IPv4 Addresses Will Run Out in 15 Years

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Abstract

This paper studies the address spacing usage of IPv4. We show that the current available IP addresses can handle the requests in the next 15 years. But with more devices and services introduced, we predict that we will transform to IPv6 over the next 10 years.

1. Introduction

Most of the computers, routers and other devices on today's Internet use IPv4, the current standard protocol for the Internet, which is already twenty years old. IPv4 has been remarkably successful despite of its age, and it is needed by all the new machines added to the Internet. However, the growing shortage of addresses, which is the greatest issue with the use of IPv4, may crash the Internet. Therefore, many people believe that IPv4 will be replaced by IPv6 soon.

In this paper, we will focus on the current assignment and usage of IP addresses and the growing demand for IP addresses from new applications. We will show that even without the request from new devices, there will be no IPv4 addresses to be assigned 15 years later from now on. And with the introduction of new applications, we can see a large-scale adoption of IPv6 in the next couple of years.

2. Backgrounds

In IPv4, IP addresses consists of 32 bits, which can create 2^{32} = 4,294,967,296 (over 4 billion) unique host interface addresses available in theory. For each interface of the network devices on the Internet, a global unique IP address is required by IPv4. Usually, we present an IP address by the dotted-decimal notations which use a decimal number for each byte, such as 192.168.11.11. Not only the interfaces use IP addresses, but an IPv4 protocol also uses some special IP addresses for its functionality: network ID and Multicast address for each IP network.

The actual assignment of an address is not arbitrary. Originally, all the IPv4 address spaces were managed directly by the IANA (Internet Assigned Numbers Authority) [1], a nonprofit organization. Now there are 4 main regional organizations to assign IP addresses: **APNIC**[2] (Asia Pacific Network Information Centre, Asia-Pacific Region), **ARIN**[3](American Registry for Internet Numbers, North America and Sub-Sahara Africa), **LACNIC**[4] (Regional Latin-American and Caribbean IP Address Registry, Latin America and some Caribbean Islands) and **RIPE NCC** (Réseaux IP Européens, Europe, the Middle East and Central Asia, and African countries located north of the equator)[5]. We will discuss the IP address assignments in section 3.

With the rapid growth of the global Internet, the prospect of running out of IP addresses is seemingly inevitable. A new version of IP protocol, IPv6[6] was announced and has been in use by some organizations for some time. IPv6 uses 128 bits to identify each address and can assign 1500 addresses for each square root of the earth under the efficiency of IPv4. IPv6 is enough to handle the demand of addresses in the near future. But the transition from IPv4 to IPv6 involves the updates for all hardware devices, operating systems and softwares, so we have not yet seen IPv6 widely deployed, except in some experimental cases. In this paper, we study the current techniques to increase the efficiency of the assignment of IPv4 and predict that a complete transition from IPv6 to IPv4 will happen in less than 10 years. In the following, we will discuss the IPv4 techniques which are related to the IP addresses.

2.1 IP Class

An IP address consists of 2 parts, a network part and a host part. The network part of an IP address identifies the network to which the host is attached, and all the interfaces attached on the same network have the same **network prefix** or **network ID**.

A network prefix is the leftmost bits of an IP address. In this paper, we use a number following the IP address to specify the number of bits used by the network prefix. For example, the 192.168.11.0/24 means the network prefix is the left 24 bits of the IP address, so 192.168.11. 230 belongs to this network while 192.168.12.22 does not.

The size of the network prefix is not the same for each IP address. Instead, IP addresses are divided into some different classes.

Class A: The first bit of a Class A address is 0 and the network prefix uses the first 8 bits. There are 126 class A networks available. (0.X.X.X is reserved, and 127.X.X.X is used by IPv4 for loopback.). Each class A network can have about 16 million hosts by using the last 24 bits for the interfaces.

Class B: The first 2 bits of a Class B address is 10 and the network prefix uses the first 16 bits. There are 16284 class B networks. Each class B network can have about 65,500 IP addresses.

Class C: The first 3 bits of a Class C address is 110 and the network prefix uses the first 24 bits. There are 2 million class C networks available. Each class B network can have about 250 IP addresses.

Class D: The first 4 bits of a Class D address is 1110. Since these address define the multicast groups, they cannot be assigned to an interface.

Class E: The first 4 bits of a Class C address is 1111 and they are reserved and currently unused.

Thus, out of the approximately 4 billion possible IP addresses, there are actually only about 3.5 billion IP addresses available for network interfaces.

2.2 CIDR (Classless Interdomain Routing)

In the early stage of IPv4, IP addresses were assigned by the units of Class A, B or C. So large organizations applied for many Class A addresses. Now if we check the list of the current Class A address owners, we can see lots of them. For example, 3.0.0.0/8 is owned by General Electric Company, and 18.0.0.0/8 is owned MIT. Once an organization owns some specific IP addresses, these IP addresses cannot be used by other organizations unless there are business relationships between these organizations or the original owner would like to return its IP addresses. For instance, Stanford University returned 36.0.0.0/8 to IANA in 1993.

With the growth of the Internet in the early 1990s, the possibility for the IP address space to be exhausted as a consequence of inefficient assignments became the biggest issue for the IPv4 users. So CIDR (Classless interdomain routing) was used since then. The artificial classes were abandoned. The assignment units of IP addresses are not class A or even class B anymore. Instead, they are in units likes /19 ($2^{13} \approx 8000$ IP addresses per network), /22($2^{10} \approx 1000$ IP addresses per network). In this way, the efficiency has been increased with the dramatic increase in the routing table. In this paper, we also use the /8, /24 as the units of IP addresses. For example, /19 is counted as 32 /24 units.

2.3 DHCP (Dynamic Host Configuration Prototol)[7]

The main purpose of DHCP protocol is to lower the administration cost of IP network. Instead of assigning a static IP address to devices on the network, each device requests a dynamic assigning IP address from the DHCP server when it connects to the network. By using DHCP protocol, we can also increase the efficiency of the usage of the IP addresses because we only need IP addresses to support concurrent users, instead of all users. Many ISPs currently are using DHCP to support their customers who use a dial-up modem, IDSL or cables. But the drawback of DHCP is that if one customer wants to build a personal web site, he still needs to apply for a static IP address.

2.4 NATs (Network Address Tranlators)[8],[9]

The main idea of NAT is sharing the global IP addresses. It uses the functionalities of TCP protocol. For NAT to be implemented, the router which connects the WAN and the internal network is assigned with a global IP address on the WAN side. On the internal LAN side, all devices use special private IP addresses. The requests sent out to the WAN are assigned to a special port of TCP protocol. The router maps the internal IP address to a corresponding port. At the same time, the requests from the WAN are also maps to some internal IP addresses by using NAT table. With the help of virtual hosting, several web servers can share one IP address. IANA also reserves 10.0.0.0/8, 172.16.X.X/12 and 192.168.X.X/24 for the different levels of internal networks.

NAT has several disadvantages: Firstly, it requires the router to operate at the TCP level; as a result, it increases the complexity of the router software and decreases the performance when the NAT table is large. So NAT is not a long-term solution for heavy workloads. Secondly, it is either not compatible to some applications or making them more difficult to run. NAT also makes some protocols difficult to be implemented, such as SNMP, DNS. Additionally, it hides the identity of users, which is generally regarded as a negative feature in the Internet communities. So now NAT is mainly used as a short-term solution mainly by SOHO (small office, home office) users.

3. IP Address Space Usages Statistics

In the early stage of the Internet, we could use “whois” to output the whole list of the owners of the IP addresses. But now this task is impossible. So our analyses are all based on the information published.

3.1 Whole IP Address Space

Originally, all the IPv4 address spaces were managed directly by the IANA. As the Internet kept growing fast, the address spaces started to be assigned according to different regions. There are four regional Internet registries that are operating in the world. These four registries get /8 IP address ranges from IANA and assign the IP addresses (RIR). In this section, we will analyze the current usages of the IPv4 address spaces using the reports from these registries.

Normally, regional Internet registries get IP addresses in /8 units, each of which has about 16 millions addresses. So firstly, let us examine the IP address space by /8 units. In Table 1, we list the number of IP addresses assigned in /8 units. Due to some historical reasons, there are 45 whole /8 units of IP addresses owned by different organizations/corporations/institutes other than IANA or regional registries. Now it is impossible to get a whole /8 block. In the mixed /8 blocks, which mostly are the original class B IP addresses, a larger portion was assigned. From the operation model of the regional Internet registries, we can also assume that there are only one or two /8 blocks which have IP addresses available. So we can say the current available IP addresses blocks are those reserved by IANA.

IPv4 protocol (loopback, NAT)	3
Multicast	16
Undermined (240-255)	16
Organizations other than IANA	45
Unassigned (reserved by IANA)	79
APNIC	13
ARIN	17
RIPE NCC	15
LACNIC	2
Mixed	50
Total	256

Table 1 IP addresses assignment in unit /8
Source: *INTERNET PROTOCOL V4 ADDRESS SPACE* IANA reports[1].

United States	38
United Kingdom	2
Japan	1
Germany	1
NORWAY	1
CANADA	1
FRANCE	1
Total	45

Table 2 The /8 units by country (outside RIR)
Source: *INTERNET PROTOCOL V4 ADDRESS SPACE* IANA reports.[1]

3.2 Operations of Regional Internet Registries (RIRs)

Because now RIRs are the main sources of the IP addresses, we use their annual report data to study the current demands and delegations of IPv4 addresses. Figure 1 shows the IP addresses delegated in North American since 1999. The number stays at 80,000 /24s per year, which is about 1.3 /8s.

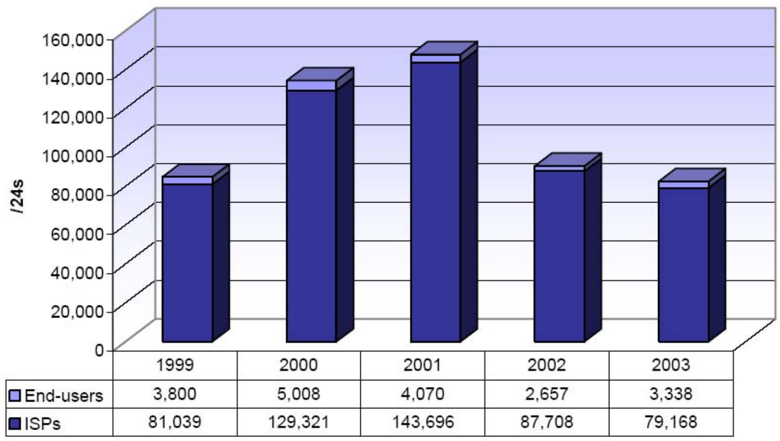

Figure 1 The IPv4 Delegations of ARIN (mainly for users in North America)[10]

Figure 2 shows the IP addresses delegated in Asian-Pacific region since 1996. We can see the sharp increase of the requests since 2000, regardless of the impact of “Internet bubble”.

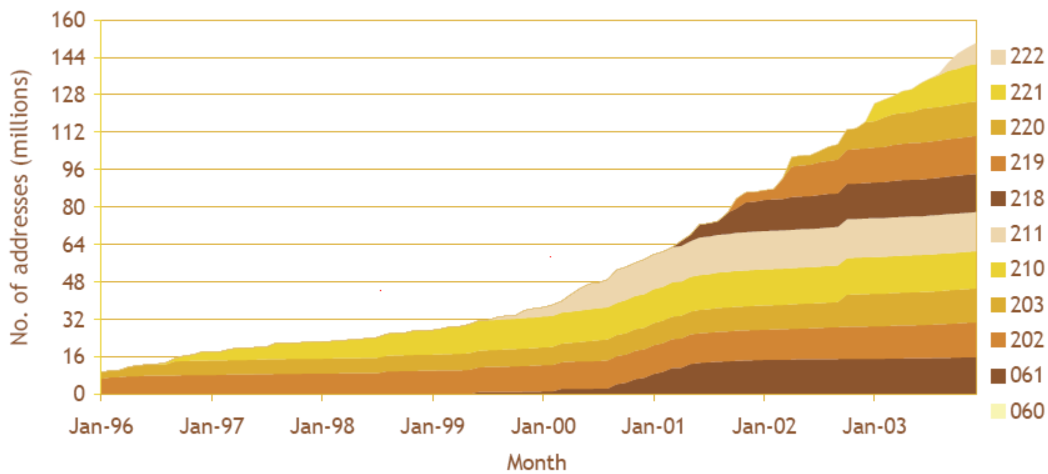

Figure 2 The IPv4 Delegations of APNIC cumulated from 1996[11]

Table 3 shows the distribution of assigned and unassigned IP addresses in the /8 ranges administered by APNIC in 2003. APNIC received 2 new /8 ranges from IANA in 2003: 222/8 (February) and 60/8 (April), so these two /8 ranges have more available addresses.

This also validates our assumption that the /8 ranges administered by RIR are almost full occupied. In April, 2004 APNIC received 2 more /8 ranges from IANA: 58 /8 and 59 /8.

APNIC-administered IPv4 address space, allocated and available

/8 range	Allocated	Total	% Allocated	% Available
060	0	16777216	0.00%	100.00%
061	15831040	16777216	94.36%	5.64%
202	15133184	16777216	90.20%	9.80%
203	14538496	16777216	86.66%	13.34%
210	15958016	16777216	95.12%	4.88%
211	16711680	16777216	99.61%	0.39%
218	16241152	16777216	96.80%	3.20%
219	16302080	16777216	97.17%	2.83%
220	14999552	16777216	89.40%	10.60%
221	16015360	16777216	95.46%	4.54%
222	9216000	16777216	54.93%	45.07%
Totals	150946560	184549376	81.79%	18.21%

Table 3 The occupation of /8 ranges administered by APNIC.[11]
*The data is from 2003 reports, APNIC got 2 /8 ranges in 2004

As shown in Figure 3, there are about 5 /8 ranges of IP addresses allocated each year around the world and the number keeps increasing, especially in APNIC. At this rate, IP addresses will run out over the next 15 years and at that time, there will be no IP addresses that can be assigned to the new networks if we still use IPv4.

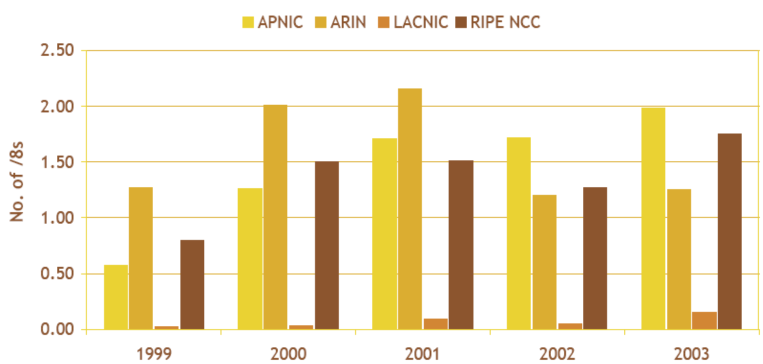

Figure 3 IPv4 /8 ranges allocated by RIRs (Yearly comparisons) [11]

3.2 Internet Waves in Asia

APNIC is the one region that has the highest increasing rate of IP address consumption and in this region almost all IP addresses were allocated through RIRs (except that Japan has a Class A range). Hence, we select the Asian-Pacific region for analysis. Figure 4 illustrates the distribution of IP addresses among different countries in the region. Among them, Japan, China and Korea use the largest number of IP addresses.

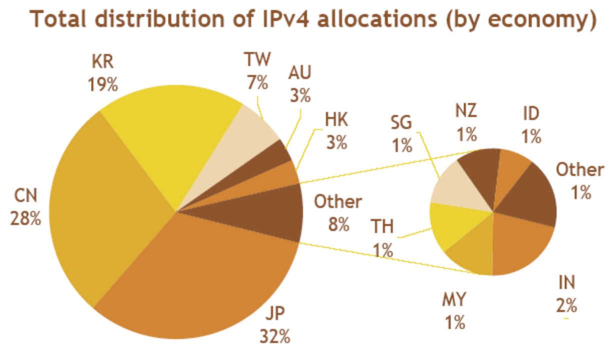

Figure 4 Distributions of IPv4 allocations of APNIC [11]

In table 4, we compare the IP address distribution by RIRs since the late 1990s. In the table we do not count the IP addresses assigned by IANA directly. If considering the fact that the North America region already has a large portion of IP address space allocated before 1996, the number of IP addresses per 100 people will be several times greater than 63. It shows that in the developed countries such as Japan and Korea, there are more than 30 IP addresses used for every 100 people while in the developing countries such as China, India and Indonesia, the level of IP address consumption is much lower.

Country/Region	Population (million)	Number of IP address though RIRs(million)	Number of IP addresses per 100 people by RIRs
North America	330	210	63
Japan	128	48	38
Korea	45	29	64
China	1300 ('2001)	42	3.2
India	1029 ('2001)	3	0.3
Indonesia	203	1.5	0.7

Table 4 Comparisons of populations, IP addresses for several largest countries [12]

However, it is foreseeable that with the economic growth and the continous spread of Internet technology, China, India and other Asian countries will create an increasingly large demand for IP addresses. There is no doubt that the strong demand for IP addresses will continue in Asia-Pacific in the next ten years. For instance, in China, there are more than 80 million Internet users now, with about 5 million college students and more than 5 million high school graduates each year who are potential users of the Internet. Yet Internet is still at its early stage in China. All now available IP addresses will be exhausted once China and India reach the level of 60 addresses per 100 people. Similar trends can be found in other regions. The demands are increasing in Latin America and Africa. So we predict that IPv4 addresses will be exhausted in less than 15 years.

4. Conclusions

Not only new users but also many newly developed devices are requesting IP addresses. For example, PDAs and advanced mobile phones already have enough processor power to work as mobile computers. And new models of mobile phones with built-in PDA have already reached the market. Users now can access to information from anywhere and at anytime. But most of these devices are not using TCP/IP protocol; instead, different phone companies provide their own standards. Therefore, there is an emergent need to connect these devices directly with Internet.

Once this is implemented, supporting these devices will eventually constitute a big challenge for IPv4 in the future. Just imaging there are more that 2 billion mobile phone users all over the world today. Not all of these users are also checking their e-mails via mobile phones right now. But how about 10 years later or 15 years later? Most of the current Internet users didn't even know Internet 15 years ago. So we are facing 2 choices, one is keeping IPv4 alive and making lots of incompatible and confusing protocols to support IPv4; the other one is transiting IPv4 to IPv6 which provides a flat and simpler computing model for all devices, including mobile devices .

Everyone will agree that IPv4 will be replaced by IPv6 sooner or later. But not everybody agrees with the time when we will start the transition. In this paper, we conclude that even without the introduction of new services, IP addresses will run out in less than 15 years at today's rate. So we will see such a change in a much nearer future.

Because of time pressure, we were unable to explore IPv6 thoroughly and to evaluate the benefits we can get from the transition. We leave this topic as the part of the future project.

5. References

[1] Internet Assigned Numbers Authority, www.iana.org.

[2] Asia Pacific Network Information Centre, www.apnic.net.

[3] American Registry for Internet Numbers, www.arin.net.

[4] Latin-American and Caribbean IP Address Registry, www.lacnic.net.

[5] Réseaux IP Européens, www.ripencc.net.

[6] RFC 2460

[7] RFC 2131

[8] RFC 2663

[9] RFC 3022

[10] ARIN Annual Report 2003, www.arin.net

[11] APNIC Annual Report 2003, http://www.apnic.net/info/reports/annual_reports/.

[12] India: http://www.censusindia.net/t_00_005.html

Japan: http://web-japan.org/stat/stats/01CEN21.html

Korea: http://www.nso.go.kr/eng/

China http://www.stats.gov.cn/tjgb/rkpcgb/qgrkpcgb/t20020331_15434.htm