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Context and Realities of the IPv4 Market:
What Technology Leaders Need to Know

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1. Introduction

The last few decades have seen unprecedented growth in the Internet. The Internet has moved from the confines of research labs to the hands of billions of customers worldwide. Users are now consuming increasingly more data on billions of devices connected to the Internet. No one could foresee that the experiment that started as ARPANET would be so successful and would have such an enormous impact on human civilization. But in recent years, there have been concerns about the unbridled growth of the Internet. Devices connected to the Internet - computers, cellphones, and now cars - need a unique identifier to connect and get recognized. These identifiers are called IP addresses, which enable devices to communicate with each other. When the Internet was envisioned in the late 1960s, its designers conceded to a 32-bit addressing scheme because memory was at a premium and at that time no one believed that there would be more than 2^{32} or 4.3 billion devices connected to the Internet. These addresses, known as IPv4 addresses, have started to get depleted in various parts of the world, which poses a threat to the growth and sustainability of the Internet.

An alternate addressing scheme called IPv6 addressing was developed fifteen years ago, but due to incompatibility with the existing IPv4 network, its adoption has been extremely slow. Although the long-term solution for the paucity of IP addresses remains a move to IPv6 or an alternate addressing system, network administrators have been using technologies like Network Address Translation (NAT) to resolve this issue in the interim. Although these technologies have gained considerable popularity, they break certain fundamental principles of the Internet like end-to-end connectivity. Not surprisingly, another alternative has emerged that provides a partial solution to the dearth of IP addresses in the short-term – a *market for IPv4 addresses.*

In the early days of the Internet, several blocks of IPv4 addresses were assigned in an ad-hoc manner to large corporations and universities. Until a few years ago, these addresses remained unused. With the scarcity of IPv4 addresses, we have seen the emergence of an IPv4 address market where IP address resources are being more efficiently allocated to new owners. There are 34 /8 addresses that were assigned to corporations or government organizations like the USPS, and several smaller blocks that were allocated to universities and other corporations. There also remains a substantial untapped supply of IPv4 addresses.[1]

This paper focuses on the economics of the IPv4 to IPv6 transition and analyzes the role the IPv4 Market will play in this transition. This paper also outlines the different actors that are involved in the transition from IPv4 to IPv6, evaluates their incentives for adopting IPv6, and discusses the change in the structure of the Internet – from direct network effects between machines connected to the Internet to a two-sided network with content providers and consumers.

This paper's analysis suggests that a true migration to IPv6 would be helped tremendously only when content providers transition to IPv6, which would provide ISPs a strong incentive to adopt IPv6. Premium content available only on IPv6 can go a long way toward facilitating the adoption of IPv6. Although the ISPs do not have a strong incentive to adopt IPv6, fundamental changes in the telecommunication industry might put competitive pressure on them to transition to IPv6. Interestingly, large corporations would be the last to transition to IPv6 due to untested technology and lack of trained IT manpower.

Another critical point that this paper addresses is the role that network externalities play in affecting IPv6 adoption. The Internet should be viewed as a good with direct network effects – when more entities come online, the utility that existing entities derive from the Internet increases. This characteristic, which has been one of the most important reasons for the unprecedented success of the Internet, is ironically inhibiting the movement of consumers from IPv4 to IPv6. Service providers do not want to move their consumers to IPv6 because there is such low IPv6 penetration.

The problem of competition between network goods has been widely studied in economics. Farrell and Saloner (1986) point out that it might be difficult for the new technology to displace the existing technology if existing technology has a huge customer base. Further, if this transition from the old to new technology is gradual, the early adopters bear a disproportionate share of incompatibility costs. It is important for policy makers to keep both the role of incentives to early adopters and network externalities in mind while designing mechanisms for the adoption of IPv6.

[1] http://www.iana.org/assignments/ipv4-address-space/ipv4-address-space.xml

Finally, this paper analyzes the need for the IPv4 address Market and suggests that the IPv4 Market increases efficiency and, given its place amongst far larger variables and secular shifts, does not inhibit the long-term adoption of IPv6. This paper also analyzes how market forces, like the uncertainty in adoption of IPv6, growth of Internet-enabled devices, and development in technologies like NAT, affect the pricing of IPv4 addresses.

2. Growing Demand for IP Addresses

The number of devices that can connect to the Internet today is over 10 billion.[2] This growth is being buttressed by an exponential increase in the connectivity of retail consumers as well as the increasing IT requirements of corporations world-wide.

2.1 Growth of Internet Enabled Consumer Devices

Analysts believe that the growth of connected devices is accelerating, leading to a forecast of 28 billion devices connected to the Internet by the end of 2020. Ericsson President and CEO Hans Vestberg is even more optimistic about this forecast; he predicts that there will be more than 50 billion devices online by the end of 2020, from computers, game consoles, and DVD players to health monitoring devices.[3] Other firms like CISCO and Intel share his vision.[4] Figure 1 shows the growth in the number of devices connected to the Internet.

Smartphones and Tablets

One of the greatest reasons for the recent increase in the Internet usage can be credited to the entry of smartphones and media tablets into the market. Although these tablets were not as popular in the past couple of years, they are now gradually becoming the fastest-growing Internet-enabled device and more than 300 million units are expected to ship by 2015, which is

[2] http://techcrunch.com/2013/05/09/internet-of-everything/
[3] http://gigaom.com/2010/04/14/ericsson-sees-the-internet-of-things-by-2020/
[4] http://newsroom.cisco.com/press-release-content?type=webcontent&articleId=888280

15 times greater than the amount shipped in 2010. In particular, the media tablet appears to be the device that will pull customers into the era of the digitally connected home. With the right hardware, for example, consumers also can push music from an iPad to an audio system, or drive video to a large-screen display.

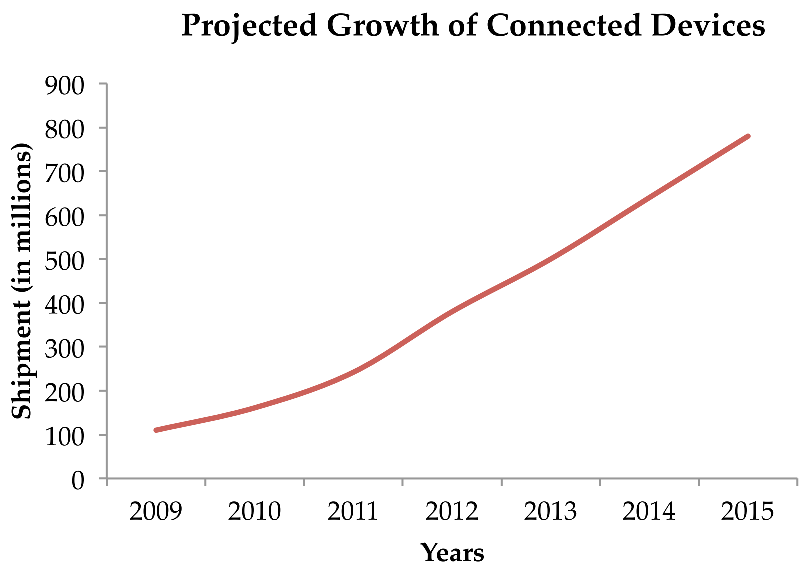

Figure 1: Shipment of Internet-enabled devices (in millions).[5] *The cumulative historical growth has led to 10 billion devices today.*

2.2 Cloud Computing

Organizations worldwide are in constant need of IT infrastructure that can scale rapidly and can be accessed from any place in the world. This is leading to increased migration to cloud computing. Several firms connect to these cloud servers, which are located in remote locations. Most of the services used in the corporate environment, such as ftp and VPN, require end-to-end connectivity between the client's computer and the remote server for security purposes. For identification purposes, the growth in cloud computing has created additional requirements for public IP addresses so that these computers can be connected.

[5] http://www.isuppli.com/Home-and-Consumer-Electronics/MarketWatch/Pages/InternetEnabled-Consumer-Electronics-Devices-to-Enjoy-50-Percent.aspx

For example, communication between the computer terminal at the enterprise and the virtual server in, for example, the Amazon Cloud, occurs over the Internet using IPv4 addresses. Each of Amazon's smallest business customers has a minimum of five dedicated IPv4 addresses that are held exclusively for use by that customer.[6] Larger businesses using Amazon Cloud may have dozens or hundreds more dedicated IPv4 addresses. As an attestation to this growth, Amazon is on pace to have over $2.5 billion in revenue from cloud computing services by 2014.[7] In addition to Amazon, a number of other major technology companies including Google, IBM, SAP, Oracle, Salesforce, and Microsoft have invested significant resources into the cloud computing space. Business enterprises' transition from in-house servers to cloud computing should accelerate considerably in the next several years and beyond, creating significant additional demand for IPv4 addresses.

2.3 Next Generation Devices

Recent developments in technology are enabling new monitoring devices for healthcare and security solutions. Most current devices work via IPv4 and require public IPv4 addresses so that they can be accessed directly from monitoring systems residing outside of home networks. Given the aging population and increasing cost of healthcare, the demand for such devices has been on the rise.[8] In addition, due to the relatively long cycle in the healthcare and home security markets, these devices will need to be supported, potentially, for decades. Besides healthcare and security industries, other public services are joining the "Internet of things" as well; for example, parking meters, ATMs, and street lamps. As a consequence, there is a renewed demand for IP addresses from the healthcare, finance, security, and other industries to keep these devices working seamlessly.

2.4 Migration of Telecommunication Services

For a long time, the telecommunication industry has been fragmented in different silos, such as telephony, television, Internet, etc. This fragmentation was a consequence of the different user-

[6] http://aws.amazon.com/articles/1346
[7] http://techcrunch.com/2012/11/27/amazon-web-services-expected-to-hit-1-5-billion-in-revenues-for-2012/
[8] http://www.marketsandmarkets.com/Market-Reports/patient-healthcare-monitoring-systems-devices-market-678.html

adoption trajectories that each of these sub-industries followed until now. However, going forward, we will see a consolidation of all telecommunication technologies, with all of these different services slowly moving towards the Internet as a medium for content delivery. The transition has been significant in the telephone industry where VoIP penetration is expected to reach 79% by 2013.[9] The change is also looming over the television industry, where IPTV and streaming video is gradually replacing cable TV. As the dominance of IP-based data delivery grows, the demand for IP addresses will subsequently increase in concert.

3. Current Supply of IPv4 Addresses

"We are running out of IPv4 addresses and the adoption of IPv6 is going to be front and centre of everything for the next several years."

Sujay Shetty, CISCO

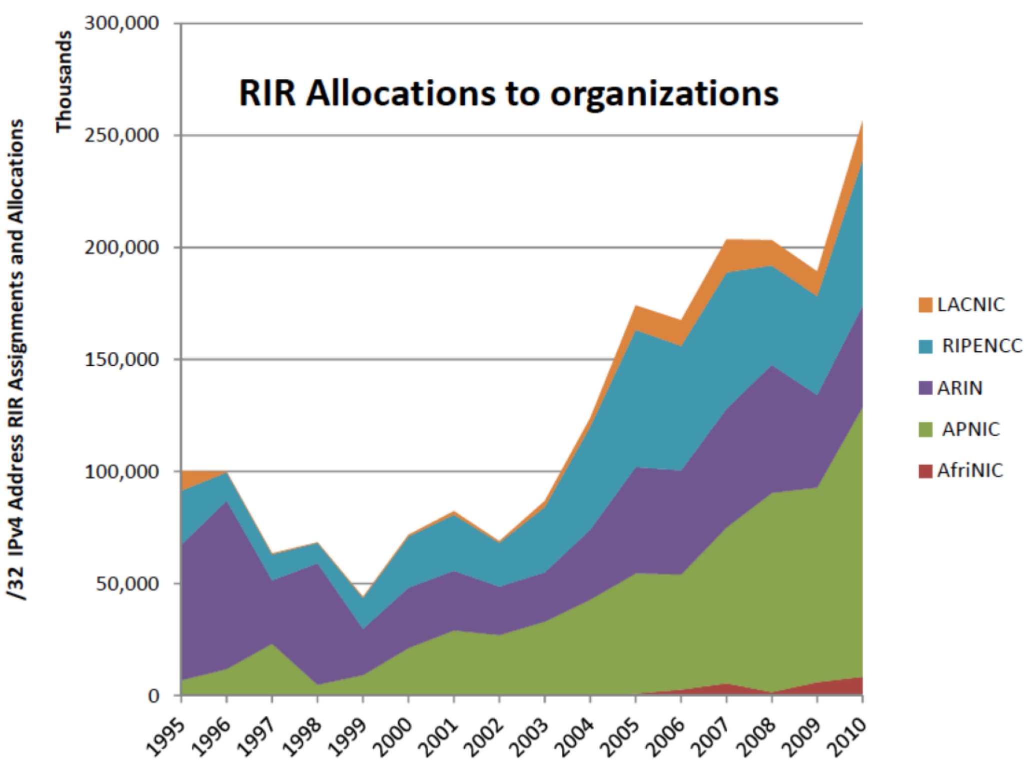

Figure 2: The allocation of IP addresses by the various RIRs[10]

[9] http://www.fiercewireless.com/press-releases/voip-penetration-forecast-reach-79-us-businesses-2013
[10] http://www.quark.net/docs/Economics_of_IPv4_on_IPv6.pdf

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3.1 Current Allocation of IPv4 Addresses

There is a huge discrepancy in the number of IPv4 addresses available per person across different countries. The United States has 4.912 addresses per person whereas countries like China and India have 0.246 and 0.029 addresses per person, respectively.[11] This, coupled with the fact that a majority of Internet consumers these days come from developing countries, has created an acute shortage of IPv4 addresses. Due to the surge of demand from the Asia Pacific region, APNIC was the first RIR to exhaust its blocks of /8 addresses. Currently, China and India have access to only 20 /8 and 2 /8 blocks, respectively. This shortage will become even more acute in the coming years as the governments in these developing countries try to connect millions to the Internet.[12] This is an immense concern for India, as its recent advances have come about largely from advances in IT-enabled services, progress that might stall due to the shortage of publically available IPv4 addresses.[13]

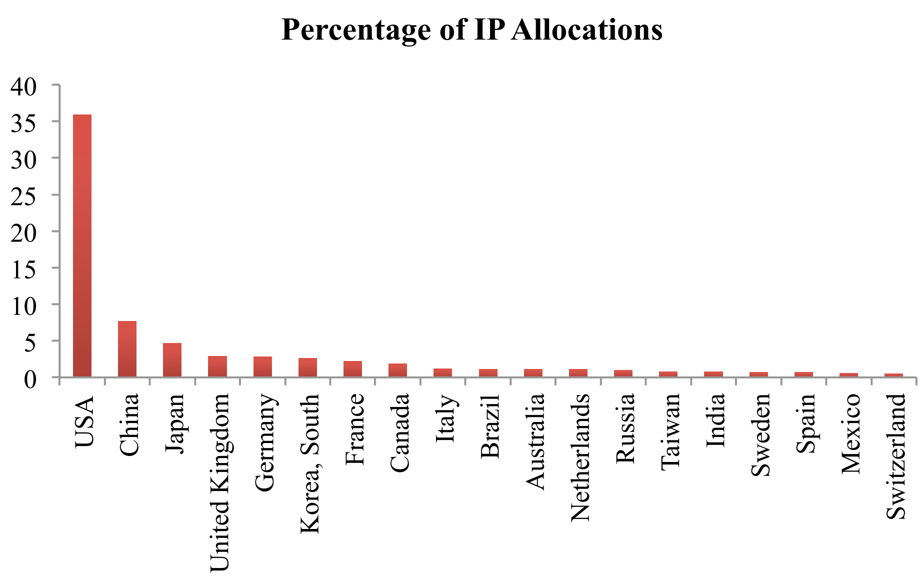


Figure 3: IP address allocation by country

[11] http://en.wikipedia.org/wiki/List_of_countries_by_IPv4_address_allocation
[12] http://data-informed.com/india-to-open-new-internet-frontier-connecting-500000-villages-to-broadband/
[13] http://articles.economictimes.indiatimes.com/2012-06-14/news/32235813_1_apnic-ipv4-ipv6

Even within the different geographies, the distribution of IPv4 addresses between organizations is extremely skewed with the top 1% accounting for 60% of the allocations. Hence, not only is the distribution of IP addresses between countries skewed, there is considerable heterogeneity in the distribution of IP addresses across organizations within a country.

4. The Arrival of IPv6 and Economic Incentives for IPv6 Adoption

The Internet Engineering Task Force (IETF) developed IPv6 to solve the long anticipated problem of IPv4 running out of addresses. The major difference between IPv6 and IPv4 is the address space available under the two protocols. IPv6 has a 128-bit address space, which means it has 3.4×10^{38} addresses compared to 4.3 billion addresses in IPv4. In addition to a much larger address space, IPv6 offers several additional functionalities like network-layer (IPSec), mobility, and simplified packet handling at routers that make it more powerful than IPv4. The features provided in IPv6 are documented in RFC2460.[14]

IPv6 was proposed in 1998 but its adoption has been extremely slow, and currently only ~1.5% of the worldwide Internet traffic travels over IPv6.[15] The graph in Figure 4 represents the native IPv6 traffic for those major websites that are currently IPv6 enabled.[16] A recent survey by ARIN shows that only 1% of the customers of major ISPs use IPv6 and although several ISPs are planning to add IPv6 functionality, 20% of the ISPs worldwide have yet to make a move in this direction.[17] Organizations have adopted a wait-and-watch policy, delaying the migration to IPv6 until others adopt it first.

[14] http://www.ietf.org/rfc/rfc2460.txt
[15] http://www.google.com/ipv6/statistics.html
[16] http://techcrunch.com/2012/06/07/thanks-to-youtube-netflix-and-facebook-ipv6-traffic-hits-new-heights-on-ipv6-launch-day/
[17] https://ripe66.ripe.net/presentations/157-Arbor_IPv6.pdf

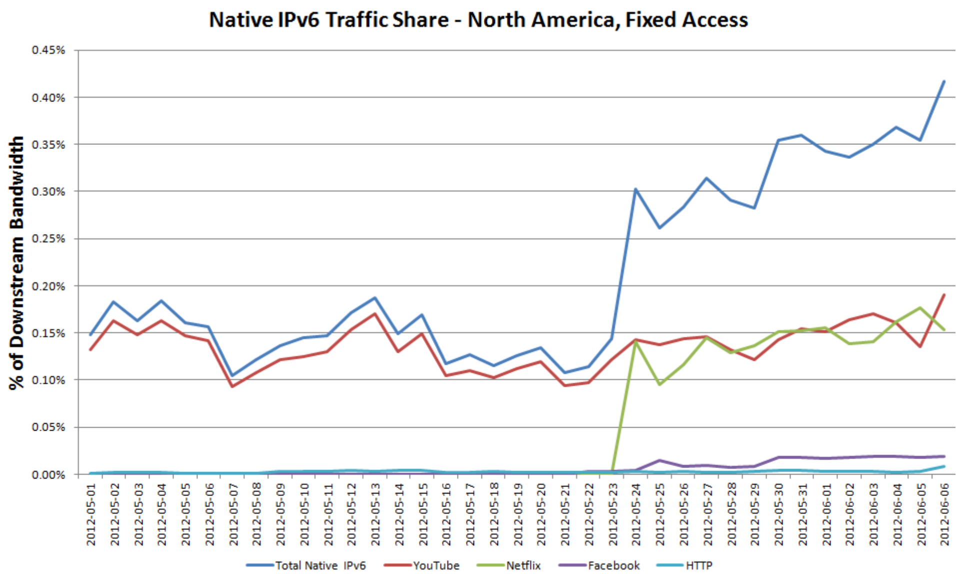


Figure 4: Native IPv6 Traffic on Major Websites.[18]

Different players in the Internet ecosystem have different incentives to adopt IPv6. The incentives of i) Enterprises ii) Retail Customers iii) Network Service Providers and iv) Content Providers have been analyzed below to provide some economic evidence for the slow adoption of IPv6 and provide insights on future outcomes.

4.1 Enterprises

Ease of IPv6 Adoption – Very Difficult

Discussions with several network administrators have revealed that the costs of moving to IPv6 are both expensive and onerous, thus firms want to delay the adoption of IPv6 as much as possible. In order to transition to an IPv6 network, firms need to change large portions of their underlying Internet infrastructure in addition to the servers and workstations. As most of the current Internet infrastructure in firms is not ready for IPv6, a move towards IPv6 calls for new hardware and software that can extend the life of existing hardware. Analysts predict that the hardware alone can cost tens to hundreds of millions of dollars for medium to large sized firms.

[18] http://techcrunch.com/2012/06/07/thanks-to-youtube-netflix-and-facebook-ipv6-traffic-hits-new-heights-on-ipv6-launch-day/

To further put the gravity of this transition into perspective, it is estimated that it would cost the U.S. Government $75 billion to transition to IPv6.[19]

This issue is further exacerbated by the fact that IT organizations today are extremely complicated entities that have different kinds of devices connected to them, e.g., tablets, cell phones, laptops, and desktops which might or might not reside in their internal network. A successful transition from IPv4 to IPv6 should ensure that all of these devices continue to operate seamlessly as the transition takes place without disrupting business functions. Given the complexity of this process, network administrators and IT managers have predicted that a complete internal transition from IPv4 to IPv6 will likely take 5-10 years at the very least. This represents a huge expense in terms of labor cost and opportunity cost that might arise due to probable downtime during the transition.

Another factor that deters the adoption of IPv6 is the lack of knowledgeable IT staff, which will impede the transition to IPv6.[20] Due to the impending scarcity of IPv4, network administrators have become extremely competent with IPv4 and NAT. This knowledge and competency has been acquired over the past ten years. However, components of this knowledge are not portable to managing IPv6 networks, and organizations face the risk of investing in IPv6 without staff having the appropriate skills to deal with problems in the new infrastructure.

These factors represent significant capital and human resource investments, as well as operational risks for organizations that want to migrate to IPv6.

4.2 Retail Customers

Ease of IPv6 Adoption – Moderate

Retail customers will have the easiest transition to IPv6. Most of them remain unaware of the issues facing the Internet and the problems associated with IPv4, and they will simply update their software for IPv6 compatibility. Service providers like Comcast and AT&T have started

[19] http://www.ampercent.com/ipv4-to-ipv6-transition/8406/
[20] http://www.nro.net/wp-content/uploads/ipv6_deployment_survey.pdf

installing routers that support IPv6 (DS-Lite).[21] Most consumers using IPv4-enabled equipment would not notice the transition to IPv6 until their service providers started charging them for use of dedicated IPv4, which is already occurring, or, likely in several years' time, their existing IPv4-enabled equipment stops functioning.

4.3 Network Service Providers

Ease of IPv6 Adoption – Difficult

Network providers will continue to have to adapt their strategies around the varying levels of inaccessibility of IPv4 addresses. The unavailability of IP addresses implied that they could not serve the growing consumer demand for Internet connectivity. Thankfully, this problem was resolved in the short-term by employing NATs. ISPs would typically have 10-100 users behind one public IPv4 address. Employing NATs had several accidental benefits for network service providers. As a device behind the NAT has to go through the ISP's NAT server in order to "talk" to another device in the public Internet, the ISP can easily examine the data packets and restrict access to bandwidth-heavy traffic. NATs disrupt the end-to-end connectivity principle of the Internet. As a consequence, they give enormous power to the ISP over the content and traffic that can flow over its networks.

Thus, one would imagine that ISPs would be reluctant to move from the IPv4/NAT to IPv6 where they would have to relinquish control over the content that flows through their infrastructure.[22] Perhaps as a hedge, ISPs have been at the forefront of the IPv6 revolution, having recently made legitimate efforts to transition to IPv6. With an immense growth in consumer demand, IPv6 is the only viable way to efficiently and easily serve customers. Initially, the ISPs tried to position NATs behind NATs in order to serve more customers with the existing pool of IP addresses; however, there are serious drawbacks and performance issues when devices are placed behind multiple layers of NATs. Several peer-to-peer applications stop working when they are behind a NAT, disrupting gaming services like Xbox and PlayStation, as well as file sharing applications. The transition to IPv6 can be seen as a move to enhance the customer experience. In addition, the

[21] http://www.comcast6.net/
[22] http://www.potaroo.net/ispcol/2012-09/telecommsandip.html

revenue model of the entire telecommunication industry is set to change. For a long time, ISPs have charged for connectivity to the Internet, not for the content consumed. Consequently, service providers will likely move to usage based pricing, which is already in practice in the mobile broadband industry.[23] It will be very interesting to see how service providers begin to think about IPv4 as their payment packages begin to reflect data consumption, which is positively correlated with dedicated IPs. Through these future data packages, they will more visibly be passing the IPv4 pricing onto the consumer.

4.4 Content Providers

Ease of IPv6 Adoption – Moderate to Difficult

In 2012 and into this year, we have seen an enormous debate among content providers like Google, Netflix, Hulu etc. and the ISPs. The ISPs claim that the business model of web-based companies rests on the infrastructure provided by the ISPs, therefore the ISPs should have a share in the revenues generated by these firms. This is clearly unacceptable to web-based companies, who have been fighting with the ISPs while advocating net-neutrality.[24] In a scenario where the consumers reside behind the ISP's NAT, it is extremely easy for the ISP to provide differential treatment to data packets based on their origin or destination. ISPs have not had leverage in the debate to-date. However, if the debate on net-neutrality is lost, the ISPs could immediately start charging content providers based on quality of service. A transition to IPv6 prevents this from happening, as it (i) reinforces the end-to-end connectivity between the consumer's device and the content provider's servers and (ii) the inbuilt security in IPv6 ensures that an intermediate router or device will not be able to access the content of the data packet. This provides some explanation for the strong push content providers like Google are making towards IPv6. IPv6 would change the balance of power and give web-based firms direct connectivity to users. IPv6 opens up an opportunity for Google to crawl through the data behind NATs and promote the "Free Culture" without needing to make a massive infrastructure investment like Youtube.com.[29] Current web-based firms thrive on direct access to consumers as they can not only collect better data from them but also target them with better advertising and services. Some large content providers have

[23] http://www.potaroo.net/ispcol/2012-12/flat.html
[24] For more on net neutrality read http://en.wikipedia.org/wiki/Network_neutrality

already started the push to deliver data over IPv6. Netflix began using IPv6-enabled streaming servers to connect to consumers with IPv6 enabled devices.[25] However, there are millions of small websites that might not be able to incur the cost of transitioning to IPv6 given the operating metrics of their businesses.

The migration to IPv6 is less cumbersome for content providers than for ISPs due to the fact that most of their hardware is housed within centralized locations (compared to a more spread out layout for ISPs) and is relatively easier to upgrade as a whole. However, lots of legacy hardware and software will still need to be upgraded and staff will need to be trained to ensure their Tier 1 six sigma uptime rating.

5. Bridging between IPv4 and IPv6

When the transition from IPv4 to IPv6 occurs, it will be gradual and several technologies will be employed in the interim to keep the Internet up and running during the transition phase. Some of the more commonly used technologies are described below.

5.1 Network Address Translation (NAT)

NAT (Network Address Translation or Network Address Translator) is the translation of an Internet Protocol address (IP address) used within one network to a different IP address known within another network. One network is designated the inside network and the other is the outside. Typically, a company maps its local inside network addresses to one or more global outside IP addresses and maps the global IP addresses on incoming packets back into local IP addresses. This helps ensure security since each outgoing or incoming request must go through a translation process that also offers the opportunity to qualify or authenticate the request or match it to a previous request. NAT also conserves the number of global IP addresses that a company needs and lets the company use a single IP address in its communication with the world.

[25] http://techblog.netflix.com/2012/07/enabling-support-for-ipv6.html

In the mid-1990s NAT became a popular tool for alleviating the consequences of IPv4 address exhaustion.[26] It has become a common, indispensable feature in routers for home and small-office Internet connections. Most systems using NAT do so in order to enable multiple hosts on a private network to access the Internet using a single public IP address.

5.2 Other technologies

Dual-Stack

Dual-stack refers to the side-by-side implementation of IPv4 and IPv6.[27] Networks that are dual-stack enabled can concurrently run both IPv4 and IPv6 protocols. A more detailed description of the dual stack architecture is available in RFC 4213.[28] Several ISPs like Comcast are moving to dual-stack support in their infrastructure as it enables the devices in the network to connect to IPv4 networks as well as helps IPv6 networks avoid problems associated with transitions from one protocol to another.

Tunneling

Tunneling is a mechanism that enables IPv6-enabled devices to communicate with each other by encapsulating IPv6 datagrams as IPv4 datagrams, effectively using IPv4 as a link layer for IPv6. This technique is commonly used in situations where the communicating devices are located on different networks and do not have an IPv6 enabled path between them.

6. Market for IPv4 Addresses

Due to the shortage of IPv4 addresses, ARIN instituted a policy allowing the transfer of IPv4 addresses between organizations. The original policy was aimed at freeing up unused IP addresses to reduce inefficiency in the allocation scheme, while protecting its members by

[26] http://en.wikipedia.org/wiki/Network_address_translation
[27] http://en.wikipedia.org/wiki/IPv6#Dual_IP_stack_implementation
[28] http://tools.ietf.org/html/rfc4213

requiring the receiving organizations to reasonably demonstrate need for the addresses prior to the addresses being designated.[29]

One specific deal dramatically affected the nature of the IPv4 market: the sale of 666,624 IPv4 addresses by Nortel to Microsoft for the sum of $7,500,000 (or $11.25/IPv4 address). This deal set the precedent for IP addresses to be considered assets on the balance sheets of publicly traded enterprises, and thus audited, technology companies.

What is fascinating about this purchase and many subsequent ones is that they have occurred within the ARIN region when ARIN still had over 100 million addresses available for free.

6.1 Unabated Demand for IPv4 addresses

Until recently, certain analysts believed that exhaustion of IPv4 addresses would impede the interest in IPv4 and finally lead to a widespread adoption of IPv6. However, the interest in IPv4 addresses is unabated even though most of the RIRs have effectively run out of IP addresses. Figure 5 shows the continued interest in searches related to IPv4 by region. Most of the interest stems from developing countries like India and China, which have a small fraction of the overall IP address space, as mentioned earlier. There is also considerable interest from North America driven by the maturity of the Internet and its penetration in all lines of business. A detailed description of the demand for IP addresses is presented earlier in Section 2. There are several reasons for the continued interest in IPv4 addresses. The most obvious reason it that 99% of the Internet traffic continues to be over IPv4 networks and billions of consumers are connected to the Internet over the IPv4 protocol. The second, less obvious reason is that network administrators are extremely comfortable working with NAT and IPv4, and they are unfamiliar with issues related to IPv6. As previously stated, the lack of appropriately skilled technical labor would slow down the adoption of IPv6.

[29] https://www.arin.net/policy/nrpm.html#eight3

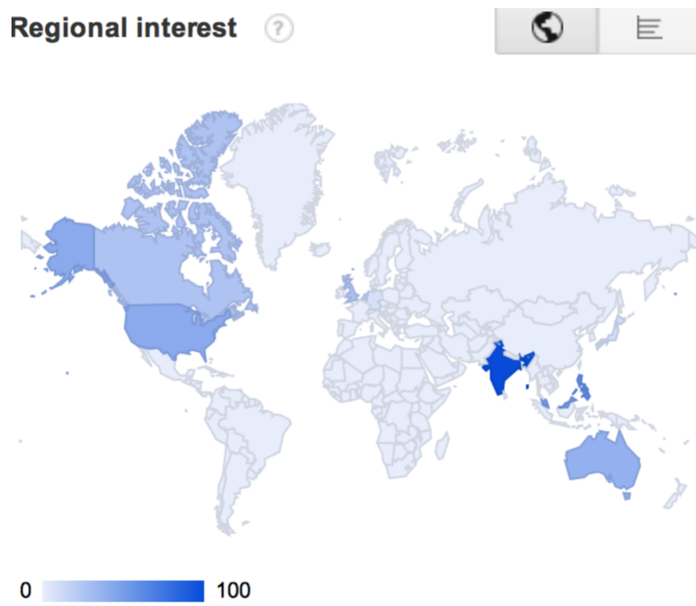


Figure 5: Heat map showing the interest in IPv4 addresses

6.2 IPv4 Transactions

Mueller, Kuerbis and Asghari (2012) presented very detailed analysis of the current trends in the IPv4 market and concluded very interesting observations in their study on the IPv4 Market. Here is a summary of their report:[30]

- Market activities spiked from the year 2011 to 2012.
- Extrapolated from the data of the first 6 months in 2012, assuming 60% projected increase with stable market price from $10 - $11, the value of the market will reach $500 million by 2013.
- Prospective demand parties in ARIN still seek addresses from the transfer market even when ARIN still has addresses to allocate.
- Transfer sizes are generally smaller in the APNIC region.

[30] http://www.internetgovernance.org/wordpress/wp-content/uploads/IPv4marketTPRC20121.pdf

Table 1: IPv4 transactions since 2009[31]

Number of Transfers Excl. M&A

RIR	# of Transfers	Total Size (MM)
APNIC	85	4.9
RIPE	64	1.5
ARIN	71	11.6
Total	**220**	**18.0**

Table 2: ARIN IPv4 Transfer Statistics since 2011 (Excludes 8.2- M&A)[32]

	2011	2012	2013 (Thru Nov.)	Total
8.3 Transfers	15	23	17	55
8.4 Transfers (Inter-Regional)	N/A	6	14	20
Aggregate IPv4 Addresses (MM)	1.9	4.9	4.8	11.6

Observations:

- Number of transfers has grown substantially, and is significantly understated due to leaving out 8.2 transfers, which account for mergers and acquisitions instead of lone IPv4 asset sales. Of the 659 M&A transfers (an "8.2 transfer") that have happened since 2011, we believe that a small but not insignificant portion of these transactions was done primarily for the IPv4 assets.
- In 2012, there were a total of 24,863,488 IPv4 addresses allocated/assigned by ARIN, with 4,864,000 numbers being traded in the Market. This corresponding percentage of numbers allocated via the transfer market was 19.6%, which was a rapid increase from 8.6% from 2011.
- The total percentage from transfer in 2013 is in line with 2012, but has not vastly accelerated, as companies have been accessing the free pool, likely signaling one final "land grab" for the remaining 26 million addresses which are free.[33]

[31] Data Compiled from RIRs websites as of 11/2013. Number of transactions in APNIC and RIPE does not include multiple transactions to with same counterparties and is our best guess having teased out that noise. Does not include Inter-regional transfers
[32] https://www.arin.net/knowledge/statistics/index.html. 8.3 signifies a Transfer of the IP alone, i.e. does not include acquisitions of companies; 8.4 is inter-regional transfers between ARIN and APNIC
[33] Taken from Arin.net as of 11/13/2013

Table 3: 10 Largest Acquirers from ARIN Free Pool- 2013[34]

Organization	IPv4 Alloc. thru Oct '13
AT&T	4,194,304
Akamai	3,670,016
Nobis	917,504
Time Warner Cable	753,644
BrightHouse Networks	524,288
Microsoft	524,288
ColoCrossing	458,752
Enzu	360,448
Unified Layer	327,680
Sonic	294,912

- The table above is interesting in that allocation/assignment policy only allows organizations to request 3 months worth of supply compared with 2 years' worth of need in the transfer market. This means, in theory, these 10 companies above alone could be able to justify the acquisition of approximately 50 million in IPv4 from the transfer market if you assume that each of these enterprises has sought 3 months of space twice this year thus far.

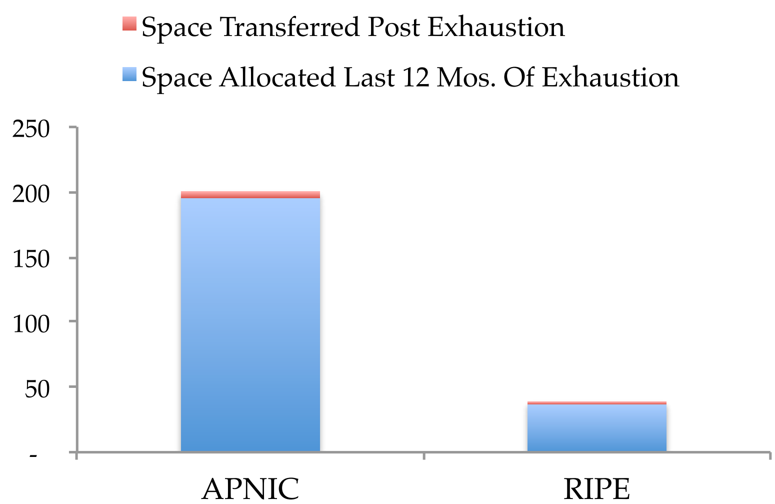
6.3 Post-Depletion Observations and Implications in RIPE and APNIC

Two of five RIRs in the world have depleted their available IPv4 pools, down to each of their final /8 blocks and have implemented an "emergency" allocation policy. APNIC exhausted its supply in April 2011, followed by RIPE NCC in September 2012. As discussed earlier in the paper, the explosion of Internet-enabled devices will only drive the demand higher, but based on our research and analysis, it is clear that the addresses supplied by the existing market are only meeting a fraction of the current demand.

By observing and analyzing data retrieved from the APNIC Lab database[35], as well as RIPE[36] and APNIC[37] transfer logs, we arrived at the following figures.

[34] http://www.wleecoyote.com/blog/Recent-large-ARIN.htm

Table 4: APNIC & RIPE Pre-Depletion Allocations Vs. Post-Depletion Transfers



The graph above provides several inferences. First, and as has been pointed out elsewhere, APNIC appears to have been quite liberal in its needs based underwriting during the last 12 months prior to exhaustion, as it allocated over six times the amount of space as the RIPE NCC. Second, post exhaustion, companies have made adjustments, like substituting free space for NAT and going back for a final allocation from the final, "emergency" /8 and reconfiguring their networks. Transfers have only accounted for approximately 3% of pre-exhaustion "demand" in these regions (as measured by allocations), and we think this percentage will move closer to 10-20% of pre-exhaustion per year in the coming years, because the "demand" shown above, even considering the APNIC final year blip, is only increasing.

6.4 Current Pricing of IP addresses

There are two sources that give an indication of prices for IPv4 addresses. One reference is the price paid for IPv4 blocks from one organization to another in the IPv4 market. Another reference

[35] http://labs.apnic.net/ipv4/report.html
[36] https://www.ripe.net/lir-services/resource-management/ipv4-transfers/table-of-transfers
[37] http://ftp.apnic.net/transfers/apnic/

for IPv4 pricing is the rent charged by ISP providers to consumers who want a static public IPv4 address.

It is difficult to gather all the data on the transfer of large IP blocks because the RIRs do not require the buyer and seller to inform the Registry about the transfer. Having said that, the price for IP addresses has generally been anchored around the $11.25 per address due to the precedent set by the Microsoft-Nortel deal.

Domain hosting companies and cloud services tend to offer cheaper rates for static IPv4 addresses as compared to ISPs because these addresses are currently sold as value-added services on top of their basic services.

Table 5: Lease prices for static IP addresses[38]

Category	Company	Price/Address/Month ($)
ISP	Qwest	5.95
	O2 (U.K.)	8.15
	Bluehost	2.00
	BellSouth (AT&T)	14.95
	Comcast Business	14.95
	China Telecom	25.00 (bundled with internet)
	Reliance (India)	13.50
Domain Hosting	GoDaddy	5.99
	PadHost	6.95 (with web hosting)
	WebHost	2.75
	Dreamhost	3.95
Cloud Services	Amazon EC2	0.01/hr
	Rackspace	2.00
	Google	0.01/hr

[38] http://www.quark.net/docs/Economics_of_IPv4_on_IPv6.pdf

7. Economic Analysis of IPv4 address pricing

7.1 Macro Factors Affecting IPv4 Pricing

There are several factors that determine pricing of IPv4 addresses. These factors and their effect on prices are outlined below:

i) Growth in Internet-enabled devices and services

Effect on Price – Modest Upward Pressure

As more devices connect to the Internet, the demand for IP addresses will grow, and this should increase the prices of IP addresses. Given the almost certain unwavering growth of the Internet of things, e.g. traffic cameras, refrigerators etc., it is likely that we might witness an explosion in devices connected to the Internet. Keeping these factors in mind, the prices of IPv4 addresses will have an inverted-U relationship with the number of Internet-enabled devices as shown in Figure 9. Further intensifying this trend, there will be an explosion of firms providing web-enabled services, and more services mean more unique IP addresses.

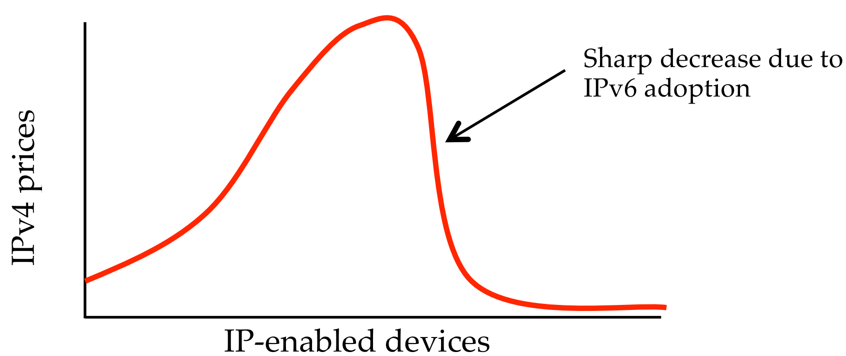


Figure 9: Variation in Price of IPv4 with IP-Enabled Devices

ii) Advancements in and Further Proliferation of NAT

Effect on Price –Meaningful Downward Pressure

Recent advances in NAT technology have removed several drawbacks associated with "NATing". Several features of IPv6 have been back engineered into NATs and, apart from some peer-to-peer applications, several components of the Internet work well with NAT. This suggests that ISPs and organizations can leverage their existing IPv4 addresses to serve more consumers, which has the direct effect of keeping prices in check as a substitute exists.

iii) Uncertainty of IPv6 adoption

Effect on Price – Upward Pressure

Since its proposal in 1996, IPv6 has seen very little adoption. The uncertainty in the adoption has reduced the incentives for newcomers to adopt IPv6 (due to the direct and indirect network effects). If the horizon for IPv6 adoption becomes longer and more uncertain, it might lead to an increase in the prices of IPv4 as network administrators will not want to invest in IPv6 technology, and will place a higher premium on IPv4 reserves serving as insurance.

7.1.1 Different Stages of IPv4 Internet Penetration Globally

The parameters surrounding both current demand and eventual IPv6 migration will vary across geographic regions. These differences can be based on the penetration of the Internet, the maturity of the broader economy, and the availability of trained network professionals. Logically, in economies where per capita GDP is a fraction of the levels in the developed world, the IPv4 demand will be quite price elastic, largely irrespective of population and network proliferation. The Big Mac Index is somewhat analogous here - Big Macs and monthly mobile plans are three to six times more expensive in the United States than they are in India for example, and this directly affects a country's willingness to pay provided that there are, albeit imperfect, substitutes.

There will likely be bifurcation between firms in the developed world (ARIN, RIPE) and those in the developing parts of the world (APNIC, AFRINIC) with the latter being almost forced towards utilizing IPv4 addresses across multiple devices using NAT or developing effective leasing methods. Eventually, as the transitions to IPv6 occur, these regions should also be leaders in this transformation, provided their dependence on NAT has not made their networks too unwieldly. Some evidence of this is clearly visible from the pro-IPv6 stance taken by the Chinese and Indian governments.[39] [40] What remains to be seen is, in IPv4 resource-starved locales, whether the governments are able to get comfortable storing potentially sensitive information on foreign soil. This issue is in its nacency and will likely increase in importance, since storage is becoming increasingly ubiquitous (not just in commercial retail), and there has been a great deal of distrust borne from the NSA spying leaks, making data transfer and storage sensitive from a national security standpoint.

7.2 Micro Factors Affecting IPv4 Pricing

The prices for IPv4 addresses will continue to be driven i) by the mature economies where Internet penetration and technological innovation are high and ii) by firms that have huge sunk costs in legacy network technologies, particularly firms in the developed parts of the world (ARIN and RIPE). Firms in these regions with historical investments in an IPv4 infrastructure will have to incur higher costs to use NAT or IPv6. These costs can also depend on the functionality required by the connected devices. For example, if these devices need to run a P2P protocol that doesn't function behind a NAT, then the option of NAT would not be considered. Additionally, newer firms that do not have any residual components in their networks will be more willing to invest in NAT and IPv6, both because their network is likely less layered, and they are not prone to the sunk cost fallacy, as the incumbents likely are.

[39] http://www.zdnet.com/blog/china/china-vows-to-accelerate-ipv6-move-to-reverse-current-disadvantages/454
[40] http://www.dot.gov.in/ipv6/ipv6activities.html

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7.2.1 Case Studies:

IaaS Provider

Rackspace is a leading hosting/IaaS cloud services provider. Rackspace derives the majority of its revenue from its hosting/cloud (IaaS) service. Therefore, Rackspace can serve as a "pure play" as it relates to IPv4 resources since it does not need to strip out other business lines that do not consume IPv4.

From various sources and Rackspace's public filings, we gathered the following information.

Table 6: Rackspace IP Info

# of Servers (as of Q1 2013) (A)	94,122
Current IP Space (ARIN WHIOS) (B)	929,792
Average IP Address Per Server (C = B / A)	Approx. 9.9
Average Monthly Revenue per Server[41] (D)	$1,278
Average Monthly Contributed per IP per Server (D / C)	Approx. $129

The results of these calculations are shown in the matrix below:

$$IP\ Value = \sum_{i=1}^{yr} \$129 \times r \times 12mth \ \div\ (1 + 10\%)^{i}$$

$$Where\ Yr = 5, 10, and\ 15; r = 1\%, 2.5\%\ and\ 5\%$$

Table 7: Rackspace Value per IP Address Value Matrix

		IP Address Contribution to Total Revenue (r)		
		1%	**2.5%**	**5%**
Years to IPv6 Adoption (yr.)	**5**	$58.7	125.6	$293.4
	10	$95.1	$216.7	$475.6
	15	$117.7	$273.2	$588.7

i) Assumes 10% discount rate
ii) Assumes average monthly contribution per server and IPs addresses per server stay constant

[41] http://investing.businessweek.com/research/stocks/financials/drawFiling.asp?docKey=136-000110769413000008-4DO5IJE58V14NP1AMPER48MI1A&docFormat=HTM&formType=10-K

As one can see, even with conservative assumptions, Rackspace and other IaaS providers can capture significant revenue per IP address. There is unlikely to be any additional fixed or variable costs to acquiring additional space; it requires minimal human capital at the initial assignment phase with the "maintenance" of potentially renumbering also being very modest. Therefore, you would expect the vast majority of the revenue derived for each additional IPv4 address to fall straight to the bottom line. The fixed costs of the service offering are all there, and each additional tenant with each additional IPv4 address provides generous economies of scale.

While determining value is far from an exact science because customers' needs vary substantially, IPv4 resources should certainly be part of their cost analysis calculus, along with servers, electricity, and cost per square foot. Certain customers will demand dedicated space, and the IP address contribution to revenue for such a customer might very well be in that 2.5%-5% range. Given the fierce competition in the U.S. IaaS market, keeping high connectivity and a 99.99% uptime will remain a high priority, and it will be a marketing tool used to differentiate businesses and prevent customer loss for companies like AWS, Rackspace and ViaWest. As Geoff Huston wrote on one of Kalorama's blogs,[42] Melbourne Free University's website was taken down for several weeks because it was sharing an IP address with an entity conducting nefarious business practices. Consequently, the price it will be willing to pay in the future for a static, dedicated IP address would be significantly higher. As this phenomenon becomes more frequent and enterprises become more technologically sophisticated, the demand for dedicated IPs in the hosting environment will stretch far beyond the largest corporations. Virtual storefronts ("shingles") are simply too important to today's businesses, almost irrespective of the business sector or idea being advanced.

To summarize from Table 7 above, Rackspace might derive ~ 2.5%-5% of total revenue per IP address from a customer that requires a private cloud, yet it will only derive ~0.5% of total revenue from a small business that is price sensitive on its online presence. In both instances, Rackspace benefits substantially from having significant IPv4 resources.

[42] http://blog.kalorama.com/archives/1278

ISPs

ISPs mostly provide Internet access to their subscribers and do not provide additional services like HVAC, power, load balancing, or server warehousing etc. Therefore, public IP space is a larger variable in their revenue equation, on a relative basis compared to other businesses. Choosing from all major ISPs in the U.S., we picked Comcast as an example in our case study.

From various sources and their public filings, we gathered the following information and made defensible assumptions. Lee Howard, Technology Director of Time Warner Cable, assumed in a previous study that the average revenue generated per IPv4 address per household account per year to be $400 across the industry.[43]

Therefore, the value derived over the lifetime of an IPv4 space from time zero would be as follows:

$$IP\ Value = \sum_{i=1}^{yr} \$400 \times r \div (1 + 10\%)^{i}$$

$$Where\ Yr = 5, 10, and\ 15; r = 1\%, 2.5\%, 5\%, and\ 7.5\%$$

Therefore, the value captured by each IP address under different situations can be seen in the following matrix.

Table 8: Comcast Revenue per IP Address Value Matrix

		IP Address Contribution to Total Revenue (r)			
		1%	**2.5%**	**5%**	**7.5%**
Years to IPv6 Adoption (yr.)	**5**	$15.2	$37.9	$75.8	$113.7
	10	$24.6	$61.4	$122.9	$184.3
	15	$30.4	$76.1	$152.7	$228.2

i) Assumes 10% discount rate

Again, different customers require different connectivity levels, and Comcast has different pricing plans to accommodate each one of them. We believe a static IP would definitely matter

[43]http://www.nanog.org/meetings/nanog56/presentations/Wednesday/wed.general.howard.24.pdf

and would be worth more to a hard-core gamer who uses a plan at a cost of $89.99[44] per month, compared to a basic plan subscriber who only uses the Internet to check his/her email. IPv4 scarcity should only accentuate this pricing bifurcation.

Another interesting component is that companies are still not thinking about how much value they can create on a per IP basis because the resource has been free. Yet their product managers are certainly well-versed in the revenue per server, per MHz, and per square foot because they have had to factor the estimated ROI of these expenditures into their broader business strategy and operating forecast for years. We naturally ascribe higher value to that for which we pay, so it is only a matter of further exhaustion for demand parties to start analyzing this resource as one of the inputs in their broader PP&E.

7.2.2 Psychological Component

While rents captured should serve as a primary derivative of the value of the underlying IP address, as with any market regardless of its maturity, valuation does not always correlate to these fundamentals. People felt quite differently about real estate in Phoenix and Miami in 2006 than they did in 2008. We have seen the same ebbs and flows in technology; investors and strategics have been quite active in the wireless and fiber networks this past year (bids for Clearwire, Sprint, and Charter Communications). That same phenomenon is likely at play here. Companies are focusing on the topics that will affect them in the coming weeks and quarters, paying close attention to what their competitors are doing, while consistently neglecting to prioritize IPv4-v6 planning for the long term. Once a truly large purchase occurs (i.e., larger than Amazon's four million address purchase), it will be on the radar of the entire C-suite of the prospective buyers that ultimately need the space throughout this decade. During this aftermath, we'd imagine the market will see greater volume and liquidity. We saw this spike in interest for spectrum in Europe in 2000, when all of the large telecoms spent incredible sums, partially because it was what their competitors were simultaneously doing.[45]

[44] http://wwwb.comcast.com/internet-service.html
[45] http://online.wsj.com/article/SB10001424127887324412604578515222989449746.html

7.3 Supply of IPv4

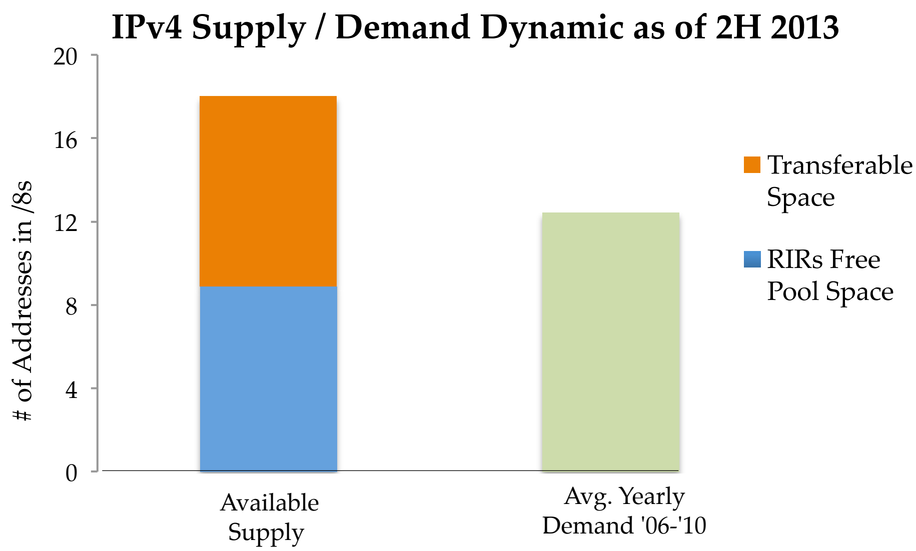
Somewhat surprisingly, there is a significant amount of IPv4 space that is not being used. The issue is, however, that most of this space will never come to market for strategic reasons (government or enterprise). When one takes this space out of the equation, you are left with about 300 million IPv4 addresses, including that which remains in the free pools. Bear in mind that the global consumption is about 200 million addresses per year,[46], so this could be digested in a few years. Additionally, the frictional costs of transacting makes this 150 million number far lower in reality. We think the amount of space that could reasonably be moved would be capped at a level below actual demand. This might change as the system becomes more automated. In short, however, we think there is a significant disconnect between space that is not routed and space that could reasonably be transacted.

Table 9: IPv4 Space Supply Situation

IPv4 Supply Situation (/8s)	
Total Number of IPs un-routed (/8s)[47] (a)	64
RIR Remaining Space (/8s)[48] (b)	9
Government Agency Holding (/8s)[49] (c)	13
Technical and IANA Reserved Blocks [50](/8s) (d)	33
Actual Transferable Space /8s (e) (e = a – b – c – d)	9

[46] https://ripe66.ripe.net/presentations/193-NRO_Q1_2013-1.pdf
[47]http://www.internetgovernance.org/2012/08/17/thirty-percent-of-ipv4-space-is-still-unused/
[48] https://ripe66.ripe.net/presentations/193-NRO_Q1_2013-1.pdf, Note: only include non-exhausted regions: ARIN, AfriNIC, and LACNIC
[49] http://www.iana.org/assignments/ipv4-address-space/ipv4-address-space.xml
[50] http://www.iana.org/assignments/ipv4-address-space/ipv4-address-space.xml

Table 10: Global IPv4 Supply and Demand[51] Comparison



8. Conclusion

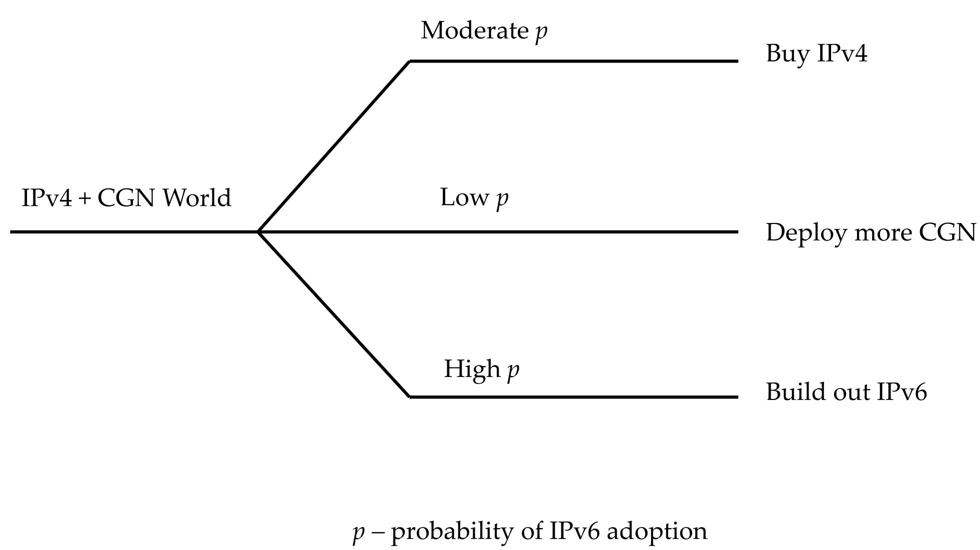


Figure 11: Decision Tree of Real World Effects to IPv6 Adoption Probability

[51] https://ripe66.ripe.net/presentations/193-NRO_Q1_2013-1.pdf , Note: reason to choose 06 -10 is because before APNIC run out, they assigned numbers generously to their members

This paper provides a comprehensive description of the current state of the Internet vis-à-vis the scarcity of IPv4 addresses and adoption of IPv6. One of the main findings of our analysis suggests that until there is a large probability of IPv6 adoption, it is suboptimal for firms to invest in IPv6 migrations. Unfortunately, even when the probability of IPv6 adoption is relatively high, firms might still prefer to buy IPv4 addresses or use NAT to extend their existing address spaces or a combination of these two strategies. This result is driven by both the uncertainty associated with IPv6 adoption, as well as with the network effect and a lack of available incentives. Given that it is difficult for firms to adopt IPv6, policymakers should be considering the pros and cons of the alternatives - namely IPv4 and NAT- and work towards implementing measures that can effect change, like credits or taxation.

We first discuss the feasibility of NAT. There is considerable economics literature that talks about network adapters like NAT (Farrell and Saloner, 1986). It has been shown that such adaptors reduce the incentive for market participants to move to newer and better technologies like IPv6 due to high sunk costs and low incompatibility costs, thereby reducing network transmission efficiency. In the present context, this implies that policy makers should provide significant incentives to the early adopters of IPv6 since they are and will be bearing a disproportionate share of this cost.

Critics of IPv4 markets fear that the bridge created by a market would be so successful at extending the life of IPv4 that it would become a roadblock on the path to IPv6 (Edelman, 2008; Hofmann, 2009; Lehr, Vest, & Lear, 2008; Mueller, 2008). However, the absence of the IPv4 Market would lead to a larger proliferation of NATs that will negatively impact the adoption of IPv6 in the future due to increased complexity of the network and the lack of compatibility with IPv6. As a consequence, the adoption of IPv6 will not be at an economically optimal level. Suffice it to say, NAT has a much more profound impact on IPv6 adoption than an IPv4 transfer market does or ever would.

A transparent, well-functioning market should modestly help bridge the current shortage of network addresses while affording IPv6 technology time to mature. However, as we have seen in the RIPE region as witnessed through the modest number of transactions post depletion, the IPv4 Market is but a small bridge in the far broader IPv4-v6 migration landscape. It is an option certain incumbents will need to access in order to grow an existing service, as well as the potential lifeblood to a startup that could be significantly disadvantaged otherwise. The IPv4 Market will likely be utilized quite differently by competitors within the same industry: for some it might provide strategic optionality; for others, it might be viewed strictly as prudent risk management, while others, due to substantial preexisting space, might not need to utilize it at all.

It remains to fully be seen how the Market for IPv4 addresses affects the adoption of IPv6. However it provides the most logical and economically viable bridge to IPv6.

About the Author

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Vibhanshu's research focuses on the effect of emerging technologies on consumer behavior, business strategy and market structure. He is particularly interested in multi-channel coordination and examines issues in multi-channel retail, advertising and pricing. He studies how consumers respond to different forms of advertising and how companies can strategically use new advertising channels to connect with their consumers. In another stream of research, he examines the dynamics of e-commerce platforms like Amazon and iTunes and their interaction with traditional retail channels. He has worked with several companies in the past like LEGO, Adobe, FICO, IBM and Omnicom and advises several hi-tech startups on strategy and marketing.

He received a B. Tech. in Computer Science from IIT Kanpur, an MA in Statistics, and a PhD in Applied Economics and Managerial Science from the Wharton School of the University of Pennsylvania. In his free time, he enjoys photography, running and travelling with his wife.