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1. Introduction

The paper examines the transition from IPv4 to IPv6. More specifically, the aim of the paper is to present information on the status of the transition process and on the drivers and barriers concerning this transition. This includes an update on the availability of IPv4 addresses and on how far the adoption of IPv6 has come. It also includes a discussion on *what* but also *who* the drivers and barriers are, including an examination of the implications of implementing transfer markets for IPv4 addresses.

The numbering space for IPv4 is very limited taking all the present and future applications of Internet into consideration. Already at the beginning of the 1990s, there was concern regarding the coming depletion of IP numbers. Some 20 years later, the last publicly available IPv4 addresses were allocated by IANA in February 2011, but still IPv6 has only developed very slowly.

IPv6 and its almost infinite numbering space has been available since 1996 and even though there are a lot of built-in advantages of IPv6 compared to IPv4, IPv6 traffic on the Internet is still less than 1% of total traffic. This begs the question what it is that holds back the development of IPv6 when taken into account that it is a long time ago that Internet was basically an American 'thing' used for a limited array of applications. Today, Internet is a world-wide technology, and the kinds of usages of Internet have expanded tremendously. Internet of Things (IoT), for instance, will in the future require an enormous mass of addresses.

From its outset, the allocation of IP addresses has been uneven, providing the economically developed markets, especially the US, with huge advantages when it comes to the number of available IP addresses. The poor and emerging economies including China and India suffer from this and, therefore, have an incentive to promote a more rapid transition. This adds an additional issue to the IP address scarcity issue, namely the uneven geographical distribution of IP address allocations.

There is no backwards compatibility between Ipv6 and IPv4. Therefore, methods must be implemented for enabling connection between the two protocols in the transition period. The systems used to circumvent the problems of having two parallel systems in function at the same time are tunneling, dual stack, and translation (NAT). All three systems add to the costs and, therefore, constitute a disincentive for users to implement IPv6-based equipment and systems. The result is that first-mover advantages are bleak. The functionalities can be lower and the costs higher when deploying IPv6.

The most important reason, however, for the sustainability of IPv4 is the system of private addresses. Private addresses can accommodate more users than the number of IP addresses, due to the reuse of the private IP addresses in the private networks. This decreases the demand for public addresses. At the same time, it creates a kind of firewall system where the private addresses can be protected behind the single public point of entry. When implementing IPv6-based systems, another kind of firewall system may in some instances need to be installed.

The result of all this is a very slow implementation of IPv6 although the need for a larger addressing space is obvious with the increasing number of people using Internet and the steeply growing amount of applications and services. Internet institutions and public agencies have taken different policy initiatives to promote IPv6. These policies are 'soft' initiatives as it is not possible to order a mandatory transition. Internet is not like a national system of broadcasting, where a transition from analogue to digital technology can be decided centrally. The Internet is a complex international system, and it will be the equipment and service producers - primarily the corporate ones - who decide on the transition.

Taking these issues into consideration, the purpose of the paper is to examine the following questions:

- What is the status of the allocation, assignment and advertisement of IPv4 addresses?
- How far has the adoption of IPv6 come?
- Which and who are the drivers and barriers of the transition from IPv4 to IPv6 and how do these factors and forces affect the transition processes? – This includes a discussion on corporate and policy initiatives and also includes an examination of the potential implications of IPv4 transfer markets.

The theory framework for the analysis is primarily concerned with the hysteresis of the complex Internet system, including the concepts of path-dependence, lock-in and switching costs. The theory notion of network effects also comes into play. We are dealing with a system with strong direct network effects, where the two IP address standards are incompatible. Furthermore, theory on the characteristics regarding consumption rivalry and excludability regarding IP addresses is important when discussing the possible implications of implementing market transfer mechanisms. In fact, the whole field of issues relating to the IP addressing system lends itself to a large array of social science approaches. In spite of this, only a smaller community of researchers including among others Milton Mueller (2006, 2008 and 2010), Laura DeNardis (2009), and William Lehr et al. (2008) have worked with the IP addressing systems and the transition from IPv4 to IPv6 from a social science perspective. In the following section, a brief state-of-the-art is presented.

Empirically, the paper builds on secondary material from Internet organizations, primarily IANA and the regional and local registries, the Internet Governance Project, and from international organizations like OECD and ITU. The paper also builds empirically on a round of interviews with stakeholders, i.e. providers of IP equipment, service providers, institutional users, and representatives of Internet and public institutions. This provides the basis for a realistic assessment of the processes of transition.

The following section present a brief state-of-the-art concerning social science approaches to the IP address transition question and also includes a presentation of the theoretical framework for the analysis in the paper. Thereafter, there is a section on the status of the transition process and the actors – corporate and otherwise – affecting this transition. This is followed by a section discussing the transition process in light of the relevant theory approaches and a concluding section.

2. State-of-the-art and theory framework

The introduction mentions that the examination of the transition from IPv4 to IPv6 lends itself to a wide range of non-technical, including social sciences, approaches. In a seminal paper from 2010, Milton Mueller ‘links the analysis of IP address policy to the vocabulary and concepts of institutional economics’ (Mueller, 2010). Mueller (2010) summarizes institutional economics approaches to the study of the Internet addressing and routing space. Most papers and other publications on the IP addressing system has either a technical character (e.g. Punithavathani & Sankaranarayana, 2009) or is mainly a description of the development of the transition process (e.g. OECD, 2010). Other papers are a combination of development descriptions and possible policy measures (e.g. OECD, 2008). Academic papers with a theory-based social science approach are rather rare in spite of the promising potentials of analyzing IP addressing issue from different social science perspectives.

With respect to the transition from IPv4 to IPv6, theories on diffusion, adoption and implementation could be an avenue. Game theoretical approaches could also constitute a productive framework[1]. And, many other approaches can be used. In this paper, three approaches of which the two first are closely related are used for understanding the transition process. One theoretical area is concerned with path dependence, lock-in and switching cost. The other - and related - framework focuses on network effects. The third approach deals with the characteristics concerning consumption rivalry and excludability regarding IP addresses.

Path dependency is a contested notion. Paul David has presented the generally most cited papers on path dependency (e.g. David, 1985), while Stan Liebowitz and Stephen Margolis have put forward a criticism of the concept of path dependency discussing the extent of its applicability (Liebowitz and Margolis, 1990). In spite of this controversy which in essence deals with the extent to which the market mechanisms function efficiently, it is obvious that path dependency plays a role in the processes of transition from the IPv4 standard to IPv6. The two IP standards are incompatible. They can only communicate with one another via translation mechanisms. And, as the IP addressing system is part of a networked system – the Internet – there are network effects at play. The dominant standard will be the more attractive of the two, leading to a situation of lock-in and switching costs unless translation/conversion mechanisms are installed or there are other types of advantages or necessities of transiting to the new standard.

The result has been that although the IPv6 standard was developed with certain inherent advantages as compared to IPv4 regarding, e.g., security, QoS, auto-configuration, mobility, and multicasting, IPv4 has been the preferred standard by equipment and service producers and network operators, as IPv4 is the standard used by most other pieces of equipment and services on the Internet. At a point of time, however, IPv6 will eventually be the dominant standard – though some have contested that this will ever happen. The question is when, but also how, the tipping point will be reached where IPv6 will be dominant and network effects will work in favor of IPv6.

Having known for a long time that IPv4 addresses would run out, different initiatives to promote IPv6 have been taken from Internet governance organizations as well as public authorities – and lately also, to an increasing degree, by private corporations. The paper discusses such initiatives and will concentrate on one measure aiming at alleviating the problems of the transition between the two IP standards. The issue in question is the controversial mechanism of market transfer of IPv4 addresses.

[1] At the European Regional ITS conference in 2011, a paper on ’Game-Theoretic Analysis of IPv4-IPv6 Migration Process’ by Tuan Anh Trinh and Gyula Sallai was presented.

From a theory point of view, this issue has be discussed by, first and foremost, Milton Mueller (2008 and 2010), William Lehr, Tom Vest, and Eliot Lear (2008), and Andrew Dul (2011). Adapted from Elinor Ostrom (2005), Mueller (2010) discusses the goods character of IP address standards. The framework from Ostrom (2005) is an adaptation from the theory of public goods first presented by Paul Samuelson (1954). On the basis of this paper by Samuelson, a two-by-two table with rivalrous vs. non-rivalrous consumption on the one dimension and excludability vs. non-excludability on the other can be constructed. This leads to four different kinds of goods having different positions in a market economy (see Figure 1).

Figure 1: Character of goods

	Excludable	Non-excludable
Rivalrous	**Private goods**	**Common goods**
Non-rivalrous	**Club goods**	**Public goods**

IP addresses have in policy discussions regarding the IP addressing system been referred to as having a public goods character. This is, however, a highly debatable characterization, as the notion of public goods entails that there is rivalry in consumption as well as excludability. Although one cannot say that there is rivalry in the consumption of IP addresses in the sense of final consumption, as they can be used for new applications after having served a former purpose, one can say that there is rivalry in occupation (Mueller, 2010). This applies to the individual IP address or address block, and as the number of IP addresses is limited, one could say that there is rivalry in consumption. Regarding the other dimension, even if allocation and assignment of IP addresses has been organized with a conservation purpose in mind, reasonable requests, where a 'need' could be documented, have been met. There is obviously excludability with respect to the individual addresses and address blocks, but other IP addresses have been available for use. It could, therefore, be said that there has been non-excludability. This would lead to the conclusion that IP addresses have been common goods – also called common pool resources[2].

With the depletion of IPv4 addresses, however, a new situation arises, where there is no longer access to IPv4 addresses unless they are taken away (reclaimed) and reallocated or bought from someone else. This means, in relation to the 'character of goods' table that IPv4 addresses become a kind of private goods. There is rivalry in occupation and there is excludability. This is the basis for the discussion concerning market transfer of IPv4 addresses. It is also the basis for the suggestions regarding reclamation of unused IP addresses. These two issues are interrelated in the sense that a reclamation procedure can be installed with the internet registries (RIR or LIR) as the organizers of a market transfer of IP addresses.

[2] In his discussion of the issue, Mueller (2010) ends up by concluding that there is rivalry in occupation as well as excludability, as the allocation and assignment system is a mechanism that excludes users from direct access to the appropriation of IP addresses. The major reason for not ending up with a market based allocation and assignment of IP addresses has, according to Mueller (2010), has been to secure an efficient routing system.

In a document published by the Internet Governance Project, Mueller (2008) discusses the different suggestions for market transfer of IP addresses and the likely implications. The overall conclusion is that the Internet community should not be irrationally concerned about the prospects of market transfer mechanisms and should even get started before IPv4 addresses run out totally. The paper was written in 2008 and now in 2012 IPv4 addresses have actually run out in the case of the overall IANA allocations. The discussion of market transfer is, consequently, more acute than ever.

In a paper by William Lehr, Tom Vest, and Eliot Lear (2008), the economic and institutional implications of implementing market mechanisms in the allocation of IPv4 addresses are more thoroughly debated. The authors agree that the implementation of market mechanisms is probably not avoidable, but they disagree on the desirability of this development. The overall concerns are primarily with the institutional consequences for the present IP address allocation system, which has hitherto functioned relatively well, and with the implications on the transition to IPv6. The question is whether it will retard the transition process or whether it will just make it less painful.

3. Status, trends and actors

In this section, we provide an analysis of the level of development and use of IPv4 and IPv6 addresses, i.e. we discuss the following questions mentioned in the introductory chapter of this paper

a) What is the status for the allocation, assignment and advertisement of IPV4 addresses?
b) How far has the adoption of IPv6 come?

In the discussion of the adoption of IPv6, apart from giving the current status of adoption, a discussion on the parameters that are essential in driving the development of IPv6 is given.

a) *Status for the allocation, assignment and advertisement of IPv4 addresses*

Since the standardization of IPv6 in the beginning of 1990s it has been obvious that, at one point in time, address resources in IPv4 would be insufficient for the development of the Internet. However, the timing for the depletion of IP numbers has been forecasted wrongly (in particular by the IPv6 lobbyists) in favor of quicker transition to the IPv6 protocol. This has probably had the opposite effect ('the wolf is coming') on the transition. However, as seen in the following the address space of Ipv4 is exhausted in some regions and in other regions will be exhausted in the coming years. The effect of this exhaustion is another thing that is discussed in the following section of this paper.

In this section, we try to give a realistic status picture of the IPv4 address issue in year 2012. Before that we will present definitions of important phases/aspects of the use of IPv4 addresses: Allocation, assignment and advertisement. This is mainly because the terms are used differently in the current debate on IP addresses.

Allocation: The whole IPv4 address space is maintained by IANA (Internet Assigned Number Authority). IANA allocates blocks of IPv4 addresses to the five regional RIRs (Regional Internet Registries): RIPE NCC (Réseaux IP Européens Network Coordination Centre), ARIN (American Registry for Internet Numbers), APNIC (Asia-Pacific Network Information Centre), LACNIC (Latin America and Caribbean Network Information Centre) and AfriNIC (African Network Information Centre).

Assignment: The RIRs assign IPv4 addresses to ISPs, network operators and companies in their region based on certain criteria.

Advertisement: Advertisement denotes the part of assigned IP addresses that are in real use. Many of the addresses that are assigned are not in use, and this has of course intensified the discussion of re-allocation/re-assignment and trade in IP addresses.

When it comes to the allocation of IPv4 addresses the status is that, apart from IETF reserved addresses, all the addresses are allocated to different RIRs. There is, however, an ongoing discussion concerning the fact that the allocation from its outset has been uneven, putting developed countries and in particular the US in much better position than developing countries, a problem that is vital for the accession countries due to their economic growth and dependency to the Internet. Figure 2 shows the different allocations.

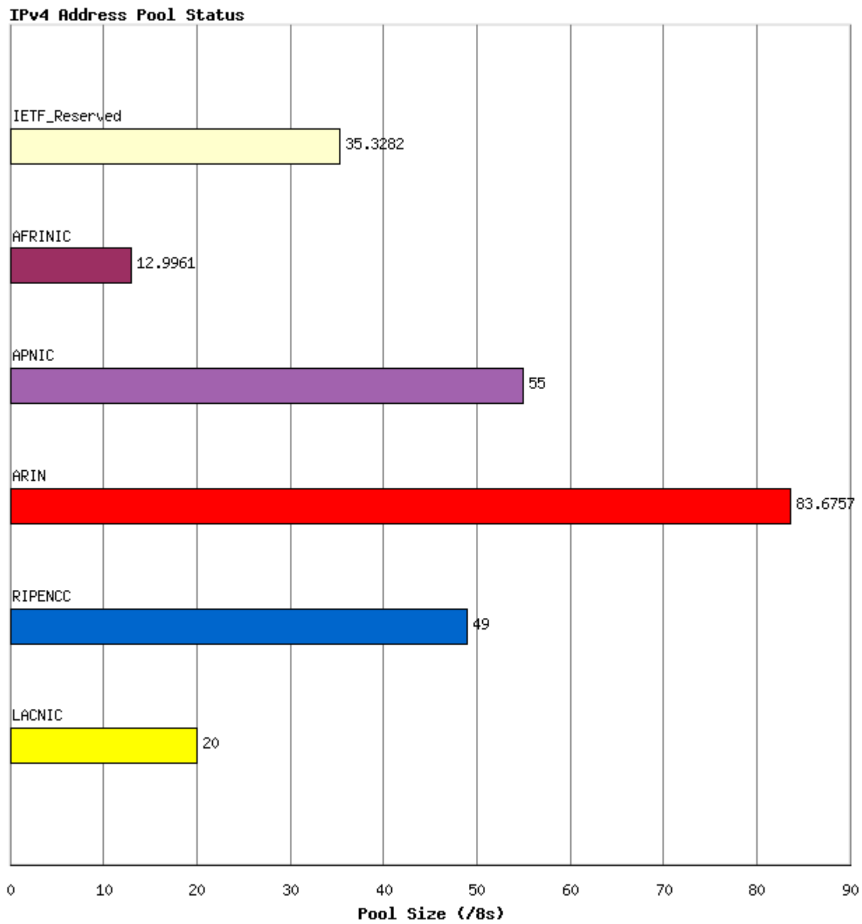


Figure 2: IPv4 address allocation status[3]

[3] http://labs.apnic.net

When it comes to the assignment, there are certain evidences that the different RIRs either are running out of IPv4 addresses or will run out in the near future. The following figure (figure 3) indicates the RIRs address pool exhaustion dates.

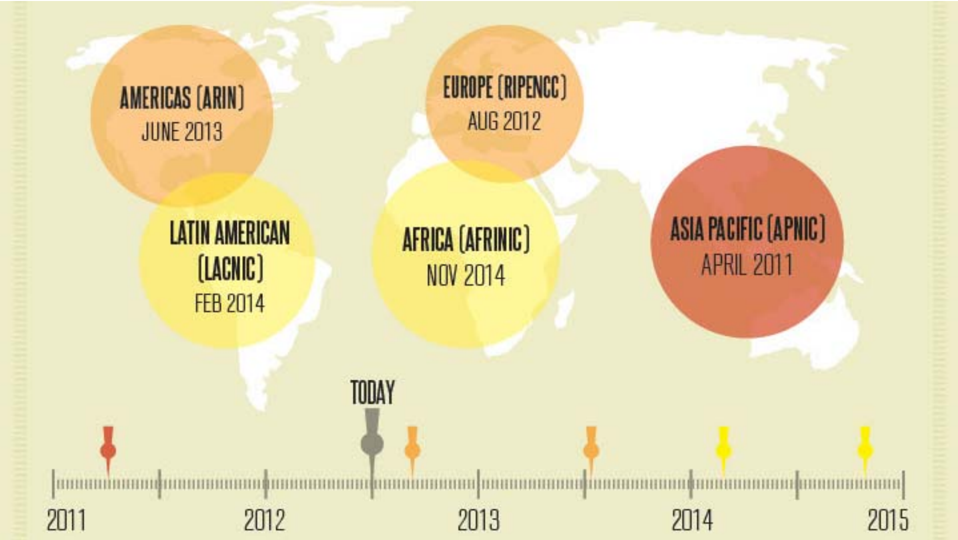
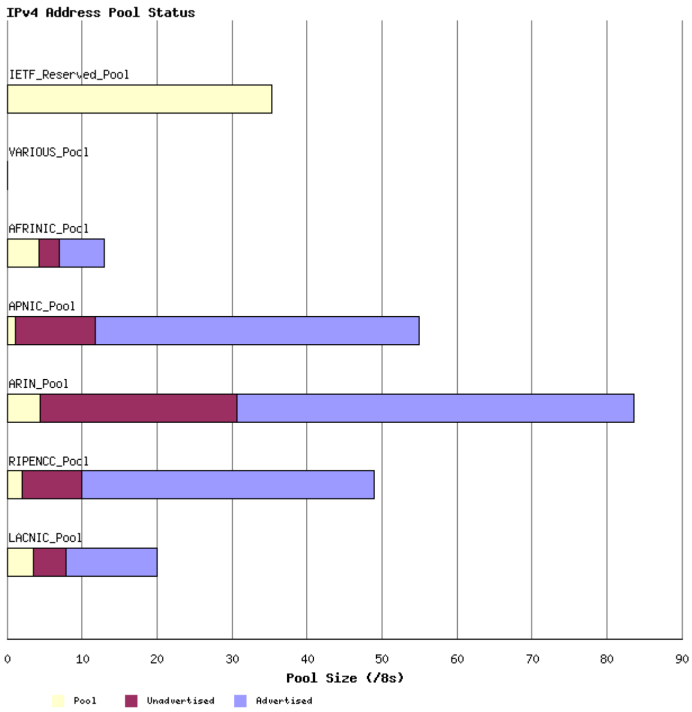


Figure 3: Projected RIR address pool exhaustion dates[4]

The figure only indicates the projected IPv4 address assigned by RIRs and does not say anything about the advertisement part (the actual use of address) and the potential for trade/transfer of addresses (intra-region or inter-region). The advertisement issue is depicted in figure 4. The figure shows that the portion of unused IPv4 addresses is not insignificant.



[4] http://www.worldipv6launch.org

Figure 4: IPv4 address advertisement status[5]

b) Adoption of IPv6

Even though the address space of IPv4 is being exhausted in a relatively short term at the global plan, the adoption of IPv6 protocol has been insignificantly low and counts for below 1% of the total traffic of the Internet. In this section we will study the level of adoption of IPv6 in different markets/countries and give some indication of the major driving forces for the development.

APNIC on their web site: http://labs.apnic.net organizes different up-to-date statistics about IPv6 adoption over the whole world[6]. The following map (which is interactive on the web site) gives the current status of adoption

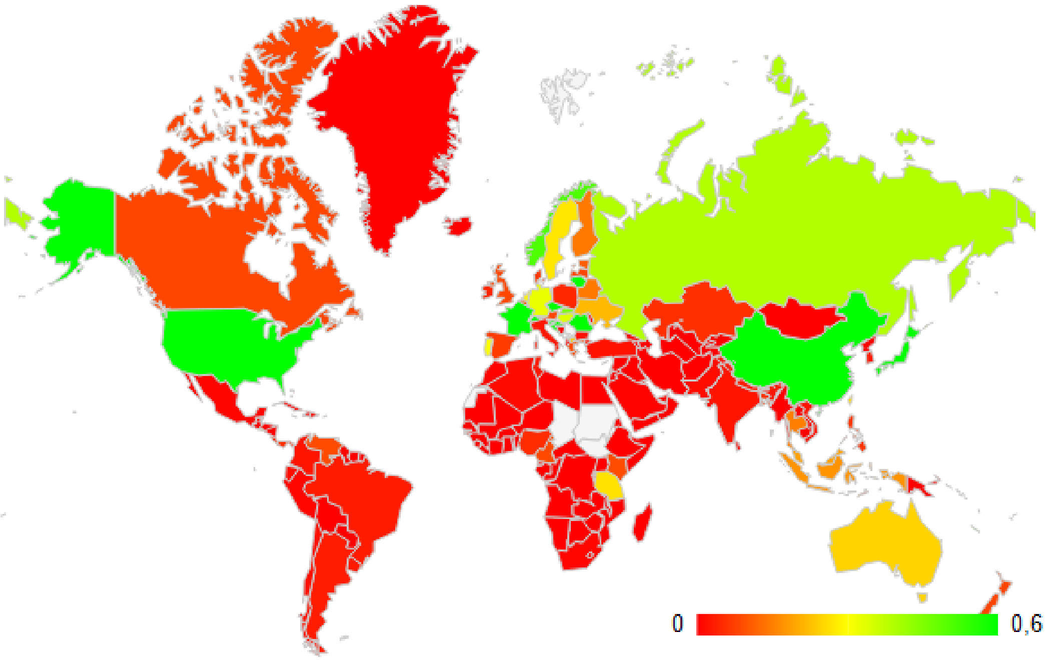


Figure 5: IPv6 adoption map[7]

The map shows that even though the deployment is not high anywhere, there are some differences in the level of adoption and, e.g., the US, some European countries and China and Japan are in the forefront of deployment.

The same resource gives a current estimate of the status on the country/market basis. In the following figure, the top 10 IPv6 countries in the world are depicted.

[5] http://labs.apnic.net

[6] To do the estimates, an IPv6 deployment measurement has been set up that tests a randomly selected set of some 1 million users per day by posing to their web browser the same simple IPv6 capability test (Source: Geoff Huston in the ISP column – June 2012).

[7] http://labs.apnic.net

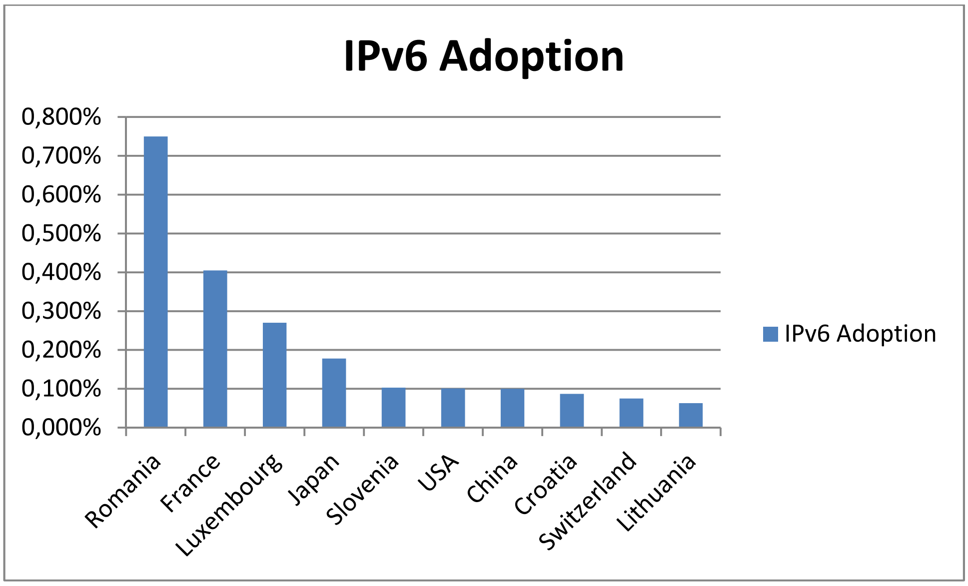


Figure 6: Use ratio of IPv6 users relative to Internet users in top 10 countries [8]

The percents in the figure indicate the ratio of IPv6 users relative to the number of Internet users and for example in a country like China there are over five million IPv6 users.

The figure shows that the top ten countries consist of some European countries, the US and China and Japan. It is not surprising that China is among top 10 IPv6 countries as they have suffered from low allocations of IPv4 address space.

On the other hand, many of developed countries with high rates of internet users like the UK are far behind in the process. The same source shows that UK with 0.08% of Internet users is in the same group of countries like Kazakhstan (0.07%) and New Zealand (0.07%).

However, it is an interesting research question to study the reasons for these deployment levels in different countries. This is partly done in the next section that focuses on the drivers and barriers for the development of the IPv6 protocol. In the following, we provide a discussion of some of the driving forces for the adoption of the IPv6 protocol.

The main reasons for developing the IPv6 protocol was the insufficient address space of IPv4 and some traffic engineering considerations of enabling QoS and security in the IP networks. Today it seems that the address issue is *the* vital issue as the lack of addresses has forced the development into the current paradigm that compromises one of the main characteristics of the IP networks, namely the end-to-end principles, and creates a number of ad hoc /complex solutions to cope with the scarcity situation.

The end-to-end principle that was first introduced in a paper entitled 'End-to-end argument in system design' (Saltzer et al., 1981) has been instrumental in the way the Internet has developed. In the Internet, the network design has be based on a 'dumb core network', where processing is moved to the edge of the network. For the end-to-end principle to work efficiently it is needed that all devices have a public IP address and can communicate with each other without being hidden behind different Network Address

[8] Based on http://labs.apnic.net

Translations (NAT). NAT has been an efficient way of reusing the private addresses in the IPv4 era but it has worked against the end-to-end principle and established complexities for new innovations and services.

The recreation of the original end-to-end architectures requires the shift to IPv6. But this has shown to be difficult because the Internet is a network of networks with a number of independent and autonomous actors driving the process. However, many market players and decision makers can see the unavoidability of the change and in recent years we have seen a number of factors and initiatives that seem to drive the process of change. In the rest of this section, we will list some of the major drivers for this development and, based on these and the discussions above regarding the status of IPv4 and IPv6, we conclude that 2012 is an important turning point in the transition from IPv4 to IPv6.

Exhaustion of IPv4 addresses: The exhaustion of aIPV4 addresses will in itself stimulate the demand for IPv6 addresses. This can have different effects in different part of the world and can stimulate the change more rapidly in the developing countries and in particular the emerging economies.

National rankings: For a number of years we have had national rankings in the study of broadband development, however, the broadband infrastructures will be real IP infrastructures when the end-to-end architecture is implemented and this requires the deployment of IPv6. In future research, it could be interesting to follow the national rankings and identify the dynamics of this development. This could, like broadband, stimulate the development of IPv6

Policy initiatives: Specific policy initiatives can stimulate the transition. One of the known instruments is to mandate the adoption of the new technologies in the public institution. In this context, one important initiative is the US government's initiative of transition to IPv6 for all governmental web sites in the US by the end of 2012. In the EU, the issue of transition to IPv6 was the only agenda point in the Digital Agenda Assembly of June 2011. During this meeting it was discussed to take the same type of actions as in the US and mandate the governments to make the transition in the public web sites. Furthermore, the discussions in the assembly showed that different European countries have already similar initiatives with Germany to be ahead of other EU countries.

Internet Society IPv6 day 2011 initiative: On 8 June 2011 the ISOC planed a one day IPv6 event where the major ISPs and web site provides like Google and Facebook enabled IPv6 during the day. Even though the amount of IPv6 traffic was insignificant also during this day the initiative has been evaluated as being a successful well performed global scale trial, leading to observation of some interoperability issues and fixing them.

Support from major market players and 'the ISOCs IPv6 day 2012': An important driver is the support from major market players and this has been materialized by making the IPv6 day of 2012 permanent, i.e. from 6 June 2012 a number of market players have permanently turned on IPv6 as part of their core products. These market players are: 3000+ web site operators (like AOL, Bing, Google, Facebook, etc.), 65 network operators (like Time Warner Cable, Free, Verizon Wireless, etc.), and 5 router vendors (CISCO, D-Link, NEC, YAMAHA, ZYXEL). [9]

[9] Worldipv6launch.com

Access to the content: One of the issues discussed in the aforementioned European Digital Assembly was the need to be accessible to/from developing world (DAE, 2011). The assumption was that in the future some content and applications may be accessible only on the IPv6 platforms and to avoid this, Europe must speed up the transition for not falling behind.

Internet of Things: The Internet is entering a new paradigm, where the number of connected things/devices/objects is increasing massively. This is based on the development of sensors and sensor networks which are incorporated in all kinds of smart solutions that are leaving the labs and entering the markets, these being the smart home, smart energy, smart learning, smart traffic, etc.

This has resulted in a situation where the requirements on the address space expand. The vision of World Wireless Research Forum (WWRF) for 2017 is that by that year there will be 7 trillion wireless devices in the world (WWRF, 2009). A study done by Cisco IBSG research estimates that there will be 25 billion devices connected to the Internet by 2015 and 50 billion by 2020. This is depicted in the following figure:

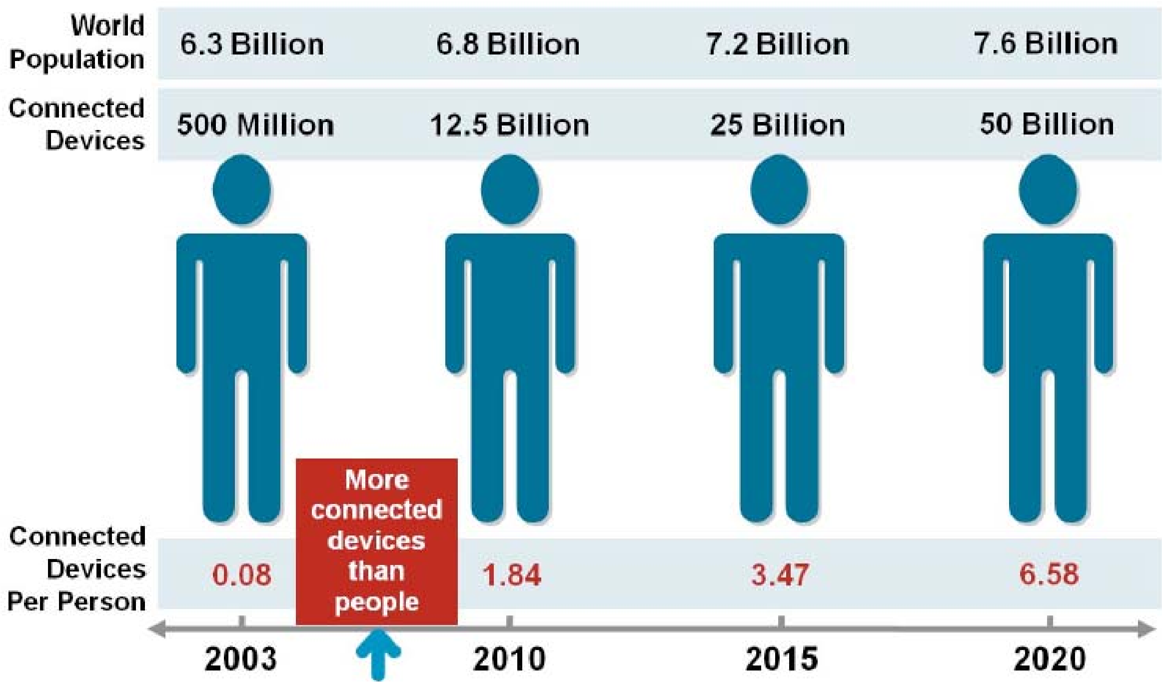


Figure 7: The Internet of things (Source: Evans, D. (2011))

There are, furthermore, a number of standardization initiatives like RPL – IPv6 Routing Protocol for Low power Lossy Networks (LLN) and 6LowPAN – IPv6 over Low Power Wireless Personal Networks, to make IPv6 more compatible with the low capacity small devices / objects (Atzori et al., 2010, Hui et al., 2008). Other studies show that many light weights IPv6 implementation like implementation of TinyOS-based IPv6 stack are available on the market, where IP can successfully work in as little as a few kilobytes of RAM (Dunkels et al., 2008).

All of these are good indications for at Internet of Things / objects will be a major driving-force in the future development of IPv6.

4. Discussion

This section will mainly discuss two issues: Which and who are the main drivers and inhibitors of the take up of IPv6 and can tipping points in this development be identified? And, what will be the effect of a system with market transfers of IPv4 address blocks with respect to the extension of the IPv6 take up period?

As shown in the previous section, there is a high degree of hysteresis and path dependence in the transition process between IPv4 and IPv6. The basic reason is the installed base of IPv4 addresses where network effects are at work in direction of the preservation of IPv4 dominance. IPv4 equipment, services and applications communicate with other IPv4 enabled nodes on the network, while translation mechanisms are needed for communications between IPv4 and IPv6 devices. IP versions 4 and 6 are not compatible and there are considerable switching costs for the IP system at such as well as for the individual producers of equipment and services and the users.

The switching costs are related to investments, operations, and training. In order to communicate, using the IPv6 standard, new equipment has to be developed and bought, operation procedures have to be changed, and staff has to be trained. It is estimated that for large organizations, it may take up to a couple of years to make a full transition from IPv4 to IPv6 with all the different installations, procedures and training elements that need to be in place.

From a system point of view, there are huge costs of shifting from one system to another, and one of the questions is how these costs will be distributed among the different actors: equipment producers, service and application providers, and users. From the single actor point of view, the costs will be highest at the beginning of the process and the incentives to shift are practically non-existing. There are no real first-mover advantages even though IPv6 in principle entails a number of built-in improvements as compared to IPv4. Upgrades and workarounds relating to IPv4 have been implemented over the years making the immediate advantages of IPv6 bleaker.

Many incremental innovations and improvements have been deployed in the IPv4 system. This applies, for instance, to security improvements. When implementing the IPv6 protocol, users may experience new security issues that they did not have with the IPv4 system, and the anticipation of such problems holds back the uptake of IPv6. The IPv6 system makes it possible to re-install the original idea of the IP system as a complete end-to-end system which may entail certain security problems. The private addresses in the IPv4 system have had the side-effect of acting as a kind of firewall protecting the private systems. When implementing IPv6, it may be necessary to develop similar firewall mechanisms.

In practice, most IPv6 implementations are dual stack arrangements, meaning that the equipment, services, or applications will operate an IPv4 stack as well as an IPv6 stack. Such dual stack arrangements add to the costs of IPv6 implementation and also add to the complexity of the system.

Deployment of the IPv6 standard has come further on the server side compared to the service and application side. But it is a chicken and egg situation or a situation with a mutual dependence. Services and applications based on IPv6 will first be developed when servers are moving in that direction and vice versa. However, as shown in the previous section, it seems that more private business organizations on the equipment side as well as the service and application side have taken decisive steps to implement IPv6 not only on a trial basis but permanently.

When examining the inhibiting factor, the private addressing system also needs to be discussed. Private addresses were from the inception of the system reserved for uses within private settings. An implication of this system is that those using private addresses can have many more pieces of equipment or services on their systems than the number of IP addresses they have. This lowers the pressure on the IPv4 address space and can, consequently, contribute to the prolongation of this system. On the other hand, the translation system that facilitates the use of private addresses also translates between IPv4 and IPv6, which may lower the barriers to a transition to IPv6. In fact, the system of private addresses as well as the translation between IPv4 and 6 'softens up' the transition process, in the present situation, more than it hinders the transition.

If trying to answer the 'who'-question regarding inhibition of the transition to IPv6, the organizations that have been the slowest to adopt are the service and application providers. Server producers have been faster. The individual users will mostly not be aware of whether they communicate via IPv4 or IPv6. They just want to be able to access all services, and this has held back service and application providers.

On the driver side concerning the transition to IPv6, there is primarily the fact that IPv4 addresses are running out. This has now and then been formulated as 'hitting a wall', but in actual fact it's a more extended and softer process, for instance because of the system of private addresses but also, as we shall see, the potential development of market transfer mechanisms. The two systems will co-exist for a long period of time still with dual stack arrangements but also translation mechanisms and tunneling technologies. There will, thus, be parallel systems running which is more costly and complex than maintaining one system, and this can, in itself, at a point of time contribute to the full transition to IPv6.

While the original development of the IPv4 system and its continued existence function almost automatically because of network effects, turning the system around towards IPv6 requires strong actors with a keen interest in promoting the transition. The main drivers have traditionally been the organizations, either non-governmental or governmental, which have broader interests than the individual companies trying to limit their individual costs on a relatively short-term basis. This means the Internet community and its organization, international organization like ITU, OECD and the EU, and national public authorities. These institutions have for many years tried to promote the IPv6 standard, as they been in a position to foresee the exhaustion of IPv4 addresses. Many different initiatives have been taken including public authorities implementing IPv6. But the fact is that the development of IPv6 hitherto has moved very slowly. Initiatives promoting IPv6 have for many years not had much impact on the deployment and use of IPv6. Recent data has generally shown that IPv6 traffic has been well under 1% of total Internet traffic.

Lately, however, private corporations have begun to put more emphasis on deploying IPv6. In the previous section, it is shown how an increasing number of the large players on the Internet have committed to enabling IPv6 traffic on a permanent basis. This has been announced in relation to the IPv6 day on 6 June this year. In 2011, there was also an IPv6 day, but for many of the companies participating in the activities on that day, it was only on a trial basis. The trial, however, documented that running IPv6 on a larger scale was possible and has thus paved the way for the permanent commitments in 2012.

On the more structural side, the fast development of Internet users and the spread of new applications and devices put a pressure on the transition to the IPv6 system with its almost infinite numbering space. As discussed in the previous section, Internet of Things (IoT) is one of these developments. IoT can, of course, also function in a system of private addresses, but if the perspectives in IoT are to be extensively developed, a huge number of addresses is needed, and re-installing a full end-to-end system can also have advantages for IoT. Internet 'purists' have for long been campaigning for promoting the end-to-end function of the system, and though such purist positions may not in themselves have a great influence on the actual implementation, it does affect the policy processes in Internet organizations. The end-to-end mechanism and can also be the basis for an extension of innovation initiatives relating to Internet.

Another structural factor is that there are difficulties in running two parallel systems. This applies to increased delays, problems of running P2P applications, VoIP, and location-based services. It also means that there are services which are difficult to access. The complexity of the system becomes high with parallel systems and with translation mechanisms. This can also lead to an increased pressure for the wider spread of IPv6.

Lastly, there are the areas of the world that only have small allocations of IPv4 addresses. This applies to the APNIC region (Asia and Oceania), to Africa (AfriNIC) and Latin America (LACNIC). Among these regions, Internet development has been fastest in Asia and Oceania, first and foremost China and India, and we have also witnessed IPv6 development in this region. However, when looking at IPv6 development from a country perspective, the fastest developments are not necessarily among the countries with the lowest allocations. Countries in Europe and North America are high on the list of frontrunners in the field.

The discussion on the barriers and drivers of IPv6 leads to the question as to where the tipping points are in this development. There are obviously different tipping points, where an important point will be reached when there are more IPv6 than IPv4 enabled pieces of equipment and services. Network effects will then be strongest in favor of IPv6. However, an important tipping point is reached long before this. If a tipping point is defined, as in sociology, as the event of a previously rare phenomenon becoming rapidly more common, the events and commitments around the IPv6 day in 2012 could be considered as a tipping point. On the S-curve, we are still at the very bottom. However, we are approaching the position on the curve, where growth becomes increasingly shaper and where an initial take-off begins.

Another and more important discussion relates to the implications of implementing market transfer mechanisms. This has been a controversial discussion as market mechanisms run counter to the traditional mode of functioning of the IP addressing system. In the traditional system, IANA allocates address block to the regional registries (RIR), which when allocates to local or national registries and further down the line, IP address blocks are assigned to private market actors, e.g. the ISPs. The ISPs and other market actors do not own the addresses; they have the use right, and addresses have traditionally not been transferred to other user entities.

However, with the depletion of IPv4 addresses, the issue of reclaiming of IP addresses and market transfer becomes relevant. Previously, the IP addressing space could be looked upon as a 'common pool' as discussed in the theory section of the paper. But when there is depletion, one could say that IP addresses increasingly have a private goods character. This is the situation where markets come into question.

Transfers are already taking place today. In reality, they have taken place for many years – but in a kind of grey zone, where companies having a block of IP addresses have been sold to another company. In a paper from 2012, Mueller (2012) reports that 'over three dozen transactions in IP address blocks are documented in the ARIN region'. And, there are address brokers being formed, e.g. http://tradeipv4.com, and ARIN has a listing service for the transfer of IP address blocks (Dul, 2011).

The question could be raised whether market transfer mechanisms will extend the transition from IPv4 to IPv6, as transfers will provide the possibility for new users to get access to IPv4 addresses even though there are no more address blocks for allocation. This issues has been discussed widely in the Internet community and has also been examined academically by, e.g., Mueller (2008 and 2012), Lehr et al. (2008), and Dul (2011). The strongest arguments coming out of these discussions are, on the one hand, that setting a price on IPv4 address blocks will lead to increased costs of acquiring IPv4 addresses and will eventually lead to increased incentives for take up of IPv6 addresses, which will still be a free common pool resource. This is the traditional economics argument, and will be likely to apply in this case. Another argument is that there will, at any rate, be a continued pressure on IPv4 addresses even when more organizations and people start using IPv6. This is because the dual stack arrangement will require a continued demand for IPv4 addresses. A market mechanism will see to it that the problems in this process, which in the end will lead to the dominance of IPv6, will be alleviated. Both these arguments speak in favor of implementing market transfer mechanisms and also that it is not likely that market transfer mechanisms will retard transition to any great extent.

An obvious problem is that there are no general rules in the Internet community (IANA and the RIR, etc.) for such market transfer mechanisms – as pointed out by Mueller (2012). Without any general rules, the markets will develop in different directions making the international market unclear. There is, at least, an issue here that needs to be debated.

5. Conclusion

Already at the beginning of 2011, IANA ran out of available IPv4 address blocks. In 2012, IPNIC - the regional registry for Asia and Pacific - has also run out of IPv4 address blocks for allocation, and the other regional registries will run out in the following years. This will, obviously, put pressure on the whole Internet system, as the number of users keeps on increasing, and especially the applications will grow enormously in numbers in the coming year, for instance with Internet of Things.

IPv6 is there to replace IPv4, but even though IPv6 addresses have been available since 1996, the development of IPv6 has been very slow. The reasons are multiple but can be summarized in the hysterisis and path dependence in the system, which is caused by the many different kinds of switching costs associated with a transition. At present, IPv6 traffic is well below 1% of total Internet traffic.

Lately, however, it seems that a take-off of IPv6 is beginning to take place. In the paper, we have characterized this as a tipping point in the development of the transition from IPv4 to IPv6. If following the sociologically oriented definition of a tipping point as the event of a previously rare phenomenon becoming rapidly more common, such a characterization seems to be appropriate. In connection with the IPv6 day on 6 June 2012, a considerable number of large Internet players committed themselves to enabling IPv6 traffic on their systems permanently.

In the paper it is also discussed what the likely implications a market transfer system for IPv4 addresses will be for the further implementation of the IPv6 protocol. The conclusion is that this will not in any significant manner retards the growth of IPv6. Not only will a transfer system lead to higher costs of getting access to IPv4 address blocks, which eventually will be an incentive for IPv6 growth. It will also alleviate the problems related to IPv6 deployment, as there will continuously be a need for IPv4 addresses, as the transition will witness parallel systems for many years to come with dual stack arrangements.

6. References

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