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GSR 2013 Discussion Paper

The Need for More IP Addresses

Work in progress, for discussion purposes

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1 THE NEED FOR MORE IP ADDRESSES

Author[1]: Latif Ladid, Senior Researcher, University of Luxembourg

Introduction

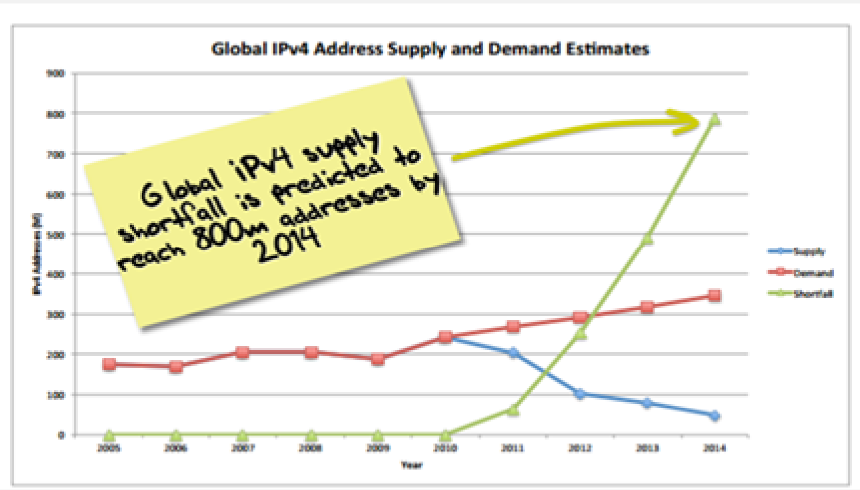
The Internet has shown its incredible potential as a unique economic enabler. The ability to build networks between people, groups, data, and things – the all-embracing Internet of the future -- will, in the next 10 years, generate a value exceeding USD 14.4 trillion, touching all sectors of the economy (See Section 1.3.3). A world linked together by the “Internet of Everything” will turn raw information into knowledge, creativity into practical innovation, and facts into greater relevance than ever before, providing richer experiences and a more sustainable global economy.

We are not, however, there quite yet. Currently, 99.4 per cent of physical objects that may one day be part of the “Internet of Everything” are still unconnected. Moreover, large areas of the world remain unserved or underseved by Internet connections. Meanwhile, recent technological developments in cloud computing, wireless networks, so-called “Big Data,” high-performance computing, processing power, sensor miniaturization, and many others, translate into a digital data universe that is increasing exponentially. The ability to economically extract value from this universe will offer unprecedented opportunities for welcome progress – if there is sufficient ability to connect to the growing Internet.

One of the key technologies that can enable this progress is the new Internet Protocol version 6 (IPv6). This new iteration of the IP protocol stands poised to push the boundaries of the Internet beyond what is now possible with the current version, IPv4. Moreover, IPv4 addresses are quite simply running out. IPv6 will allow users to get the most value from the “Internet of Everything,” and it will enable greater connection of underserved communities and countries. Yet today, there are significant market, business and technical challenges in making the transition from IPv4 to IPv6. The world stands poised for a great leap over those challenges and toward the possibilities of an unbounded new Internet.

This paper explores the transition process and suggests ways to build momentum for IPv6 around the world. Section 1 explores some of the transition challenges, which include establishing a valuable business case and accounting for transition costs. This section first explores the current status of IPv4 and the progress of transition to IPv6. It then seeks to break down the technical and economic factors, including costs that may be impeding transition. Section 2 then explores how governments, standards bodies and international organizations can help foster the conditions to promote take-up of IPv6 technology.

Figure 1: Coping with Demand for Internet Addresses



Source: Geoff Huston, APNIC

1. *The Status of IPv4 and the Transition to IPv6*

Perhaps the threshold question to address in explaining the transition from IPv4 to IPv6 is "why?" Why is it necessary or beneficial for all stakeholders of the Internet ecosystem (regulators, policy-makers, fixed and mobile operators, ISPs, manufacturers and users) to move toward the IPv6 address space? Of course, IPv6 has been developed to increase the number of possible Internet addresses (see Section 1.1 below). But it also has been designed to revisit some critical IPv4 functionalities to better cater for a wide range of applications and new services and to support the Internet's growth. So, the transition from IPv4 to IPv6 is ultimately essential to pave the way for the maturation of the Internet around the world. Without this transition, the Internet will be stuck in second gear, unable to cope with the demands and needs of an interconnected world.

To understand the complexity of this transition process – and how governments and multi-stakeholder groups can facilitate it -- it is helpful to consider the following aspects:

- The importance of IP addressing, its distribution worldwide and its key function in a data- intensive world of online services, applications and networks that is putting strain on the availability of addresses;
- The status of IPv6 deployment and adoption trends from IPv4 to IPv6;
- The costs entailed in IPv6 adoption;
- The main roadblocks/challenges in deploying and transitioning to IPv6, such as a lack of business incentives or consumer awareness, as well as technical incompatibility and security issues;
- The existing policies, regulatory measures and guidelines developed to support the transition from IPv4 to IPv6;
- The best practices and recommendations that can encourage, facilitate and support a swifter adoption of IPv6;
- Potential innovative steps that policy-makers could take to accelerate or facilitate IPv6 deployment; and
- Measures already taken by the ITU, industry, and governments to promote awareness of the criticality of IPv6 deployment.

The following sections lay the groundwork for considering these issues by surveying the current status of IPv4 address deployment and the nascent transition to IPv6 as it stands today.

1.1 Status of IPv4: Preparing for the `IPocalypse'

At full deployment, the total number of IPv4 addresses that can be used from the 32-bit address space is 3.7 billion. At the outset, then, it becomes apparent that, in a world with more than 7 billion people, the existing addressing system inevitably will be tethered by a short leash on the way to the "Internet of Everything."

Moreover, the IP address system was not originally designed to distribute addresses by country. Rather, addresses were assigned to networks as they were built (on a need-basis), giving a lion's share to the earliest networks and users (See Figure 2). These were mostly within the U.S., which continues to have 42 per cent of IPv4 addresses. Asia now has around 20 per cent, which is far better than the 9 per cent it had back in 2000[1].

[1] Latif Ladid – stats from year 2000.

1.1.1 Depletion of IPv4 Addresses

The number of IPv4 addresses available from the central, global Internet Assigned Numbers Authority (IANA)2 registry is not simply low – it has been completely depleted as of 3 February 2011. The remaining unclaimed IPv4 addresses are now in the care of Regional Internet Registries (RIRs), which have the task of distributing them in their regions. The Internet community failed to predict this address exhaustion and waited until the end in order to sound the bells of deployment of IPv6. This gave the Internet community, ISPs and enterprise users alike no time to better prepare for this transition.

As time goes on, the depletion situation grows worse. The global IPv4 supply **shortfall** is predicted to reach 800 million IP addresses by 2014, according to Geoff Huston, Chief Scientist at APNIC, the Asian RIR.3 APNIC and RIPE NCC have exhausted the addresses provided to them by IANA since 15 April 2011 and 14 September 2012, respectively. The North and South American RIR will be depleted by mid-2014. Meanwhile, the yearly demand is increasing from 300 million to 350 million annually just for the baseline ISP consumption to keep the normal growth of the Internet going. These numbers do not take into account the new needs for emerging IP-based services like the "Internet of Things," Smart GRID efforts, and Smart Cities, to name just a few.

How bad is the exhaustion situation? Well, the remaining address space among all five of the regional registries is about 5 blocks of 16 million IP addresses, which is a total of 84 million. North America has only 2.5 blocks left. It is abundantly clear that the world is facing an impending "IPocalypse," and the only solution at hand designed by the Internet Engineering Task Force (IETF)[4] over the past two decades to cater for the growth and the scalability of Internet addressing is IPv6. The big shift to IPv6 will happen by default.

Increasingly, IPv4 addresses are kept viable only by the use of a stop-gap solution: the extension of Network Address Translation (NAT) to the carrier level – a technique called Carrier Grade NAT (CGN) -- which is currently in deployment in large scale. CGN is basically implementing NAT at the carrier network and won't share a single IP per many users but rather certain ports among the same users. The Internet experience will be dramatically reduced by not getting at least one global IP to link the NAT to the Internet. The end-user will get just a certain number of ports. Applications like Google maps might need up to 250 ports; anything less will make the map patchy.

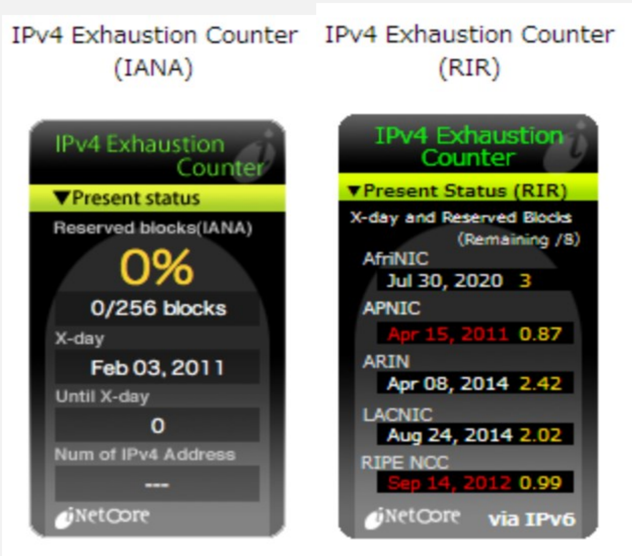
Figure 2 illustrates the exhaustion of IPv4 addresses as it plays out across the central (IANA) and regional (RIR) registries. The first (left) counter shows that the central pool has fully assigned its 256 IP blocks. The second (right) counter shows the remaining IP blocks per region at the registry level. Each block contains 16 million IP addresses. The RIR policy is that when the RIR reaches the last IP block, it will only assign 1,024 IP addresses, and only to those entities that will deploy IPv6 -- at least for now in Asia and Europe.

[2] IANA is the department of ICANN, a nonprofit private US corporation, which oversees global IP address allocation, autonomous system number allocation, root zone management in the Domain Name System (DNS), media types, and other Internet Protocol-related symbols and numbers. See http://www.iana.org/about

[3] APNIC (Asia Pacific Registry www.apinic.net)

[4] IETF: http://www.ietf.org/

Figure 2: The IPv4 address **exhaustion** clock[5]



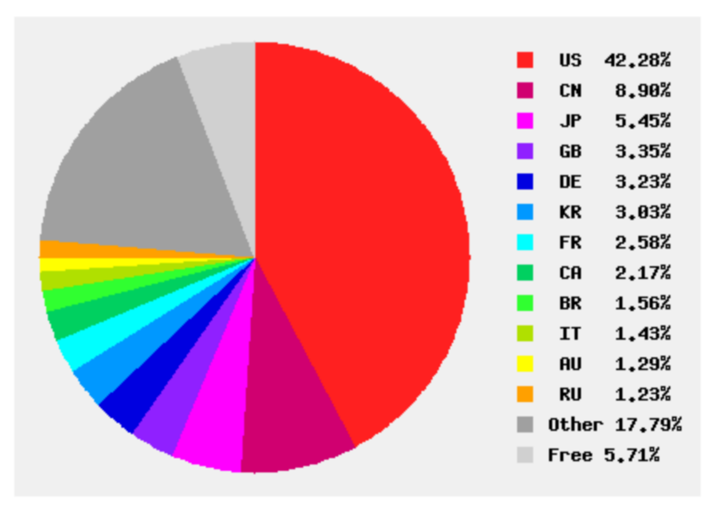
1.1.2 The Remaining Address Space Per Country

By linking to the website for BGP (Border Gateway Protocol)[6], one can view the number of IP addresses assigned to networks in every country of the world. The numbers are generated from information published by the RIRs (AFRINIC for Africa, APNIC for Asia, ARIN for North America, LACNIC Latin America and the Caribbean, and RIPE NCC for Europe, Middle East and parts of Central Asia) on their FTP servers as of 27 April 2013.

The list of the countries shows certain historical disparities in the assignment of the address space. The introduction of the registries has compensated to a certain extent in the 15 years, helping contribute to a more balanced distribution of the IP addresses (though always on a need basis) and the promotion of balanced Internet policies through a bottom-up, community-defined consensus. Obviously, the need for 800 million IP addresses by 2014 to sustain the growth of the Internet as a global good remains a critical issue to resolve. The only solutions are promoting IPv6 and training the community in good use of the remaining IPv4 address space during the transition period.

[5] Source: Netcore: http://inetcore.com/project/ipv4ec/index_en.html
[6] BGP Expert (http://www.bgpexpert.com/addressespercountry.php)

Figure 3: Distribution of IPv4 Address Space Worldwide



Source: BGP Expert

1.2 Current Deployment of IPv6

If we are nearing the IPocalypse, are we making any progress at deploying IPv6 addresses? Industry statistics show that, in fact, IPv6 is entering the market at a respectable pace. But will it be enough to meet the demand for Internet growth?

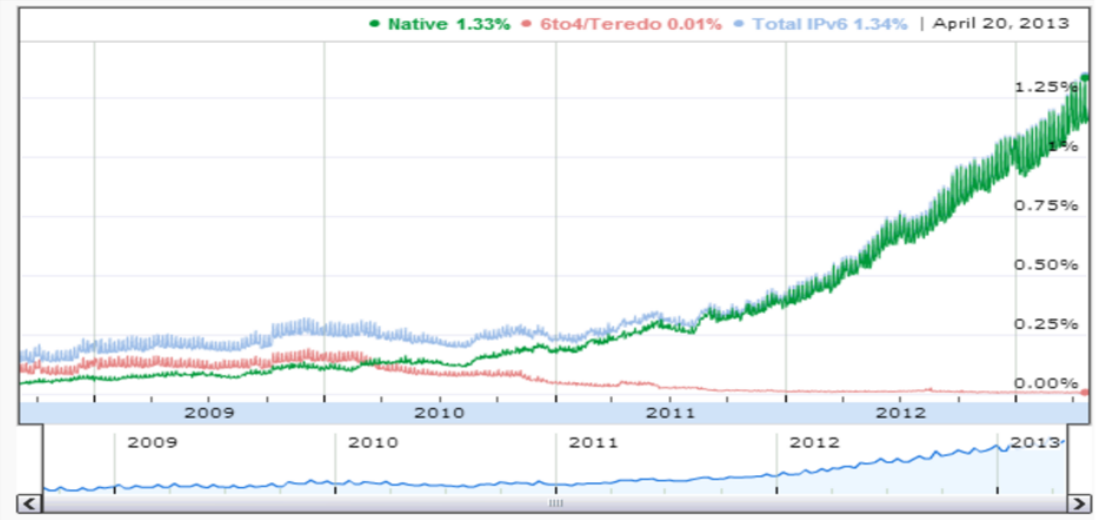
1.2.1 Growth of IPv6 Connections

A chart found on the website of the Internet research organization CAIDA[7] shows that the number of IPv6 connections is increasing constantly worldwide. Europe leads with over 50 per cent of the network connections, while there is also a strong showing in Asia, as well. A comparison of the densely connected IPv4 universe to the IPv6 world demonstrates the high IPv6 readiness of the non-US based networks and the possible balancing factor of IPv6 services in the future. Google, meanwhile, measures continuously the availability of IPv6 access among Google users. The graph in Figure 4 shows the percentage of users accessing Google via IPv6.[8]

[7] http://www.caida.org/research/topology/as_core_network/pics/ascore-2011-apr-ipv4v6-standalone-1600x876.png

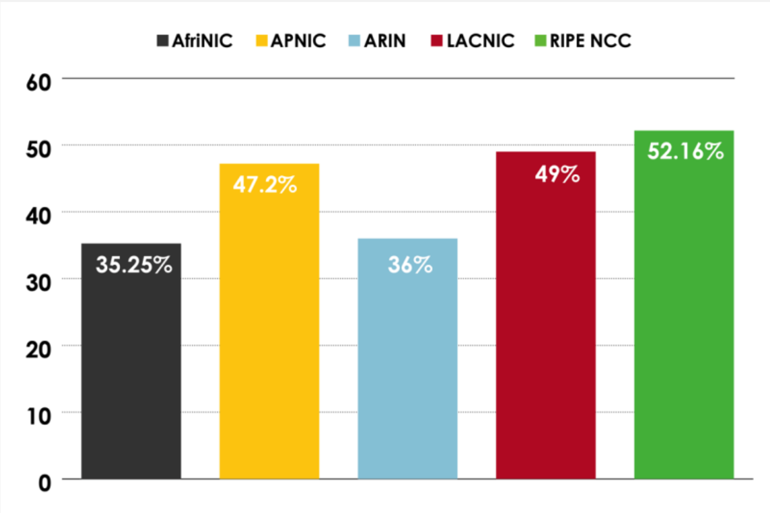
[8] "Native" refers to equipment with IPv6 capability, in contrast with "dual stack" equipment that combines IPv6 technology with IPv4 capabilities.

Figure 4: Google IPv6 Users[9]



As of end of 2012, the percentage of all ISPs transitioning to IPv6 that are located in the two exhausted regions (APNIC and RIPE NCC) was nearing 50 percent.[10] Though the percentage of IPv6 ISPs in the ARIN[11] region is low, it is still the highest in absolute terms (See Figure 5).

Figure 5: IPv6 address assignment



Source: Internet Number Resource Report: NRO

The top 500 websites have been tested for IPv6 connectivity, and 22.4 per cent of them can be accessed by default over IPv6. These top 500 web sites produce 80 per cent of the world's hits and traffic; they are using IPv6 packets to send their content to the end-users accessing them via IPv6.

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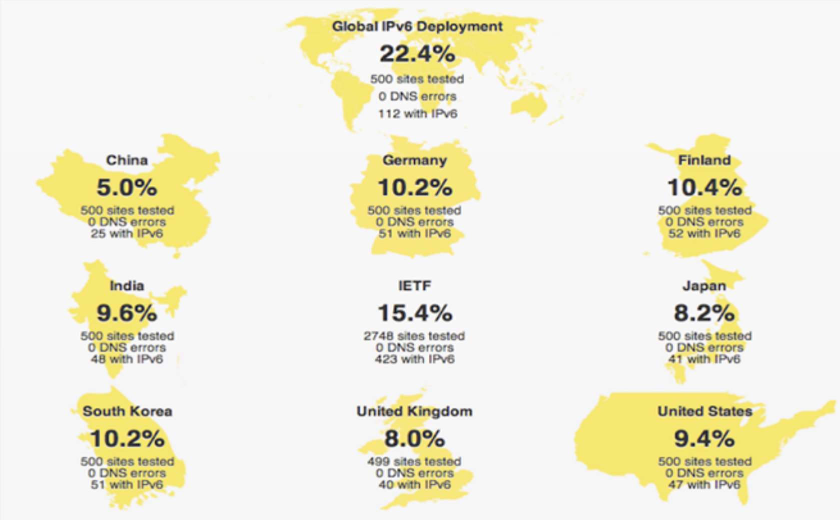
[9] Source Google: http://www.google.com/ipv6/statistics.html

[10] APNIC (Asia Pacific Registry: www.apnic.net)

[11] ARIN (North American Registry: www.arin.org)

Figure 6: Performance Indicators: 500 Sites Tested



Source: Lars Eggert, IRTF Chair– IPv6 Deployment Trends

The worldwide level of IPv6 adoption by ISPs reflects the fact that as of 26 April 2013, 15,850 IPv6 prefixes have been allocated by the RIRs. Of those, 6,470 have been routed in the BGP table and 4,420 are alive on the routing table. This does not mean that the ISPs are offering IPv6 service. Only a few do, so far, but many have announced they are offering, or planning to offer, IPv6 service during 2013 and 2014.

Cisco has calculated (See Figure 7) that the global adoption of IPv6 in the Internet core backbone[12] has reached 59.16 per cent, with a global content penetration of 35.82 per cent. The user penetration, however, is still very low at just 2.27 per cent. This is primarily due to the lack of IPv6 service offered by telecom and mobile operators.

Figure 7: Global IPv6 adoption

Source: Cisco

[12] http://6lab.cisco.com/stats/

1.2.2 The Global ISP take-up

As indicated in Section 1.2.1, a total of 15,850 IPv6 prefixes have been assigned to 183 countries. In Europe, the largest number of ISP assignments has been to France Telecom and Deutsche Telekom. In Figure 8, the table[13] indicates that by May 2013, Verizon had the most IPv6 traffic (30.68 per cent) in its network, due to the offering of IPv6 service with 4G to its customers. Swisscom had begun offering IPv6 service (14.88 per cent), making Switzerland the number one IPv6 country in the world. It crossed the 10 per cent penetration threshold before Romania (8.7 per cent), France (5.1 per cent) and Luxembourg (4.9 per cent). The Belgian ISP VOO had just launched IPv6 service, propelling Belgium to a healthy 2.8 per cent penetration rate by ISPs.

1.2.3 Worldwide Vendor Readiness

In 2004, the IPv6 Forum[14] introduced a logo programme dubbed "IPv6 Ready."[15] The goal was to create a worldwide interoperability scheme to urge vendors to accelerate adoption of IPv6 based on real, interoperable compliance testing and validation. Due to the complexity and worldwide scope of this task, a committee was formed to represent the breadth of interoperability labs from around the world: the Japanese TAHI[16] team; the US-based UNH-IOL lab;[17] the European-based IRISA/ETSI[18]; The Taiwan, Republic of China TWINIC[19]; and the Chinese BII lab.[20] Their task was to collectively design the interoperability specifications and test scripts for worldwide execution. The adoption of this programme was an immediate success and vendors from around the world took the tests to check on their products (See Figure 9).

Figure 8: List of Fixed and Mobile operators showing IPv6 traffic

Network operator measurements, 22nd May 2013 (notes)

Show 10 entries Search:

Participating Network	ASN(s)	IPv6 deployment
ATT	6389, 7018, 7132	9.26%
KDDI	2516	8.64%
Free	12322	18.11%
Verizon Wireless	6167, 22394	30.68%
RCS & RDS	8708	16.72%
Comcast	7015, 7016, 7725, 7922, 11025, 13367, 13385, 20214, 21508, 22258, 33287, 33489, 33490, 33491, 33650, 33651, 33652, 33653, 33654, 33655, 33656, 33657, 33659, 33660, 33661, 33662, 33664, 33665, 33666, 33667, 33668, 36733	1.69%
Deutsche Telekom AG	3320	3.65%
Swisscom	3303	14.88%
SoftBank BB	17676	0.93%
VOO	12392	22.78%

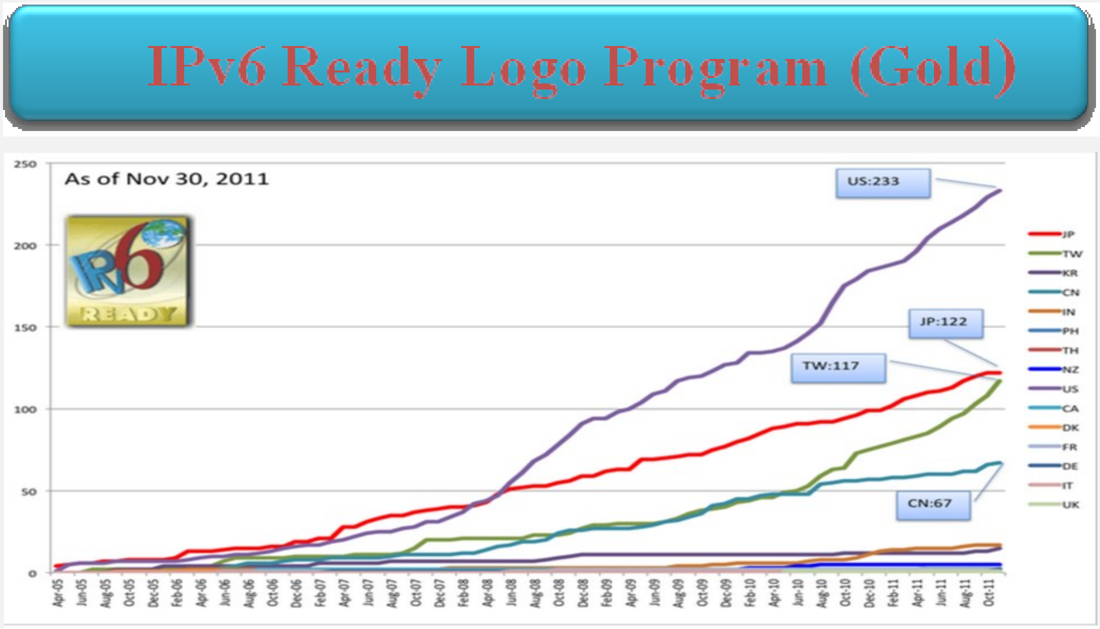
Showing 1 to 10 of 110 entries

First Previous 1 2 3 4 5 Next Last

Source: SiXXs.net

[13] http://www.worldipv6launch.org/measurements/
[14] http://www.ipv6forum.com/
[15] www.ipv6ready.org
[16] http://tahi.org/
[17] https://www.iol.unh.edu/services/testing/ipv6/
[18] http://www.irisa.fr/tipi/wiki/doku.php
[19] http://interop.ipv6.org.tw/
[20] http://www.biigroup.com/

Figure 9: IPv6 Ready Products from around the world



Source: IPV6 Forum

A large number of Asian vendors have adopted IPv6 in their routers and security solutions (IPsec). An important development to note is the entry of a large number of new vendors from China and Taiwan, Republic of China, joining the classically large participation of U.S. and Japanese vendors. Remarkably, there is almost a non-existence of European vendors. The number of products certified as IPv6 ready is spread among vendors primarily from among the following countries:

- United States: 233
- Japan: 122
- Taiwan, Republic of China: 117
- China: 67

Despite the marked progress in adopting IPv6 in these and other jurisdictions, use of the updated protocol remains low in relative terms, particularly when highlighted by the depletion of IPv4 addresses and the demand for new addresses. IPv6 adoption has not reached a critical mass where it can either alleviate IPv4 depletion significantly or improve the accessibility of Internet content and applications. What is needed is definition of the business case for IPv6, in order to accelerate sustainable adoption.

1.3 Building the Business Case for IPv6 Adoption

Unfortunately, defining the business case for IPv6 has been a rather challenging task. IPv6 stands ready to revitalize the growth and use of networking and the Internet as a platform for commerce, education, entertainment and general information sharing. However, at the end of the day, it is still seen as just communication “plumbing.” The market has long looked to IPv6 to deliver the next “killer applications” when, in reality, IPv6 is just a tool, albeit a critical one, in the development of new applications and network-based services. This reality, combined with most businesses’ short-term perspective on return-on-investment (ROI) and quarterly earnings, have created a reluctance to invest in upgrading Internet infrastructure to IPv6, most notably in North America and Europe.

Another impediment to IPv6 adoption has been one of the Internet IPv6 community's own making: extolling the virtues of IPv6 primarily from a technical perspective. While IPv6 offers a number of technological advancements, such as a larger address space, auto-configuration, a more robust security model for the peer-to-peer environment, and better mobility support, these features have been offered in a technology vacuum that has not resonated with big business. Both business and government leaders are concerned about how problems are resolved, how revenue is generated, or how to build efficiencies and cost savings into their organization. IPv6 certainly has the ability to help deliver these scenarios, but the focus of the story needs to be on the solution – not the technology that helps deliver that solution.

The Internet IPv6 community may need to motivate industry by developing appealing and compelling business-case justifications that focus on solutions built with and upon IPv6. To that end, IPv6 should be placed in context as a solutions tool and a foundation for innovation. In short, the discussion should be about IPv6 as a key to greater business or organizational success, not as a mythical quest for its own sake.

1.3.1 IPv6 as a Solutions Tool

Organizations utilize information technology every day to solve business problems. The adoption of networking technologies to facilitate communications, conduct financial transactions and or exchange information has been quite successful in boosting productivity and operational efficiency. But there is growing evidence that these gains have been pushed to their limits with current technology. Ignoring for a moment the issue of impending IPv4 address exhaustion, the limited volume of addresses has short-changed technology advancements in areas like "any-casting," multicasting, or peer-to-peer exchanges. Most advanced network support features like security and quality of service were afterthoughts – not part of the original design of IP. As a consequence, the standards bodies and industry have provided solutions that extended the capabilities of the network, but also drastically increased the complexity of the network and created additional problems.

Today, organizations are finding it increasingly more difficult to deploy new, cost-effective IT solutions that are simple to support.

As a simple example, let's examine a Business to Business (B2B) relationship between an organization and its partners. Each organization must participate in business processes. This requires great coordination, extra equipment, and constant management. And this represents just one of hundreds of ways IPv6 can be used to solve "real world" problems that add value to the organization AND improve return-on-investment.

1.3.2 IPv6 as a Foundation for Innovation

IPv6 has several advantages over its predecessor, including a larger and more diverse address space, built-in scalability, and the power to support a more robust end-to-end (i.e., without NAT) security paradigm. As such, it serves as a powerful foundation for the creation of new and improved, net-centric sets of products and services. This list is by no means exhaustive, but it does highlight a number of very promising technologies for which IPv6 can provide an important boost for further expansion:

- *Ubiquitous Communications* – with increases in the number of mobile phone users, the expansion of Internet-related services through cellular networks, and an increasing number of connection mediums (UMTS, LTE, WiFi, Wimax, UWB, etc.), there is a need for a uniform communications protocol that supports mobility and can handle a large number of devices.

- *Voice over Internet Protocol (VoIP)/Multimedia Services* – VoIP has been making excellent progress from a technology-adoption perspective. A move from ITU-T Recommendation H.323 to Session Initiation Protocol (SIP) has enabled more robust VoIP implementations with a greater level of simplicity and expandability.

- *Social Networks* – People interact. But the form in which they do this has changed drastically over the years – from written letters, to phone calls, to e-mails, to SMS and IM messages. That evolution continues today. The ability to transfer photos, conduct conversations in private Peer to Peer (P2P) transfers, display personal information on the Internet, find like-minded communities, or play interactive games requires an Internet that is flexible, supports ad-hoc connections, and can be secured. IPv6, with its auto-configuration capabilities and support for IPsec at the IP stack layer, will be a critical tool to enable this environment.

- *Sensor Networks* – Sensor networks are a new concept. They can be found in manufacturing equipment, heavy machinery, security systems, and heating, ventilation, and air conditioning systems. Sensors are building blocks for integrating all of those proprietary systems onto one communications network, which then must be protected through security features. IPv6 provides technical improvements to achieve this more readily.

- *Product Tethering/Communities of Interest* - Manufactures love to have relationships with their products once they leave the factory. But the current reality is that most consumer electronic goods producers have little, if any, interaction with the end users of their products. In a world where all things can be connected, the opportunities to monitor and troubleshoot performance, update software and market new, value-added services to existing customers are almost endless.

1.3.3 Making the Business Case to Vendors

A recent study released by Ericsson predicts that 50 billion devices will be connected to the Internet by 2020, dwarfing the scale and scope of the current Internet and the mobile worlds. Mobility will play a greater role in the future, as the enabler of the Internet of Things.

For its part, Cisco has recently released a study on the "Internet of Everything," making the business case for a USD14.4 trillion market, by 2022, for networking basically everything.

Figure 10: Cisco business case for Networking with IPv6.

Source: Cisco 2013

So the opportunity exists with IPv6 for those willing to consider the protocol as a tool for defining solutions to existing business problems, and as a platform for innovation for next-generation products and services. How, then, can industry continue the groundswell for IPv6 integration?

First, there is still a need to understand IPv6 and its features, and most importantly, how those features map to potential networking problems. Although the IPv6 Community has provided all manner of educational opportunities for industry, there remains a deficit in coordinated efforts to increase IPv6 awareness at three levels:

- Strategic planning at the corporate level,
- Improved return-on-investment (RoI), and
- Technical knowledge at a tactical level.

To achieve a measure of success, the IPv6 Community needs to follow this basic strategy:

- ✓ **Generate an interest in business solutions at the CEO/CTO level**. Stories about the virtues of auto-configuration and the power of IPsec EH should be left at the door to the boardroom. Solutions that fix business problems or build competitive advantages are more compelling. The fact that IPv6 is the glue that makes those solutions function should be icing, not the cake. Once the business solutions are "sold," IPv6 will become part of the long term strategies of these organizations.

- ✓ **Create a framework for return on investment to justify sound decision-making**. Providing executives with the framework for an ROI improvement model will expedite this process.

- ✓ **Solutions sold at the CEO/COO level will need competent engineering and architecture to deliver**. This requires formalized education and knowledge transfer, and CEO/COO level of executives needs to understand and support this process.

1.4 Addressing the Cost of IPv6 Transition

One of the key hurdles to formulating a business case for IPv6 adoption is the perception of costs versus benefits. The potential costs associated with deploying IPv6 consist of a mixture of hardware, software, labor, and miscellaneous costs. The transition to IPv6 is not analogous to turning on a light switch; instead, many different paths can be taken to varying levels of IPv6 deployment. Each organization or user throughout the Internet supply chain will incur some costs to transition to IPv6, primarily in the form of labour and capital expenditures, which are required to integrate IPv6 capabilities into existing networks.

Expenditures and support activities will vary greatly across and within stakeholder groups depending on their existing infrastructure and IPv6-related needs. By and large, ISPs offering services to large groups of customers will likely incur the largest transition costs per organization, while independent users will bear little, if any, costs.

1.4.1 Breaking Down the Cost Factors

Factors influencing these costs include the:

- Type of Internet use or type of service being offered by each organization;
- Transition mechanism(s) that the organization intends to implement (e.g., tunneling, dual-stack, translation, or a combination);
- Organization-specific pattern of infrastructure, which comprises servers, routers, firewalls, billing systems, and standard and customized network-enabled software applications;
- Level of security required during the transition; and
- Timing of the transition.

Table 1-1 provides a list of relative costs that may be incurred by stakeholder group and gives a percentage breakdown by cost category.

Table 1-1: Overview of Relative IPv6 Costs

		Transition Cost Break-down[a]				
Stake-holders	***Relative Cost***	Hard-Ware (HW)	Soft-ware (SW)	Labor	***Timing Issues***	***Key Factors in Bearing Costs***
Hardware Vendors	Low[b]	10%	10%	80%	Currently most are providing IPv6 capabilities	Rolling in IPv6 as a standard R&D expense; international interest and future profits incentivize investments
Software Vendors	Low / Medium[c]	10%	10%	80%	Currently some are providing IPv6 capabilities	Interoperability issues could increase costs
Internet Users (large)	Medium	10%	20%	70%	Very few currently using IPv6; HW and SW will become capable as routine upgrade; enabling cost should decrease over time	Users will wait for significantly lower enablement costs or (more probably) a killer application requiring IPv6 for end-to-end functionality before enabling
Internet Users (small)	Low	30%	40%	30%	Availability and adoption schedules	With little money to spare, these users must see a clear return on investment (ROI)
Internet Service Providers (ISPs)	High[d]	15%	15%	70%	Very few offering IPv6 service; no demand currently; very high cost currently to upgrade major capabilities	ISPs see low or nonexistent ROI, high costs, and high risk

Source: RTI estimates based on RFC responses, discussions with industry stakeholders, and an extensive literature review.

[a] These costs are estimates based on conversations with numerous stakeholders and industry experts. Several assumptions underlie them. First, it is assumed that IPv6 is not enabled (or "turned on") or included in products and no IPv6 service is offered until it makes business sense for each stakeholder group. Hardware and software costs are one-time costs. Labour costs could continue for as long as the transition period and possibly longer.

[b] For hardware vendors producing high-volume parts that require changes to application-specific integrated circuits (ASIC), the costs could be very high and would not be offered until the market is willing to pay.

[c] Software developers of operating systems will incur a relatively low cost; however, application developers will incur greater relative costs, designated as medium.

[d] The relative cost for ISPs is particularly high if the ISP manages equipment at user sites, because premises equipment is more costly to manage and maintain.

Table 1-2 provides an item-by-item list of the costs to deploy IPv6 by stakeholder group. This is a relative comparison of costs and should not be interpreted as representing the actual size of each stakeholder group's cost. Further, small Internet users (e.g., home and small businesses) are not captured in Table 1-2 because they will likely incur virtually no costs. Small Internet users will receive software upgrades (e.g., operating systems and email software) as new versions are purchased, that their IPv4-only hardware (e.g., routers and modems) will be replaced over time as part of normal upgrade expenditures, and that IPv6 will eventually be provided at no additional cost.

Table 1-2: Relative Costs of IPv6 Deployment by Stakeholder Group [a]

Item	*Hardware, Software, Service Providers*	*ISPs*	*Enterprise Users*
Hardware			
Replace interfacing cards	H		M
Replace routing/forwarding engine(s) [b]	M	M	
Replace chassis (if line cards will not fit)		M	M
Replace firewall		M	M
Software			
Upgrade network monitoring/management software		H	H
Upgrade operating system		M	H
Upgrade applications [c]			
• Servers (Web, DNS, file transfer protocol (FTP), mail, music, video. etc.)			L
• Enterprise resource planning software (e.g., PeopleSoft, Oracle, SAP, etc.)			H
• Other organization-specific, network-enabled applications			H
Labor			
R & D	M	L	
Train networking/IT employees	H	H	H
Design IPv6 transition strategy and a network vision	M	H	M/H
Implement transition:			
• Install and configure any new hardware	L	H	H
• Configure transition technique (e.g., tunneling, dual-stack, NAT-port address translation	M	M	M
• Upgrade software (see Software section above)		L/M	L/M
• Extensive test before "going live" with IPv6 services		H	H
Maintain new system		M/H	M/H
Other			
IPv6 address blocks			L
Lost employee productivity [d]			
Security intrusions [e]		H	H
Foreign activities		M	M
Interoperability issues		M/H	M/H

Source: RTI estimates based on RFC responses, discussions with industry stakeholders, and a literature review.

[a] The relative designation (L = low, M = medium, and H = high) indicates the estimated level of cost to members of each stakeholder group. These costs are not incremental, but reflect differences in costs between stakeholder groups. The blank spaces indicate that a particular cost category does not affect all stakeholder groups.
[b] The "brains" of the router are commonly found on line cards.
[c] Portions of the first column, principally relating to software upgrades by hardware, software, service providers, is blank because the costs of these activities are reflected in the corresponding categories in the "Enterprise Users" column.
[d] Because of unexpected down-time during transition period.
[e] Based on unfamiliar threats.

1.4.2 Breaking Down Costs by Stakeholder Group

This section takes a closer look at costs by breaking them down according to the various entities that may incur them.

1.4.2.1 Hardware, Software and Service Vendors

Vendors that provide products and services include: networking hardware companies, such as router and firewall manufacturers; networking software companies, including operating system and database management application developers; and service vendors, including companies that offer training, service and support. Obviously, these companies will need to integrate IPv6 capabilities into their products and services, if they have not already done so, in order for IPv6 capabilities to be available to end users and ISPs. Once IPv6-capable products are installed in user networks and their labour forces have been trained, ISPs will be enabled to offer IPv6 service, and users will be able to purchase IPv6-enabled devices and applications. Many companies in this category are already developing, and some are even selling, IPv6-capable products and services largely because of demand outside the United States (e.g., Asia).

The majority of the costs being incurred by hardware and software developers appear to include labour-intensive research and development (R&D) and training costs. These costs, however, have not been large enough to deter most of those companies from beginning to develop IPv6 products and capabilities. R&D activity has generally been conducted in small intra-company groups dedicated to developing IPv6-capable products with, to date, limited, small-scale interoperability testing with other hardware and software makers. Based on industry experience with the early deployments of IPv4 equipment, large-scale deployment may bring to light additional interoperability issues.

1.4.2.2 ISPs

ISPs comprise two main categories: (1) companies (e.g., AOL, Earthlink, and myriad smaller companies) that provide Internet access service to corporate, governmental, nonprofit, and independent Internet users and (2) companies that own and maintain the backbone hardware and software of the Internet (e.g., Verizon, Sprint, AT&T). The categories overlap because companies that own the backbone Internet infrastructure (i.e., Category 2 companies) often provide Internet access service to customers, either directly or through a subsidiary. Today, most backbone transport networks have already upgraded their major routers and routing software to accommodate IPv6. As a result, providing IPv6 connectivity to customers who do not require additional equipment, service, or support will be relatively low-cost. Consequently, this analysis focuses on those ISPs in Category 1 that have large customer service provision capabilities.

These ISPs will likely incur relatively high transition costs as they enable IPv6-capable hardware and software and work through system interoperability problems. To date, however, little demand has appeared in the United States for IPv6 services or applications. As a result, given the costs to reconfigure networks, experts and industry stakeholders agree that U.S. ISPs are currently not positioned to realize a positive return on investment from large-scale offerings of IPv6 service.

For Category 1 ISPs to offer a limited amount of IPv6 service, they would need to integrate some transition mechanism(s), such as tunneling. The costs of doing so will probably not be large. If several routers and service provisioning software are upgraded and limited testing is performed, IPv6 service could be provided to a limited number of Internet users today at minimal additional cost.

1.4.2.3 Internet Users

Costs to upgrade to IPv6 for Internet users vary greatly. Independent Internet users, including residential users and small and medium enterprises (SMEs) that do not operate servers or any major database software, will need to upgrade only networking software (e.g., operating systems), one or more small routers, and any existing firewalls to gain IPv6 capabilities. This cost will be relatively minimal if the hardware and software are acquired through routine upgrades.

Larger organizations, such as corporations, government agencies, and nonprofits, will incur considerably more costs than home or small network users. The relative level of these costs, however, will depend on existing network infrastructure and administrative policies across organizations, the extent to which a specific organization wants to operate IPv6 applications, and whether it intends to connect to other organizations using IPv6.

The magnitude of the transition costs is still uncertain because only a few test beds and universities have made large-scale transitions. According to officials at Internet2,[21] the time and effort needed to transition their backbone to IPv6 was minimal, and no significant system problems have been encountered. However, Internet2 indicated that their experimental system was implemented and maintained by leading industry experts. It is unclear what issues might arise from implementation by less-experienced staff. If normal upgrade cycles are assumed to provide IPv6 capabilities, transition costs will be limited to training and some reconfiguration.

1.4.3 Breaking Down the Costs by Type

Internet users, as a whole, constitute the largest stakeholder group. The robustness and diversity within this group demands a more detailed explanation of costs broken out by hardware, software, labour, and other cost categories.

1.4.3.1 Hardware Costs

Depending on individual networks and the level of IPv6 use, some hardware units can become IPv6-capable via software upgrades. However, to realize the full benefits of IPv6, most IPv4-based network hardware will need to be upgraded with IPv6 capabilities. Specifically, high-end routers, switches, memory, and firewalls all will need to be upgraded to provide the memory and processing needed to enable large scale IPv6 use within a network at an acceptable level of performance. It is generally agreed that to reduce hardware costs, all or the majority of hardware should be upgraded to have IPv6 capabilities as part of the normal upgrade cycle (generally occurring every three to five years for most routers and servers, but potentially longer for other hardware such as mainframes). At that time, IPv6 capabilities should be available and included in standard hardware versions. In the

[21] Internet2 (a US Research network: http://www.internet2.edu/)

short term, replacement of some forwarding devices and software could be used to set up small-scale IPv6 networks.

1.4.3.2 Software Costs

Significant software upgrades will be necessary for IPv6 use; however, similar to hardware costs, many of these costs will be negligible if IPv6 capabilities are part of the routine requirements in periodic software upgrades. Software upgrades include server software, server and desktop operating systems, business-to-business (B2B) software, networked database software, network administration tools, and any other organization-specific network-enabled applications. Currently, the main software costs that user organizations envision pertain to element management, network management, and operations support systems that are often network-specific and will need revised software coding to adjust for IPv6. Given the anticipated growth in IPv6-capable software, it is likely that if Internet users upgrade their commercial application software in three or four years, they will acquire IPv6 capabilities. However, they will still need to upgrade their company-specific software.

1.4.3.3 Labour Costs

According to experts, training costs are likely to be one of the most significant upgrade costs, although most view it as a one-time cost that could be spread out over several years. The magnitude of these training costs will, of course, depend on existing staff's familiarity and facility with IPv6. On a daily basis, the change in operating procedure for IPv6 will be minimal. Most network staff, however, will need some understanding of the required network infrastructure changes and how they might affect security or interoperability. The North American IPv6 Task Force[22] notes that the relative programming skills of software engineers at a particular company could substantially affect upgrade costs. A company with more skillful programmers might have to hire one additional employee, while another might need three or four, during a transition period that could last five or more years. Additionally, increased network maintenance costs following IPv6 implementation could be more pronounced, depending on the relative level of IT staff skills and technical understanding. Similarly, training costs should be minimal for large organizations with existing IPv6 expertise (e.g., universities).

1.4.4 Bridging the IPv6 Chasm

As stated at the beginning of Section 1.3, the business case has been the Achilles' heel of IPv6. The focus for many businesses in the Internet and telecom sectors is, and always has been, squarely on squeezing maximum revenues out of current infrastructure. Since IPv6 is viewed primarily as a long-term plumbing problem, many organizations and businesses are reluctant to tear open the walls, even if IPv6 represents the best investment and solution. Unlike the Year 2000 bug (Y2K), there is no 'big bang' date at which IPv4 address space will run out; thus there is no perceived urgency in transitioning to IPv6 deployment while ISPs can still take revenue from IPv4 deployment. The choice between an immediate deployment and a gradual technology refresh is fairly obvious depending on the size of the address space allocated to the region in question.

The deployment of IPv6 is a challenge that can be called the "IPv6 Chasm." While the technology is maturing, ISPs and enterprise customers are currently still stuck between the research and validation phase and full-scale deployment. The lack of IPv4 address space in Asia has accelerated the deployment in that region. Until recently, Europe and the United States had enough address space to take their time, but in the last 12 months, that has changed, and those regions have now begun to see the urgency as well.

[22] Nav6TF (North American Ipv6 Task Force: www.nav6tf.org)

Section 2 will explore the ability of inter-governmental organizations, multi-stakeholder groups and governments to help set a policy framework to accelerate IPv6 deployment, building a potential bridge across the chasm.

2 *Policy and Political Goodwill*

Over the past decade, IPv6 has enjoyed remarkable support from governments and industry standards bodies. Government policy-makers have established plans and promoted policies to help ensure that there is sufficient awareness of the need to transition to IPv6, and regulators have played a role by establishing the frameworks for network compatibility and interconnection, among other things. Industry groups have established the technical standards for IPv6 and also have elevated the level of emphasis on implementation. All of this has helped cement the concept that IPv6 is simply not a passing technology or "trend," but truly the foundation for the next-generation Internet. The list below identifies just a few examples of how governments, including regulators, and industry bodies have helped to promote IPv6 usage:

- 3GPP[23] mandated exclusive use of IPv6 for IMS (IP Multimedia Subsystems) back in May 2000;
- Large mobile operators such as Verizon and T-Mobile have introduced IPv6 in 4G -LTE (Long Term Evolution) service;
- The United States Department of Defense mandated the integration of IPv6 in June 2003, to be ready by 2008;
- In June 2005, the U.S. White House Office of Management (OMB) set a milestone for federal agencies to use IPv6 by June 2008;
- The European Space Agency has declared its support for IPv6 in testing its networks;
- The Japanese ITS project and the European Car-2-Car consortium[24] recommended exclusive use of IPv6 for its future car2car applications;
- The Chinese government created and financially supports CNGI, an IPv6 backbone network designed to be the core of China's Internet infrastructure; and
- The European Committee for Electrotechnical Standardization (CENELEC) has opted for IPv6 for its Smart Home concept.[25]

These represent just a few of the numerous examples in which IPv6 has garnered major support from a government body or an industry consortium. In the case of governments, aggressive IPv6 adoption curves have pushed industry, particularly those vendors supporting or interacting with the government, to work toward IPv6 adoption themselves. So, winning the political endorsement and goodwill can be a plausible and viable route to accelerate acceptance and adoption of IPv6. This section explores the interwoven roles that can be played in promoting IPv6 adoption by:

- Inter-governmental and international non-governmental organizations,
- Standards bodies and advocacy groups, and
- Government ministers and regulators.

The role of the government in the adoption of the new Internet protocol is a continuation of the adoption of the Internet as a whole. Governments have designed Internet promotion plans in the past for e-Government, e-

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[23] 3GPP: www.3gpp.org
[24] Car 2 Car Consortium: http://www.car-to-car.org
[25] http://ar.groups.yahoo.com/group/IEEEAR-SA/message/5

Commerce and e-Health, enabling use of the Internet as a ubiquitous service platform. The broadband Internet policies promoted are the next level of extending better service to the users.

2.1 Global IPv6 Initiatives

Intergovernmental organizations have a role to play in developing a global framework and consensus for adoption of IPv6. This section examines that role and the activities that organizations such as ITU already have undertaken to foster IPv6 adoption.

2.1.1 IPv6 and the Role of the ITU

The International Telecommunication Union (ITU) has taken action, in various forums, to encourage capacity-building for deployment of IPv6 and the seamless transition from IPv4 to IPv6. Recent actions include:

- **World Telecommunication Standardization Assembly (WTSA) Resolution 64** – Revised at WTSA-12, this resolution urges continued cooperation between ITU-T and ITU-D to assist developing countries with IPv6 transition efforts, including through a website and by assisting in establishing test beds and training activities;
- **ITU Plenipotentiary Resolution 180** – Adopted in 2010 in Guadalajara, Mexico, this resolution urges efforts to facilitate the transition from IPv4 to IPv6; and
- **ITU Council** – The Council established an IPv6 working group in 2009.
- World Telecommunication Development Conference, Resolution 63 -- Adopted in Hyderabad in 2010, the resolution encourages the deployment of IPv6 in the developing countries and requests that the Telecommunication Development Bureau (BDT) develop guidelines for migration to, and deployment of IPv6. BDT also was asked to collaborate closely with relevant entities to provide human capacity-development, training and other assistance.

Most recently, two related opinions were considered and adopted at the **World Telecommunication Policy Forum (WTPF)** held 14-16 May 2013 in Geneva. Opinion 3 ("Supporting Capacity Building for the Deployment of IPv6") called for "every effort" to be made to "encourage and facilitate" the IPv6 transition. More specifically, it indicated that if remaining IPv4 addresses are exchanged among RIRs, these transfers should be based on a need for new addresses and should be equitable among all of the RIRs. Turning to sector members, Opinion 3 urged companies to deploy equipment with IPv6 capabilities as soon as possible.

Similarly, WTPF-13 Opinion 4 ("In Support of IPv6 Adoption and Transition from IPv4") urged governments to take "appropriate measures to encourage, facilitate and support the fastest possible adoption and migration to IPv6." Meanwhile, it noted that IPv4 addresses would still be needed for some time and recommended efforts to ensure "optimal use" of those addresses. Plans and policies should be in place to accommodate new ISP market entrants that need access to IPv4 addresses at affordable prices. Both opinions took note of a trend toward marketing IPv4 addresses for trading purposes, and Opinion 4 specifically indicated that such transfers should be reported to the relevant RIRs.

Meanwhile, ITU-T's Study Group 16 conducted a transcontinental IPTV experiment over IPv6 infrastructure in February 2012. After this experiment, and upon requests from ITU membership, a global IPTV IPv6 test bed was set up among several ITU members, connecting ITU headquarters and countries such as Japan and Singapore. The purpose was to test interoperability of IPTV equipment and services, as well as other IPv6-based technologies. Another goal was to promote IPv6 capability deployment in developing countries. This test bed was updated for a second transcontinental IPTV experiment showcased in February 2013. BDT is involved in many activities related to IPv6, under PP10 Res. 180, for the adoption of IPv6.

Through these and other actions, the ITU can be seen in a largely supportive role, both in expressing the policy consensus of its members and in facilitating real-world pilot projects. ITU has sought to advise governments and encourage industry to move forward with the IPv6 transition in a seamless and timely manner, but it has not attempted to mandate any particular transition pathway. This reflects the reality of the Internet addressing system as a decentralized and largely need-driven one.

2.1.2 The Organization for Economic Cooperation and Development (OECD)

The OECD has been instrumental in researching and measuring the extent of deployment of IPv6 technology. In a 2010 report, [26] the OECD noted the challenge for expanding the Internet without completing the transition to IPv6. This challenge is partly technical:

> For technical reasons, IPv6 is not directly backwards compatible with IPv4 and consequently, the technical transition from IPv4 to IPv6 is complex. If a device can implement *both* IPv4 and IPv6 network layer stacks, the "dual-stack" transition mechanism enables the co-existence of IPv4 and IPv6. For *isolated* IPv6 devices to communicate with one another, IPv6 over IPv4 „tunneling‟ mechanisms can be set up. Finally, for *IPv6-only* devices to communicate with IPv4-only devices, an intermediate device must "translate" between IPv4 and IPv6. All three mechanisms – dual-stack, „tunneling‟ and „translation‟ – require access to some quantity of IPv4 addresses.[27]

Moreover, the OECD report, which continued a series of previous reports on IPv6, noted that "adequate adoption of IPv6 cannot yet be demonstrated by the measurements explored in this report. In particular, IPv6 is not being deployed sufficiently rapidly to intercept the estimated IPv4 exhaustion date."[28] The report issued a clarion call for greater cooperation between government and industry and for increasing government commitments ti IPv6 deployment.

2.1.3 The Role of Standards Bodies and Multi-Stakeholder Groups

While ITU has adopted a stance of promoting and encouraging IPv6 transition (and frugal use of remaining IPv4 addresses), much of the technical work to ease the transition has been addressed by standards bodies and other "multi-stakeholder" groups. As with all elements of Internet governance, these groups have been instrumental in developing and implementing the technical standards needed for open and widespread adoption of IPv6.

The Internet address space is considered to be a primary function of Internet governance in many parts of the world, especially in the North American, Asia-Pacific and European regions where Internet early adoption drove a de-centralized, technically oriented and non-governmental approach. Because of this heritage, policy-makers in these regions often see the "multi-stakeholder model" that has typified Internet governance as the best means to rapidly engage industry and civil society in the development of technical standards. Proponents of the multi-stakeholder approach are often wary of efforts by governments and inter-governmental organizations (IGOs) to increase their influence over Internet governance, in general (including IPv4 and IPv6 transition issues).

For their part, some critics of the multi-stakeholder model argue that the existing groups have not managed to broaden access to include participation from developing countries and (to some extent) non-manufacturing interests. The result has been a global debate over how to balance the roles of multi-stakeholder groups with those of governments and IGOs. This debate likely will continue during this decade, even as the IPv6 transition continues under the current governance architecture.

Table 2-1 provides a representational listing of some of the major multi-stakeholder groups and standards bodies that have key roles in Internet addressing. Many of these groups are playing key roles in the IPv6 transition

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[26] See "Internet Addressing: Measuring Deployment of IPv6," OECD, April 2010 at http://www.oecd.org/internet/ieconomy/44953210.pdf

[27] Ibid, p. 6

[28] Ibid., p. 5.

process, often by working with governments and IGOs. The chart notes the general type of organization (i.e., whether its main role is to provide a forum for standards-setting, Internet governance or policy advocacy), and its role in the IPv6 transition process.

Table 2-1 Standards Bodies and Multi-Stakeholder Organizations

Name of Organization	Type of Organization	IPv6 Role and Activities
Standards Bodies		
European Telecommunications Standards Institute (ETSI)	Standardization Body	• Interoperability Testing • IPv6 Ready Logo Programme
The Internet Engineering Task Force (IETF)	Standards, Engineering	• Sole IP designer of IPv6
Internet Governance & Advocacy Groups		
International Chamber of Commerce (ICC)	Advocacy Group	• Repeated and consistent support for IPv6 transition • Identified measurements of IPv6 deployment.
Internet Corporation for Assigned Names and Numbers (ICANN)/ Internet Assigned Numbers Authority (IANA)	Internet Governance	• Added IPv6 addresses for 6 of the world's 13 root server networks.
Internet Governance Forum (IGF)	Advocacy, Policy Discussion	• Has held workshops to address IPv6 transition issues
Internet Society (ISOC)	Advocacy, Policy Discussion	• World IPv6 Day, 2011 • World IPv6 Launch Day, 2012
RIPE NCC	RIR[29] for Europe	• Portal IPv6 ActNow • High IPv6 allocation count
ARIN	RIR for North America	• Began aggressive rollout plan in 2007
APNIC	RIR for Asia	• Monitors and supports IPv6 deployment in the Asia-Pacific region
AFRINIC	RIR for Africa	• Offers IPv6 transition support, featuring training materials and test beds
LACNIC	RIR for Latin America and the Caribbean	• Maintains a portal in 3 languages (Spanish, Portuguese, English) as a one-stop IPv6 resource
European Network and Information Security Agency (ENISA)	Advocacy, Policy Discussion	• Center of Excellence for European States on network and information

[29] Regional Internet Registry

		security

2.2 The Role of National Governments and Regulators

Government policy-makers and regulators have not been passive in promoting efforts to build capacity, deploy infrastructure and urge the adoption of IPv6. Regulators have had a foundational role in ensuring that regulations governing licensing, interconnection and numbering resources are aligned with efforts to promote the transition to IPv6. Regulatory agencies have at times cited a need to maintain a "light-handed" or "light-touch" regulatory stance towards Internet addressing, emphasizing the development of regulations for a competitive and affordable Internet access market that would promote demand.[30] Governments have, however, taken some specific steps to promote awareness of the need to utilize IPv6 to expand Internet resources. Key elements of governmental action have included:

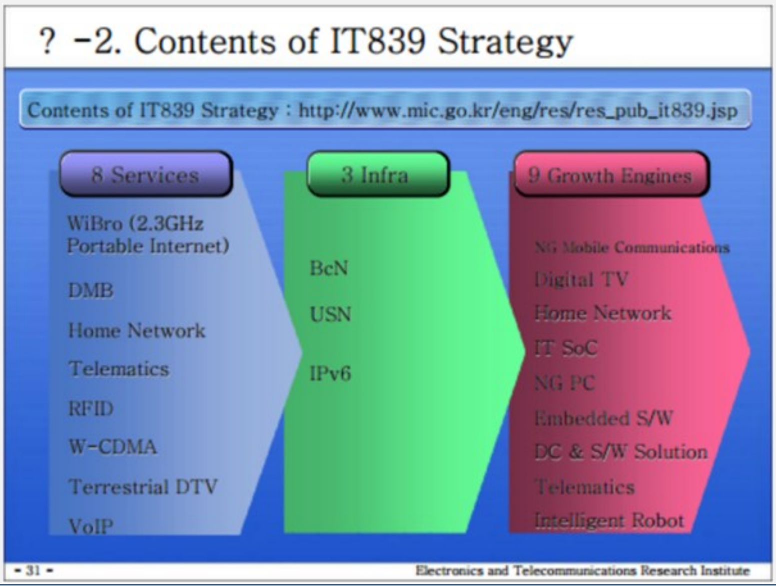
- Establishing or supporting national IPv6 transition task forces (often in conjunction with multi-stakeholder groups or RIRs);
- Establishing national "roadmaps" with benchmarks and timetables for IPv6 deployment;
- Mandating that government agencies adopt IPv6 technology for their networks, websites or services;
- Promoting the use of IPv6 in government-funded educational, science and research networks; and
- Promoting overall awareness of the transition through setting up websites, hosting workshops or forums, and setting up training programmes.

As a long-time tech leader in East Asia, Japan has sought to position itself as a model for planning in this area. The Japanese Government has designed its latest program around the concept of ubiquity called "u-Japan" (Ubiquitous Japan) as the 2010 ICT Society platform. The e-government component of this plan encourages government agencies to procure IPv6-enabled devices; the infrastructure of the Japanese government has been IPv6-ready since 2007. Similarly, the Republic of Korea has unveiled its new IT sector development strategy, dubbed "IT839," seeking to build on efforts in the previous decade to embed IPv6 in e-government services and the networks of the postal service, universities, schools, the defence ministry and local governments. Korea also has a nationwide IPv6 MPLS backbone (See Figure 11).

In some cases, governments are devoting large budget outlays to support their national roadmaps. For example, Taiwan, Republic of China, has announced a USD 1 billion budget for its "eTaiwan" programme, which entails a concerted joint effort between government and industry. The goal is to reach 6 million broadband users of IPv6 technology.

[30] See, for example, the consultation paper published by the Information and Communications Technology Authority (ICTA) of Mauritius, 17 March 2011, at http://www.icta.mu/documents/Consultation_IPv6.pdf

Figure 11: Elements of Republic of Korea's IT839 Strategy



Indonesia developed a comprehensive, phased national plan and roadmap, beginning in 2006. The first phase involved generating awareness of IPv6, establishing an implementation model that included a first-stage native IPv6 network, and developing a broad-based national policy. Meanwhile, Indonesia made a commitment to participate in global efforts to shape the development of IPv6, as well as policies on Internet governance and standards activities. Additional phases called for development of further infrastructure and training to accelerate the transition process to IPv6.

Regional approaches have proved to be helpful in several parts of the world. For example, some 29 countries and territories formed the Latin American and Caribbean IPv6 Task Force (LACIPv6TH) under the auspices of LACNIC. This regional task force has held forums on IPv6 transition in more than a dozen countries around Latin America and the Caribbean, from Mexico and the Netherlands Antilles down to Brazil and Uruguay. Among other things, the task force developed an IPv6 portal to assist as a data and information resources in the transition throughout the region.

The Arab region and Africa have also worked to share expertise on a regional basis. The Arab group formed an IPv6 Forum to spotlight individual countries' efforts:

- The United Arab Emirates has formulated and IPv6 roadmap and in March 2013 held two workshops to prepare the UAE and its Internet stakeholders for looming IPv4 depletion;
- The Egyptian Ministry of Communications and Information Technology formed a national IPv6 task force;
- The Moroccan regulator ANRT has commissioned an IPv6 study to define a roadmap and is discussing a calendar for IPv6 deployment with the country's main telecom operators;
- In Jordan, the IPv6 Forum chapter has held seminars with multiple stakeholders (including ISPs) to promote awareness and offer technical assistance;
- The Omani Telecommunications Regulatory Authority is taking the lead in promoting IPv6 transition, including by beginning to test implementation in conjunction with operators.

In Africa, the RIR, AFRINIC, has an aggressive training program that has trained some 450 engineers annually across the continent. The IPv6 address space and core network deployment has been particularly successful in South Africa, Kenya, Tanzania, Nigeria, Tunisia and Senegal.

These efforts in developing countries largely track the efforts in the early-adopting Internet countries of Europe and North America. The United States government's Federal IPv6 task force has worked with the National Institute of Science and Technology (NIST) to public several versions of a roadmap and recommendations, including 100 per cent enabling of public services with IPv6 and integration of IPv6 into agency Enterprise Architecture efforts, as well as capital planning and security processes. NIST has established a website to track the agencies' progress in meeting milestones. The European Commission, meanwhile, has spent more than EUR 100 million on research projects and awareness/outreach efforts, forming the European IPv6 task force for coordination. Individual member states have their own efforts, including:

- Spain – the GEN6 programme is developing pilot projects to integrate IPv6 into government operations and cross-border services to address emergency response or EU citizens' migration issues.
- Luxembourg – the Luxembourg IPv6 Council has defined a roadmap; the main telecom operator has followed through with offering IPv6 over fibre and published practical steps on implementation for other operators.
- Germany – the government has obtained a sizable IPv6 prefix from the RIR to completely enable its online citizen services infrastructure with IPv6.

2.3 Case Studies

This section contains case study examples of the approaches to IPv6 transition planned and implemented in several representative countries.

2.3.1 India's IPv6 Promotion Policy

The Telecom Regulations Authority of India (TRAI) has released a consultation paper on issues related to the transition from IPv4 to IPv6 in India[31]

The Telecommunications Regulatory Authority of India's (TRAI's) recommendations on accelerating growth of Internet and Broadband served as the basis for the National Broadband Policy 2004, issued by Government. To achieve targets of this policy, the Internet and Broadband connections would require large supply of IP addresses, which may not be easily available through the present version of Internet, i.e., IPv4. The next generation Internet protocol, i.e., IPv6 is seen as one solution for this, in addition, it is claiming to provide better security, QoS, Mobility support.

In the recommendations on Broadband, the need for further analysis and discussion on transition to IPv6 was recognized due to anticipated growth of Internet and Broadband connections. Meanwhile, the Government. of India has already constituted a group, called the IPv6 Implementation Group (IPIG), to speed up and facilitate the adoption of IPv6 in the country.

The Indian Department of Telecommunications (DoT) released the government's National IPv6 Deployment Roadmap in July 2010, updating it in 2013. The result is a set of "recommendations" (many of them are mandatory) for government entities, equipment manufacturers, content/applications providers and service providers. Government organizations are required to prepare a detailed plan for transition to dual stack IPv6 infrastructure by December 2017. All new IP-based services, including cloud computing or data centre services, should immediately support dual stack IPv6. Public interfaces of all government services should be able to support IPv6 by no later the 1 January 2015. Government procurements should shift to IPv6-ready equipment and networks with IPv6- supporting applications. Finally, government agencies will have to develop human resource (i.e.,

[31] TRA IPv6 Consutation paper: http://www.trai.gov.in/WriteReaddata/ConsultationPaper/Document/IPV6.pdf

training) programmes to integrate IPv6 knowledge over a period of one to three years, and IPv6 skills will be included in technical course curricula at schools and technical institutes around India.

Service providers will have a role to play in the country's IPv6 transition, as well. After 1 January 2014, all new enterprise customer connections (wireless and wireline) will have to be capable of carrying IPv6 traffic, either on dual-stack or native IPv6 network infrastructure. Service providers will be urged to advise and promote the switch-over to existing customers, as well. Meanwhile, the roadmap sets aggressive timelines for retail customers. All new wireline retail connections will have to be IPv6-capable after 30 June 2014. All new GSM or CDMA wireless connections will have to meet the same deadline, and all new wireless LTE connections will have to comply a year earlier. There will also be goals for transitioning existing wireline customers, culminating in the upgrade of all customer premises equipment by the end of 2017.

The target for new website content and applications to adopt IPv6 (at least dual stack) will be 30 June 2014, with even pre-existing content and apps converted by the following January. India's financial services industry (including banks and insurance companies) was to transition to IPv6 by no later the 30 June of this year (2013). All new registrations of the ".in" national domain would be IPv6 (dual stack) by the beginning of 2014, with full migration of the domain being completed by the middle of that year.

On the equipment side, all mobile phones, data card dongles and other mobile terminals sold for 2.5 G (GSM/CDMA) or higher technology will have to be sold with IPv6 capability (either dual stack or native) after 30 June 2014. And all wireline customer premises equipment sold after 1 January 2014 will have to meet the same criteria. Finally, all public cloud computing/data centre services should target adoption of IPv6 capabilities by the middle of 2014.

The Indian plan provides an example of aggressive government mandates and targets for IPv6 transition, extending across a broad swathe of the Indian Internet sector. It will be interesting to see if the strategy precipitates a "critical mass" of demand for IPv6 capability that, in turn, generates industry reaction to market solutions for the updated protocol.

2.3.2 Australia

Australia's IPv6 Forum Downunder,[32] in a range of activities coordinated by the IPv6 Special Interest Group of Internet Society Australia, has shifted the focus to business and implementation benefits flowing from adoption of IPv6. These activities have fostered a national discussion of IPv6 that has been accepted by the National ICT Industry Alliance[33].

In 2005, the Forum had taken the idea of promoting a national discussion of the business and transition processes for IPv6 to the National ICT Industry Alliance[34] (NICTIA). As a result, Australia began a process of IPv6 Summits, led by consortia of the leading Australian IT trade bodies and endorsed by global IPv6 Forum. Year by year, these summits have focused on awareness, business case and transition issues.

Now there are lead IPv6 adoption sectors in Australia, including research & education, defense and government. The largest high speed education network in Australia (the Australian Academic Research Network - AARNet) began implementation with a testbed network, and has now implemented native IPv6 transports and provides v4 to v6 transition mechanisms for its member and affiliates. The Australian Department of Defense has announced the adoption of IPv6 in a programme that will extend through 2013.

[32] www.ipv6forum.org.au
[33] www.nitcia.org.au
[34] www.nictia.org.au

More recently, the Australian Government Information Management Office (AGIMO) has announced a transition strategy for the whole Australian government with a target completion date of 2015.[35] AGIMO's role in the government's implementation of IPv6 includes developing the IPv6 Transition Strategy and Work Plan documents, monitoring and reporting on agencies' progress, knowledge sharing, and monitoring international trends. There are 110 agencies, as named in Australia's Financial Management and Accountability Act (FMA Act), rolling out IPv6 capabilities, including most of the major departments (Defence, Foreign Affairs and Trade, Human Services, Finance and Deregulation, etc.). But the scope also takes in more specialized agencies such as the organ/tissue donation authority and the sports anti-doping agency.

2.3.3 Canada[36]

The Government of Canada (GC) IPv6 adoption strategy consists of a phased approach to progressively enable IPv6, while continuing to support IPv4. The strategy begins at the perimeter of the GC network and moves progressively toward the centre of the network. It is a business-focused approach designed to minimize cost and risk. The strategy leverages SSC's enterprise network renewal initiative and the regular equipment and software refresh cycles.

Business partners and entrepreneurs from emerging economies who, in the future, may only have IPv6 Internet service will be able to access GC websites to do business and research. Canadian citizens travelling or living abroad and non-Canadians who may have access to IPv6 networks only will be able to access GC web services — for example, to access their personal income tax information through the Canada Revenue Agency or to apply for a student or work visa through Citizenship and Immigration Canada.

Canadian public servants will be able to:

- Access the GC network in Canada to perform their work duties when posted or travelling abroad in an IPv6-only region;
- Exchange electronic documents with business partners for goods crossing our borders, when these business partners are located in an IPv6-only region;
- Conduct GC business with other governments located in IPv6-only regions; and
- Access websites connected to IPv6 networks to do research;
- The GC IPv6 adoption strategy comprises three phases: Enabling Phase, Deployment Phase and Completion Phase.

Enabling Phase: The first phase is underway and is expected to be completed by the end of September 2013. The goal is to enable federal organizations to develop their individual plans for the adoption of IPv6. Actions planned for this phase include:

- Developing IPv6 architecture standards and technical requirements;
- Establishing governance bodies to oversee adoption, including a Steering Committee and a Community of Practice;
- Creating a change management strategy, including policies, training, and communications; and
- Enabling IPv6 connectivity for Internet-facing websites through a shared service.

[35] http://www.ipv6.org.au/summit/talks/JohnHillier_AGIMO_IPv6Summit12.pdf
[36] http://www.tbs-sct.gc.ca/it-ti/ipv6/ipv603-eng.asp

Deployment Phase: The second phase will focus on the IPv6 enablement of the principal GC externally-facing websites and is expected to be completed by the end of March 2015. Actions planned for this phase include:

- Enabling principal-existing GC Internet-facing websites to be accessible by IPv6 users;
- Requiring all new Internet-facing websites and applications put in place starting April 2015 to be IPv6-enabled; and
- Providing public servants transparent access to the public IPv6 Internet.

Completion Phase: The third phase will focus on expanding the IPv6 enablement of GC websites beyond the principal websites addressed in the Deployment Phase and, as necessary, this phase will focus on enabling IPv6 access to GC internal applications. This phase is expected to take a number of years to complete.

2.3.5 Saudi Arabia

The IPv6 Task Force Forum came as the outcome of the IPv6 Project that was introduced by the Communications and Information Technology Commission as part of the Internet Services Development Projects undertaken by the CITC[37]. The Commission sponsored the establishment of the Task Force that convened its first meeting on July 30, 2008. The IPv6 Strategy for Saudi Arabia identifies a set of milestones to be achieved within a phased time line via an action plan of initiatives categorized into two tracks: Infrastructure and Awareness. Meeting the milestones would facilitate the deployment and further penetration of IPv6 on a nationwide basis so as to eventually realize an IPv6 ready internet infrastructure in the Kingdom of Saudi Arabia.

The milestones and action plan initiatives were based on previous studies outcomes conducted by Devoteam as part of the IPv6 Sub-project. The studies assessed the IPv6 status quo and readiness of local stakeholders, extracted lessons from a comprehensive IPv6 benchmark study of eleven (11) countries and stated the status of IPv6 in relevant international bodies and organizations. The IPv6 Strategy for Saudi Arabia objectives are a set of high level goals to be achieved for the purpose of setting up the right environment to promote the deployment of IPv6 nationwide.

The identified objectives are:

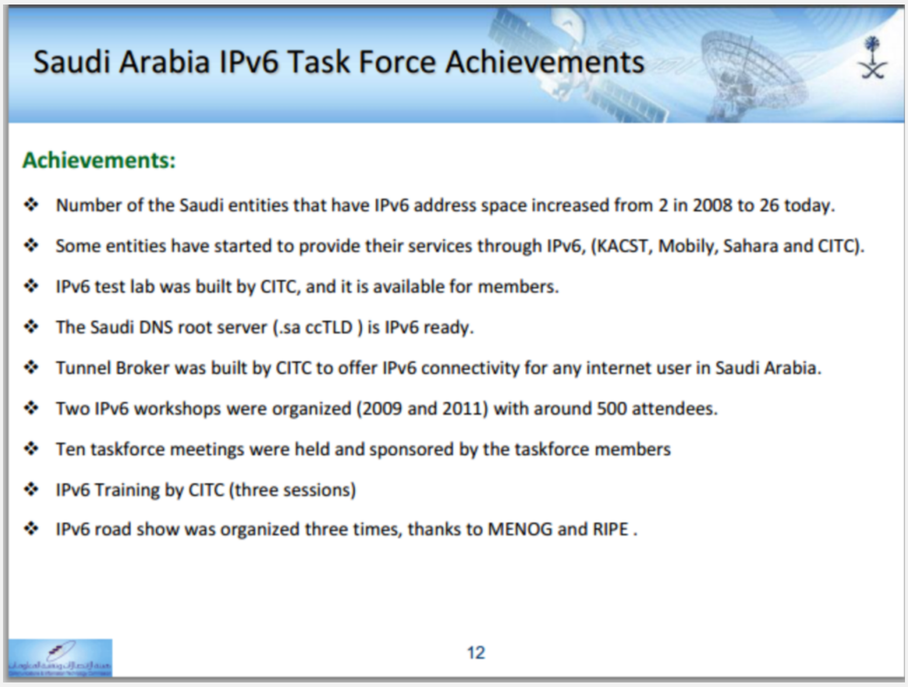
- Prepare for the IPv4 exhaustion by supporting IPv6 and ensure stability, business continuity and room for continued growth of the internet in Saudi Arabia;
- Ensure a smooth adoption of IPv6 by stakeholders so as to minimize risks;
- Raise overall IPv6 awareness nationwide by approaching stakeholders of both the public and private sectors highlighting the necessity to adopt IPv6

The IPv6 Strategy follows a two (2) track approach that addresses Infrastructure and Awareness aspects of IPv6 adoption. It has achieved tremendous progress in developing a roadmap deployment commitment for Saudi Arabia with most probably the most advanced IPv6 strategy in the Arab region[38]:

[37] http://www.ipv6.org.sa/about
[38] http://www.ipv6.sa/strategy%20

Figure 12 provides a summary of some of the objectives that the Saudi Arabian plan has met to date.

Figure 12: Some Results of the Saudi Arabian Strategy



2.4 Policy Recommendations

Despite the long-term commitment made evident by IGOs, industry/multi-stakeholder organizations and governments, all parties should consider whether the current activities and timelines are sufficient to alleviate the pressure on IPv4 addresses and spur transition to IPv6. Policy-makers and other stakeholders should consider following concrete recommendations as part of a call to action to enable IPv6:

- Create a CEO IPv6 Round Table with recognized industry leaders, focusing on industry adoption and urging the major players to include adopting IPv6 in their strategy plans. Select the target markets that are likely to be impacted first with the time-to-market in mind.
- Formulate a top-line strategic IPv6 Roadmap as a guideline.
- Increase support for the integration of IPv4 and IPv6 in fixed and mobile Broadband networks and services associated with the public sector:
  - The integration of IPv6 into e-government, e-learning and e-health services and applications will offer users greater reliability, enhanced security and privacy, and user friendliness.
  - IPv6 future-proofing should be considered in procurements, especially considering that the life cycles of public networks are often longer than commercial counterparts.
- Establish and launch IPv6 competence centres and educational programmes on IPv6 techniques, tools and applications, to significantly improve the quality of training on IPv6 at the professional level and create the required base of skills and knowledge.
  - A mixture of academic and commercial expertise should be drawn upon for the centres; university and academic sites may be among the early adopters and thus have key expertise.

  - A model has been created by the IPv6 Forum called the IPv6 Education Logo Program[39] which was adopted by the Cisco Learning Network.[40]

- Promote the adoption of IPv6 through awareness-raising campaigns and co-operative research activities, focusing on small and medium-size enterprises, ISPs and wireless service providers and operators.
- Organise IPv6 competition or contests similar to the German IPv6 Apps Contest[41] or the Singapore IPv6 Competition for Students.[42]
- Strengthen financial support for national and regional research networks, with a view to enhancing their integration into worldwide networks and increasing the operational experience with services and applications based on the use of IPv6.
- Provide the required incentives for development, trials and testing of native IPv6 products, tools, services and applications in economic sectors such as consumer electronics, telecommunications, IT equipment manufacturing, etc.
- Include IPv6 criteria in procurement guidelines for new equipment and applications for the public sector.
- Require universities to add IPv6 to the curricula for graduate degree programmes, in order to ensure the next generation of network engineers is IPv6 trained.
- Promote use of open source technologies for implementation of IPv6;[43] put URL as
- Support the existing national IPv6 task force, or create one, tasking it with:
  - The assessment of current status of IPv6 deployment, as well as with the formulation of guidelines and dissemination of best practises relating to the efficient transition towards IPv6.
  - Developing measures to align IPv6 integration schedules, favouring cohesive IPv6 deployment and ensuring that the nation can gain a competitive advantage in rolling out next-generation Internet networks and services.
  - Ensuring the active participation of national experts in the work of developing international standards and specifications on IPv6-related matters, working with groups such as ETSI, 3GPP, IETF, and ITU-T.
  - Drawing the attention of potential IPv6 systems or application developers to funding opportunities available at a national or regional level
  - Conducting an "IPv6 Launch Day" in the country (the global launch day went unnoticed by many ISPs, education and governments).
  - Establishing collaboration arrangements and working relationships with similar initiatives being launched in other world regions, with a view toward aligning IPv6 work.

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[39] http://www.ipv6forum.com/ipv6_education/
[40] Cisco Learning Network: https://learningnetwork.cisco.com/docs/DOC-10327
[41] German Ipv6 Contest: http://www.ipv6council.de/contest2011/vertikal_menu/winners/
[42] Singapore Ipv6 Contest: http://ipv6competition.com/index.html
[43] See http://www.bieringer.de/linux/IPv6

- Organize a high-level conference or summit aimed at raising IPv6 awareness, its development status and perspectives, its economic and policy dimensions, and the actions required to consolidate and harmonize international efforts.
- Encourage deployment of new security and firewall modes using IPv6, combined with the use of Public Key Infrastructure (PKI). Promote the development of secure networking applications and environments through trials, deployment and use of IPv6 IPsec protocols.

3 Conclusion

In a well-run relay race, the baton-holder is supposed to sprint into the exchange area, only slowing down as the second runner speeds up to grab the baton. It is a critical time, in which either runner might fail to make the exchange and drop the baton – and when confusion can translate into lost time. The IPv6 transition is at perhaps a similar critical juncture. IPv4 is nearing the end of its leg, IPv6 has not yet completely cranked up to speed, and for a time, they will both be running side-by-side.

Government policy-makers, regulators, international organizations, standards bodies, stakeholder groups, companies, ISPs and operators – all of them may be required to pass the baton to the new protocol. The complexity of the process, with its technological, economic and political dimensions, reflects the real diversity of Internet governance as it has evolved today. Ultimately, this diversity equals strength, but it may take some time to accelerate IPv6 adoption to reach the critical impetus for Internet expansion and technology improvements. As in a relay race, the transition indicates how well the multiple participants – all of the stakeholders involved in IPv6 – can work together. Undoubtedly, the process will provide lessons and pave the way for future improvements in the field of IP addressing and Internet governance in general. For now, the race is still being run, with the expansion of the global Internet as the ultimate prize.

[1] The paper was edited by John Alden, Vice-President, Spectrum Technologies.