would face technical restrictions and circumstances.

We are not going to examine the technical possibilities regarding a middle system such as options iii) or iv) in this report. Such middle systems might be unexpectedly difficult to be deployed. In such cases the demand for dual-stack might be really high., However, it is expected to be difficult to support dual stacks on the IPv4 host side. This is because it requires investment and will take time for sufficient demand to emerge to justify the investment in dual stacks. In other words, we cannot expect existing IPv4 hosts to invest while there are few users from IPv6 single stacks. Even if support for dual stacks is promoted in Japan, it does not guarantee that it will be promoted similarly in other economies.

Therefore, providers who are planning to have an IPv6 single stack host will likely need to develop and install a middle system themselves.

The main difference between options iii) and iv) is whether a middle system provides a service for clients or for servers. Option iii) provides service for a client, similar to the currently used NAT, and there is reasonably high transparency for address translation from IPv4 to IPv4. As a result, we can expect the same to be true for the case from IPv6 to IPv4 as well.

However, in the case of a middle system placed on the server side as mentioned in option iv), the server waits for service requests from a client. Therefore it is necessary to register the service and translation scheme in advance with the middle system itself. Therefore, option iv) is far less transparent than iii), and as a result, there is a high barrier against the IPv6 single stack on the server side.

5. Recommendations

So far, we have looked at projections made by some experts and analyzed the trends in Japan. It is clear that the allocation of IPv4 address space will terminate in the near future. However, this does not mean that the Internet based on IPv4 will terminate immediately. Yet since new IPv4 address space will no longer be assigned, the IPv4-based Internet will stop growing or will decline. All Internet users should realize this fact and take necessary measures.

To deal with the exhaustion of IPv4 address space, it is urgent for those in the industry to examine and implement measures, particularly for the IPv6 Internet. When new services are provided in the future, they will not only be based on IPv4, but IPv6 as well.

This chapter describes what each player must do to prepare for the exhaustion of IPv4 address space. Thus far, we have summarized the objective facts and avoided the authors' personal views, but in this chapter the team of authors recommends what preparations players should make as IPv4 address space is exhausted.

5.1. Classification of stake holders

In this chapter, we have classified Internet players into the following groups, as shown in Fig. 5-1 and Fig. 5-2.

- Internet Service Provider (ISP)

  An ISP provides connectivity to the Internet. They are called LIRs in the IP address management structure model. "IP address management agents (LIRs under JPNIC)" are considered as ISPs in the case of JPNIC. Agents who do not become LIRs and receive allocations of IP address space from an upstream ISP and assign IP address space to users (so-called "secondary providers") are also included among ISPs.

- Registry

  Of those organizations that allocate and assign IP address space, ICANN[29] and IANA which are responsible globally, RIRs which are responsible for each region, and NIRs which are responsible for each country, are referred as registries in this chapter. LIRs (IP registrars of JPNIC) are not defined as registries in this report.

- Internet users

  Internet users are further classified as shown below.

  - Service providers

    A service provider is an organization that uses the Internet as a means of providing various services to general users (consumers,

[29] ICANN: The Internet Corporation for Assigned Names and Numbers
Civil nonprofit corporation of which purpose is to adjust various Internet resources worldwide

end users). While an ISP's main operation is the delivery of IPv4 or IPv6 packets, organizations that provide information or perform some type of online business including providers of search engines, online banks and online shopping sites are categorized as service providers.

- Corporate users

Among organizations such as companies that connect to the Internet to conduct their business, users that use information or services on the Internet are defined as "corporate users". On the other hand, users that provide services to non-corporate, unspecified multiple users are categorized as the above-mentioned service providers.

- General users

A general user means a user who uses information and services on the Internet. When such general users set up servers themselves to provide data, they are categorized as service providers.

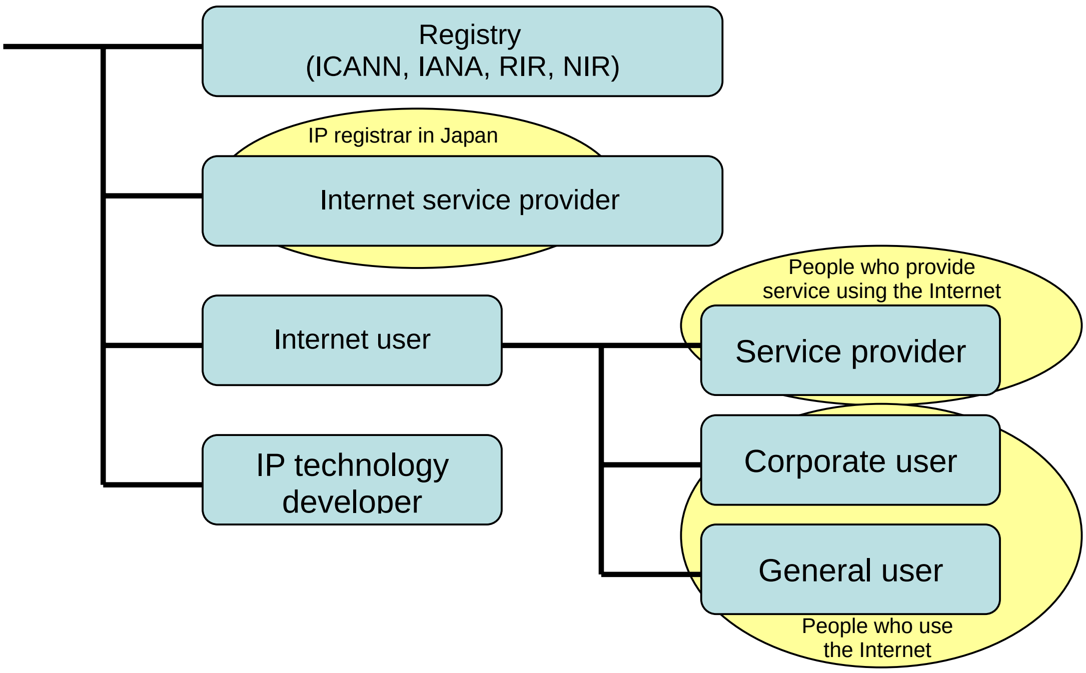

Fig. 5-1 Classification of players

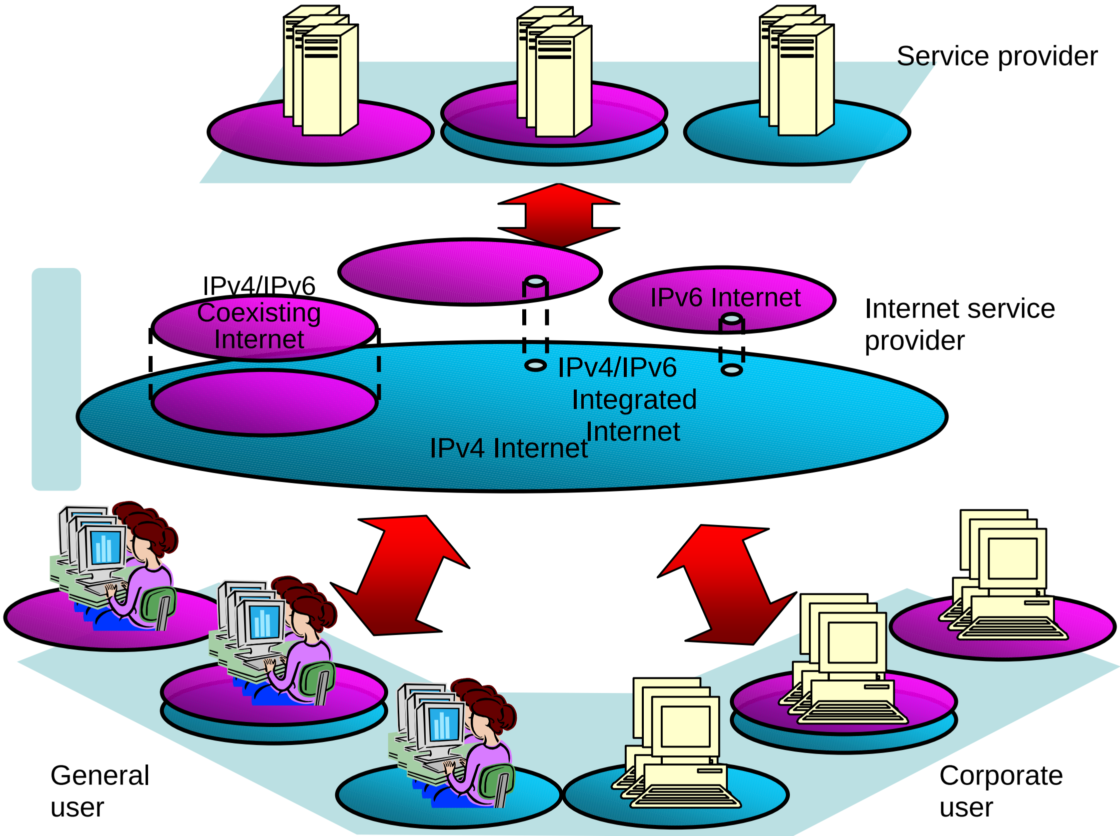

Fig. 5-2 Relationship between Internet Users and an ISP

5.2. Recommendations to registries (ICANN/IANA/RIR/NIR)

- **Each registry involved with IP address space should share a consistent policy throughout the world.**

Each regional registry should not unfairly allocate an IP address to an ISP (LIR). Each registry should allocate IP address space under the same policy and according to the same standard whichever LIR makes application. No geographical conditions should bring any advantage or disadvantage in the allocation of IP address space.

- **Registries should not change their policy in order to prevent the exhaustion of IPv4 address space or to extend the lifetime of IPv4 address space.**

It is not possible to stop IPv4 address space exhaustion any more than it is possible to stop the growth of the Internet. As Tony Hain stated in section 2.3.2, even if we “collect unused IPv4 address space and reallocate it” or we “tighten up address allocation conditions”, this would be inefficient and ineffective compared to the present speed of consumption of IPv4 address space. Therefore, if the policy is changed to extend the period during which IPv4 address space can be allocated, this would actually hinder growth in Internet usage.

Each registry should allocate the required volume of IP address space to organizations requiring them at the required time. Registries should maintain fairness as much as possible so that the allocation of IPv4 address space will terminate smoothly.

- **Registries may change their policy as long as its objective is to maintain the fairness of IPv4 address allocations/assignments.**

Policies should not be changed for the purpose of extending the lifetime of IPv4 address space. On the other hand, it is acceptable to change policy in order to maintain fairness in allocating address resources.

As at present, registries should allocate the required volume of address space to each ISP (LIR) at the required time in as fair a manner as possible. Moreover, registries may change their policy as long as this is done to ensure fairness.

Fair address distribution has been frequently discussed at RIR policy meetings and various views have been expressed. Assuming that IPv4 address space will be exhausted very soon, we need to start preparing to unify RIR awareness of such fairness.

For example, changes in policy such as dividing the expected period of IP address demand at the time of application into small parts, and applying time stamps on receipt of application may become necessary to ensure fair IP address allocation. Taking into account the demand for IP address space, such changes should be fully discussed.

- **Registries should secure IPv4 address space for critical infrastructure, etc.**

Moreover, public interest bodies such as registries and IETF[30] should secure IPv4 address space for critical infrastructure, which is the minimum requirement for operating the Internet. We need to define what constitutes the critical minimum infrastructure required for operation of the Internet. One may refer to the definition of the critical infrastructure determined when assigning IP address space for RIR for more information.

IPv4 address space is also necessary in order to create an environment in which IPv4 and IPv6 can coexist or to allow smooth migration to the IPv6 Internet, such as by deploying a middle system, as noted in section 4.6.4. Therefore, it may be necessary to secure IPv4 address space for this.

5.3. Recommendations to Internet service providers (ISP)

- **ISPs should not apply for more IP address space than necessary.**

ISPs should always be aware that IPv4 address space will be exhausted, and should strive to ensure the efficient use of IPv4 address space. When applying for IPv4 address space, they should also apply only for the necessary amount in the future. Hasty measures, such as applying for extra IPv4 address space at the last minute as exhaustion approaches, should be avoided. Registries should make fair allocations globally, even as IPv4 address space is exhausted. Therefore, even if there is a surge of applications, or an application is made to a registry in another region, no advantage or disadvantage in allocation should occur.

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[30] IETF: Internet Engineering Task Force
Voluntary association that promotes standardization of the Internet technology

- **ISPs should prepare to provide connectivity with IPv6 when IPv4 address space is exhausted. They should fully implement preparations in advance so that general users are not aware of the exhaustion of IPv4 address space.**

ISPs are key players in delivering Internet infrastructure to users, and such provision of Internet connectivity to users should not peak out even when IPv4 address space is exhausted. As with the IPv4 Internet, more effort should be devoted towards providing IPv6 connectivity.

If ISPs which provides connectivity to the Internet do not provide IPv6 service, problems such as slower network access may occur when Internet users, including service providers, corporate users and general users start using IPv6 as there will no accessibility to IPv6. These difficulties will discourage Internet users from migrating to IPv6. Therefore, if an ISP is late in supporting IPv6, the support level of IPv6 will remain the same as it is today throughout the Internet, even when IPv4 address space is exhausted. It is therefore vital that ISPs give priority to supporting IPv6.

IPv6 connectivity will not be cheap to provide, and expenses as shown below will be incurred. However, for the whole Internet to overcome the IPv4 exhaustion problem, the ISPs themselves should approach IP technology developers, including vendors, commission them to resolve IPv6 deployment difficulties and to provide low-cost IPv6 equipment. They should also strive to provide IPv6 connectivity at the appropriate time while monitoring social conditions.

- Personnel expenses including training of network engineers
  - In addition to maintaining existing networks, extra personnel expenses including training of IPv6 network operators will be required at the initial stage. To provide service continuously, training expenses for support staff will be necessary.
- Investment in IPv6 facilities
  - Network equipment including routers that support IPv6 is often more expensive, and as a result, extra capital investment is required to support IPv6.
  - Expenses may be incurred in making monitoring systems or operating systems support IPv6.
- Acquisition of IPv6 address space and peering
  - It is necessary to acquire new IPv6 address space in addition to IPv4 address space. IPv6 peering or transit expenses may also be incurred.
- Services to support IPv6
  - In order to have the services provided by each ISP such as web portals and mail services support IPv6, servers or applications will need to be modified, incurring extra cost.

The Migration Guidelines, issued by the Transfer Working Group[31] within the IPv6 Promotion Council can be used as a reference for investigating the series of technical issues related to supporting IPv6 and migration, for establishing equipment standards and for clarifying IP address maintenance costs.

5.4. Recommendations to Internet users

As mentioned in Fig. 5-1, Internet users can be classified into the three categories of "service providers", "corporate users" and "general users".

This chapter makes some recommendations for Internet users.

5.4.1. Service providers

● **Service providers should select facilities that support IPv6 when procuring new facilities.**

It is crucial for the Internet in the future that service providers support IPv6. If they do not support IPv6 after IPv4 address space is exhausted, the trend towards the use of only IPv4 will become stronger, and the load for translation from IPv6 to IPv4 will increase unnecessarily.

When a service provider builds a new facility (server, router, firewall, etc.) in the future, we recommend procuring facilities that support both IPv4 and IPv6, taking into consideration the equipment depreciation period.

Windows Vista, which supports IPv6 as a standard specification, is scheduled to be released in late 2006 or early 2007. Therefore, ISPs will presumably choose to support IPv6. When IPv6 is distributed by Windows Vista, it will be necessary to consider supporting IPv6 when procuring machines that will continue to be used.

● **Service providers should use IPv6 immediately when it does not interfere with their business.**

Service providers should carefully study to enable IPv6. For instance, difficulties may arise if a DNS announces IPv6 address before an ISP supports IPv6. In many of the operating systems at present, IPv6 takes priority in the order of name resolution of IP address and the order of attempting connection with a server. If connection with IPv6 starts while IPv6 accessibility remains imperfect, then IPv6 connection will fail and IPv4 will be used for connection instead. Depending on the environment, connection may take an extra 20 seconds or so and users would certainly claim that connection was slow[32]. A countermeasure would be to separate FQDN for IPv4 and FQDN for IPv6, while

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[31] Transfer Working Group, IPv6 Promotion Council
http://www.v6pc.jp/jp/wg/transWG/index.phtml

[32] Presentation on this content was held at JANOG17.
"Clear and present danger of IPv6"
http://www.janog.gr.jp/meeting/janog17/abstract.html#p04

it is regarded as ideal to have IPv4 and IPv6 address spaces respond to the same FQDN[33] (which means making it have both an A record and AAAA record). One measure

A service provider must properly assess the state of ISP support for IPv6. As it is expected that IPv4 exhaustion will not be long by the time ISPs support IPv6, it is recommended that service providers promptly get themselves to be IPv6 ready once ISPs support IPv6.

5.4.2. Corporate users

Our recommendations to corporate users are directed to the administrators of corporate networks (such as Information System Divisions); recommendations to general users in organizations are the same as to general users, as described in the next section.

- **When deploying a new network facility in the future, facilities that support IPv6 should be deployed.**

Corporate network facilities include network equipment such as routers, PCs, intra-company and external servers, various applications and key systems including groupware.

As the upgrade cycle of a corporate network is normally about 5 years, when the exhaustion point of IPv4 address space approaches, which is predicted to be in a few years' time, IPv6 will presumably have spread on the Internet. When companies consider upgrading facilities, we recommend purchasing equipment that supports IPv6 or will support IPv6 in the future.

When using IPv6 address space in a corporate network (as well as with IPv4), due to difficulties arising from the coexistence of IPv4 and IPv6 described in the previous section (recommendations for service providers), the company's external communications (access to the Internet, etc.) will be slower. Corporate network administrators should carefully consider this point when designing and constructing networks.

5.4.3. General users

- **General users should not concern themselves with the exhaustion of IPv4 address space, nor should they be aware of the fact that IPv4 address space will be exhausted.**

General users do not need to consider measures to respond to the exhaustion of IPv4 address space such as supporting IPv6.

ISPs, service providers and IP engineers such as vendors should respond to

[33] FQDN: Fully Qualified Domain Name
Domain name fully described without omitting any elements

the situation without general users being aware of the exhaustion of IPv4 address space or the migration to IPv6, and should ensure that general users can continue to receive all services.

5.5. Recommendations to IP technology developers (vendors, etc.)

- **IP technology developers including vendors should be aware of the exhaustion of IPv4 address space and take more effort to develop and refine their IPv6 technology. Difficulties arising from IPv6 and IPv4 coexistence must be resolved promptly in cooperation with other players.**

Developers, organizations, vendors and manufacturers involved in developing IP network technology need to work further on this issue. With regard to coexisting and integrated environments for IPv4 and IPv6 in the transition period as described in Chapter 3, all parties should cooperate to resolve this issue.

- Applications
  - When developing future applications, it may be necessary to assume that multiple IPv4 and IPv6 addresses are assigned and placed in a coexisting environment of a multi-home or multi-source IP called a dual stack.
- Networks
  - At present, the environment where all services can be used only on the IPv6 Internet has not yet been available. Some technology for migration may be needed so that IPv4 services can be transparently used even from an IPv6-only environment.
  - Moreover, we need to prevent IPv6 development problems in Internet element technology, with DNS usage for example.
- Security
  - Security technology is important in IPv4 and IPv6 coexisting or integrated environments. It is necessary to provide equivalent safety and security as with the present IPv4 Internet, at least for users.
  - In the IPv6 Internet, new forms of usage are likely to appear. When services such as Home Networks or Tag technology that are different from services on the existing Internet becomes available, maintaining security becomes an important factor.

The exhaustion period of IPv4 (whole period including pre- and post-exhaustion periods and exhaustion point) is regarded as the period of transition to the IPv6 Internet. IP technology developers should improve and refine their technology to ensure the following points.

1. It is necessary to be able to use services without problems on "IPv4/IPv6 coexisting networks" where IPv4-only Internet and IPv6-only Internet, which are independent of each other, are inter-connected.

2. It is necessary to be able to use services without problems in IPv4/IPv6 integrated networks represented by dual stack environments, where multiple IPv4 and IPv6 address spaces are assigned.

3. It is necessary to be able to use services temporarily on the IPv4 network without problems from an IPv6-only network. If this technology is inadequate, the migration will not go smoothly in the transition period described in Chapter 4.

The second point, which refers to technical problems in migrating to IPv6 in IPv4/IPv6 coexisting and integrated network environment, is described in detail in the IPv6 Fix Project[34] performed by the WIDE Project[35].

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[34] IPv6 Fix Official Homepage
http://v6fix.net/

[35] WIDE Project: Widely Integrated Distributed Environment Project
http://www.wide.ad.jp/index-j.html

6. Authors

This report was authored by the "Expert Research Team on Number Resources Utilization" under the Japan Network Information Center (JPNIC), in order to monitor the future expansion of IPv4 address demand.

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(as of March 2006)

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