Room document

Evolution of the Internet's Address Distribution Function, IPv6 and the Role of Government

9 March 2010

0. Executive Summary

Most forms of communications network require the concept of addresses to uniquely identify the network's end-points. Addresses have been variously considered as valueless tokens, ephemeral concepts, a protocol parameter, a public asset, and many other concepts besides. In the same vein, their means of distribution have been variously advocated to be a public function, a regulated function, a self-regulated activity, as well as many other forms of distribution. This document describes the address distribution function used for the Internet and identifies some of its important characteristics. The document also discusses the impact of IPv6 deployment on the address distribution function. The recommendations arising from this study are as follows:

1. **Any decisions that could impact the deployed Internet need to be based on bottom-up, transparent, consensus-seeking discussions open to all relevant experts and the broad set of stakeholders, seeking the best medium to long term solution for the global Internet (i.e., IP address distribution mechanisms should not be formulated in response to particular national, corporate, or other scenarios without due consideration of the network-wide implications of such mechanisms). For Internet addresses, these discussions are hosted by the Regional Internet Registries (RIRs) and rely on consensus-based technical contributions provided through the Internet Engineering Task Force (IETF).**
2. **Governments should encourage adoption of IPv6 in collaboration with the private sector. It is important that governments support the work of the appropriate organizations responsible for IPv6 address assignments and that they are involved in the processes of policy formation for IPv6 deployment.**
3. **Governments should act as catalysts and lead by example. e-Government services should be made available over IPv6 as soon as practically possible, and definitely before the end of 2012. Governments should not seek to regulate or replace work that is already underway.**

4. **The OECD could usefully remind member states of the recommendations related to creating a policy environment conducive to the timely deployment of IPv6, which they listed for Ministers at their Seoul meeting in 2007 (see Annex I).**

1. Internet Addresses

Internet number resources are Internet Protocol (IP) addresses and Autonomous System (AS) numbers. Anyone wanting to be on the Internet needs an IP address. Anyone wanting to participate in the Internet's routing system (as a network) needs an AS number. The Internet Assigned Numbers Authority (IANA) is responsible for global co-ordination of these resources. See Annex II for a description of the history of the number resource distribution function.

Addresses in the Internet are used to identify the point of attachment of an end-point (or "host") to the Internet. In the context of the public Internet, addresses are required to be unique, and are used by the protocol specification in the packet header to identify both the source and intended destination of the packet.

Network devices use the destination address to make switching decisions that pass packets closer to their intended destinations. The source address is used by a destination host when sending a response, and network devices may use the source address when informing a source that a packet cannot be delivered.

There are two distinct address families used by the Internet. Version 4 of the Internet Protocol uses an address defined as a unique value of a 32-bit field in the packet header (corresponding to the integer set from 0 to 4294967295). Version 6 of the Internet Protocol uses an address defined as a unique value of a 128-bit field in the packet header (corresponding to the integer set from 0 to roughly 3.4 x 10 ** 38). In both cases the address set is finite.

In attempting to characterize an address using a taxonomy of goods in economic terms, an address appears to closely match a common good, in that while the pool of available addresses remains abundant the consumption of an address is rivalrous, but non-excludable [1]. An address enables a device to be a connected end-point in the context of the Internet, but has no intrinsic value in any other context. Furthermore, without community support for the policies and processes adopted by the relevant Internet number resource distributors, the resources themselves are worthless – they're just numbers.

There are two functions that are necessarily shared, or viewed as common infrastructure service functions in the realm of address management. These are:

- the distribution (or allocation) function, to provide industry actors with addresses; and
- the registration (or registry) function to provide a public record of the current association of each allocated address with its current holder. This is a necessary function in order to satisfy the requirement that addresses on the public Internet be globally unique.

Furthermore, there is a set of common constraints that are applied in the interests of all actors. Most notable are constraints regarding the routeability of the outcome of the distribution function. The Internet's routing function is one that distributes information related to the location of each address and the topology of the network to all active network elements. The routing system itself is also of finite capacity, and this capacity is far smaller than the total number of unique addresses (for IPv4 or IPv6) for reasons of efficiency, scalability and cost [2]. For the network to remain viable in terms of the routing function, the manner of address distribution must encourage address aggregation to ensure that the number of routing entries remains within the limited finite capacity of the routing system. This aggregation capability is generally achieved by aligning allocations of address blocks to service providers, with the expectation that the provider will inform the routing system of the aggregated address blocks it is responsible for. Internet scalability is improved by aggregation, achieved by means of the RIRs' aggregation policies regarding how and when to aggregate address blocks [3].

A further constraint placed on the address distribution system is the need to balance current and future requirements for address use. Because addresses are a finite resource having a high cost of replacement (the replacement of an entire address set implies the need to undertake a comprehensive change of the entire network protocol across all networked devices), it is in the common interest of actors to exercise responsible restraint in expressing their current needs, to ensure that addresses will be available for future needs within the same network protocol. Resource requests must be accompanied by suitable justification, and policies are required to define how need is matched to supply. If this were not the case, future users would be forced to make different technology choices for their communications network requirements due to addresses being unavailable, thereby devaluing the future value of the pool of investment in the current technology base and network protocol, which, in turn, would negatively impact the net present value of the current technology base and devalue the opportunities for investment in network infrastructure.

2. Mechanisms for Address Distribution

The essential attributes of the address distribution function include considerations of efficiency, fairness, equity, consistency, neutrality and accuracy [4]. In addition, the address distribution function must be based on commonly agreed policies that apply to addresses, importantly including means to maintain routing viability across the network, and also to ensure adequate provision for future needs. For the Internet, industry actors have chosen to create and use a self-supporting (or self-regulating) administrative function to fulfil the address distribution and registration functions.

It can be difficult to find a balance between the immediate interests of individuals and organizations seeking to use IP addresses and the stated policy goals of conservation and aggregation. It is therefore necessary to formulate policies in a manner that allows such interests to be expressed, and the process used today is one of an open, community-driven process of policy development that balances the needs of the resource requestor with the needs of the Internet community as a whole. The industry also uses this same common cooperative framework to host open forums where policies that regulate these functions are developed. Address allocation policies need to be fine-tuned in recognition of operational realities, both regional and global, and of technical developments in the broadest sense. The mechanisms used are typical of industry self-regulatory frameworks in other sectors: the industry itself underwrites the cost of the common administrative function, together with the costs of application of a regulatory constraint, and does not call upon the expenditure of public funds to operate this function.

Close co-ordination between regional registries is the key to ensuring that the global, collaborative network of networks operates seamlessly. Proposals to further decentralise the resource distribution function, which arise periodically, need to be balanced against the increased difficulty of global co-ordination in the presence of such further de-centralisation. To be effective this co-ordination demands fundamental agreement on roles and functions, as well as mutual respect among the RIRs, IETF and other actors.

Such bodies depend on broad participation, in order to prevent distortion or various forms of capture by narrow interests, and in the case of the Internet address distribution function this widespread base of participation is strongly evident. The open, transparent, and collaborative model that relies on processes that are local, bottom-up, and the participation of all interested and knowledgeable participants has proved its worth in dealing with the challenges of an evolving network.

The alternatives to this self-regulatory framework include allocation functions performed by public regulatory authorities, address distribution via privatized function, public auctions, and open distribution without any form of imposed constraints. However, such mechanisms tend to have critical weaknesses in terms of satisfying all of the essential attributes of the address distribution function. A competing set of public allocation authorities creates the potential for wildly divergent outcomes, which would place the essential attributes of integrity and viability of the deployed address space under high levels of risk.

Because there are a set of common interests at play here, in order to ensure that the address distribution function is neutral with respect to the competitive interest of industry actors, the use of conventional market-based mechanisms for address distribution falls short due to the issues of potential exclusion and construction of barriers to entry though distortions that may become apparent in a market for addresses. A privatized function also would not necessarily operate in a neutral manner and runs the risk of capture, whereby an industry actor could, through capture of the address distribution function, withhold addresses from its competitors. An open distribution system runs the risk of over consumption and degradation of the routeability of the address space. It is also unclear how the essential aspects of uniqueness and integrity of the address system as a whole could be maintained in a fully open system.

3. Public Interest and the Policies of Address Distribution

As with any common good that has attributes of public interest, there are a number of attributes of the address distribution function that should be safeguarded, through the application address distribution policies designed to deal with the constraints discussed above. These issues of public interest are not only local, but include considerations of common, or network-wide, constraints. Both the address pool and the routing system are interdependent common assets. Deleterious outcomes from any local actions impose penalties and costs on the entire network, and hence on all actors.

Within the current framework, public interest considerations are addressed through a policy development process that is open, invites the direct participation of knowledgeable stakeholders and actors, and does not rely on intermediation, hierarchical representation, abstraction or redirection, but instead encourages specific interests to be exposed by the primary actors themselves, and allows conflicts to be resolved between those actors and stakeholders in the open.

As the network, and the uses to which it is put, grows and becomes ever more integrated into modern society, governments should increasingly support the work of the organisations related to address distribution and maintain a stakeholder interest in the address distribution policy formation process and its operation. This is the surest route to ensure that the concerns of governments are addressed appropriately as new policy formation takes place, benefiting from the accumulated expertise of the addressing organisations and expert advice.

4. Evolution

Technology changes, costs change, service models change, demands for addresses change over time. How can evolving needs for address allocation best be expressed? It is clear that changing environments bring involvement from new actors and stakeholders. The self-regulatory structures that have developed over time and the open and transparent direct-participatory forms of policy development have proven themselves best able to accommodate the changing policy needs and new players who together create the Internet.

One obvious example of a significant change that is affecting the address management function is the adoption of IPv6. The impact of IPv6 on the goals of conservation, registration and aggregation can be summarised as follows:

- Conservation – the goal is unaffected, although the numbers get bigger;
- Registration – the requirement doesn't change. Global uniqueness is still essential, but it is increasingly unlikely that registrants will need to return to their registrar for additional space on a regular basis, if ever. While at first glance it might appear that a single allocation lasting a network for a decade or more might lead to degradation in the quality of registration data, the RIRs require registrants to pay annual renewal fees. This is partly to check that the registration data are current and valid;
- Aggregation – again, the requirement doesn't change. However, it should be much easier to address the need for efficient routing as the IPv6 address pool is significantly larger than the IPv4 pool.

As address architectures change and impact the routing infrastructure, policies for routing, allocation, and best practices will need to evolve as well. The Internet is a work in progress by design. Thus, the functions, processes and policies integral to its operation must remain flexible to some extent. The structure of policy-making and address allocations must be able to evolve by the same rules that are used to create the policies themselves; that is, accommodating change as the Internet evolves.

Governments, in collaboration with the private sector, should encourage IPv6 adoption. Governments should act as catalysts and lead by example. e-Government services should be made available over IPv6 as soon as practically possible, and definitely before the end of 2012. Governments should not seek to regulate or replace work that is already underway. The OECD could usefully remind member states of the recommendations related to creating a policy environment conducive to the timely deployment of IPv6, which they listed for Ministers at their Seoul meeting in 2007 (see Annex I).

5. Conclusions

The IETF and RIRs are not an imposition of an external structure into the Internet and its associated service industry, but an expression of the manner in which the Internet and the related industry of service providers and stakeholders work together in order to preserve the coherence, integrity and value of the numbering resources. The structure accommodates diverse local regulatory regimes and brings them together into a coherent global framework in a seamless and highly efficient manner.

Any decisions that could impact the deployed Internet need to be based on bottom-up, transparent, consensus-seeking discussions open to all relevant experts and the broad set of stakeholders, seeking the best medium to long term solution for the global Internet (i.e., IP address distribution mechanisms should not be formulated in response to particular national, corporate, or other scenarios without due consideration of the network-wide implications of such mechanisms). For Internet addresses, these discussions are hosted by the Regional Internet Registries (RIRs) and rely on consensus-based technical contributions provided through the Internet Engineering Task Force (IETF).

The need for governments to support these organisations and to pro-actively provide their services over IPv6 is growing. The self-regulatory structures for Internet number resource distribution and the transparent, direct-participatory forms of policy development adopted by the RIRs have proven themselves best able to accommodate the changing policy needs, technology upgrades and new players who together create the evolving Internet.

Annex I

Source: Internet Address Space: Economic Considerations in the Management of IPv4 and in the Deployment of IPv6, Ministerial Background Report, DSTI/ICCP(2007)20/FINAL, **http://www.oecd.org/dataoecd/7/1/40605942.pdf**, pp5-6.

To create a policy environment conducive to the timely deployment of IPv6, governments should consider:

1) Working with the private sector and other stakeholders to increase education and awareness and reduce bottlenecks

IPv6 adoption is a multi-year, complex integration process that impacts all sectors of the economy. In addition, a long period of co-existence between IPv4 and IPv6 is projected during which maintaining operations and interoperability at the application level will be critical. The fact that each player is capable of addressing only part of the issue associated with the Internet-wide transition to IPv6 underscores the need for awareness raising and co-operation. Governments should aim to raise awareness and:

- Establish co-operation mechanisms for the development and implementation of high-level policy objectives to guide the transition to IPv6.
- Develop compelling and informative educational material to communicate and disseminate information on IPv6.
- Target decision-makers in awareness efforts and discussions on IPv6 deployment.
- Support registries and industry groups as they continue to develop policies and technologies to facilitate the management of IPv4 and adoption of IPv6, with a focus on:
    - Policies that safeguard security and stability.
    - Policies that give stakeholders ample opportunity to be ready and operate smoothly during the upcoming period of IPv4 unallocated address space depletion.
    - Ensuring that the deployment of IPv6 and the necessary co-existence of IPv4 and IPv6 safeguard competition, a level-playing field and are careful not to lock-in dominant positions.
- Make specific efforts to ease bottlenecks, by encouraging:
    - Operators to consider IPv6 connectivity in peering and transit agreements.
    - Greenfield deployments to contemplate IPv6 from the outset, to ―future-proof‖ deployments.
    - Vendors and other providers of customer premises equipment to plan for and accommodate future customer needs in terms of IPv6, in recognition of consumer Internet access as the largest current network-service growth area and the area placing the heaviest demand on IP address resources.
    - Telecommunications operators to facilitate IPv6 deployment through training, equipment renewal, integrating IPv6 in hardware and software, developing new applications, conducting risk assessments.
    - Software development companies to develop IP version neutral applications where possible, incorporate IPv6 capabilities into new software, and to conduct research and development on new applications that leverage IPv6 functionality.

2) Demonstrating government commitment to adoption of IPv6

As for all other stakeholders, governments need continued addresses to support growth in the public services that they provide online and more generally to meet public policy objectives associated with the continued growth of the Internet economy. They therefore have a strategic need to support transition to IPv6 by taking steps to:

- Adopt clear policy objectives that are endorsed at a high level, to guide the transition effort to IPv6.
- Plan for the adoption of IPv6 for governments' internal use and for public services, by developing a road map and planning time needed to conduct network assessment, infrastructure upgrade, and upgrade of applications, hosts, and servers.
- Set up a steering group to provide strategic guidance on achieving IPv6 implementation objectives.
- Ensure that all new programmes involving the Internet and ICT consider the relevancy of IPv6 and assess public programmes and priorities to determine how they can benefit from IPv6.
- Ensure that all relevant government security entities fully integrate the new dimension that IPv6 brings to security.
- Take pro-active initiatives to include IPv6 training efforts in life-long education cycles.

3) Pursuing international co-operation and monitoring IPv6 deployment

Awareness of the scope and scale of an issue is a key element in support of informed policy making. Benchmarking at the international level is essential to monitor the impact of various policies. With respect to IPv6, governments should:

- Engage in bilateral and multilateral co-operation at regional and global levels, to share knowledge and experience on developing policies, practices and models for coordination with private actors on IPv6 deployment.
- Consider the specific difficulties of some developing countries and assist them with capacity-building efforts to help build IPv6 infrastructure.
- Encourage the participation of all relevant stakeholders in the development of equitable public policies for IPv6 allocation.
- Encourage all relevant parties, including global and regional Internet registries, Internet exchange point operators and research organisations, to gather data to track the deployment of IPv6 in support of informed policy-making.
- Monitor IPv6 readiness, including by monitoring information on national peering points offering IPv6 connectivity, Internet Service Providers offering commercial IPv6 services, volumes of IPv6 transit, and penetration of IPv6-enabled devices in domestic markets.

Annex II

Internet number resource distribution, a brief history

Initially, distribution of Internet number resources was handled by one man, Jon Postel.

> *The assignment of numbers is also handled by Jon. If you are developing a protocol or application that will require the use of a link, socket, port, protocol, or network number please contact Jon to receive a number assignment.*
>
> RFC790 [5]

Subsequently, in 1987, the responsibility for the assignment of IP numbers and ASNs was assumed by the Hostmaster at the DDN Network Information Center (NIC) [6]. In 1991, the NIC transitioned to Government Systems Inc., who subcontracted the work to Network Solutions, Inc. [7]. Even before this however, it was recognised that decentralisation of the number resource distribution function was desirable.

> *With the rapid escalation of the number of networks in the Internet and its concurrent internationalization, it is timely to consider further delegation of assignment and registration authority on an international basis. It is also essential to take into consideration that such identifiers, particularly network identifiers of class A and B type, will become an increasingly scarce commodity whose allocation must be handled with thoughtful care.*
>
> RFC1174 [8]

A later document enabling this recommendation also noted that, 'The demand for network numbers has grown significantly within the last two years and as a result the allocation of network numbers must be approached in a more systematic fashion… The major reason to distribute the registration function is that the Internet serves a more diverse global population than it did at its inception. This means that registries which are located in distinct geographic areas may be better able to serve the local community in terms of language and local customs.' [9]

This document also set out the initial criteria for organisations desirous of qualification as Internet number resource distributors, or 'regional registries':

> *It is important that the regional registry is unbiased and widely recognized by network providers and subscribers within the geographic region. It is also important that there is just a single regional registry per geographical region at this level to provide for efficient and fair sub-allocation of the address space. To be selected as a distributed regional registry an organization should meet the following criteria:*
>
> *a) networking authorities within the geographic area legitimize the organization*
>
> *b) the organization is well-established and has legitimacy outside of the registry function*
>
> *c) the organization will commit appropriate resources to provide stable, timely, and reliable service to the geographic region*
>
> *d) the commitment to allocate IP numbers according to the guidelines established by the IANA and the [Internet Registry (IR)] IR*
>
> *e) the commitment to coordinate with the IR to establish qualifications and strategies for sub-allocations of the regional allocation.*

Today there are five Regional Internet Registries (RIRs) with responsibility for Internet number resource distribution within their service region. They are as follows:

- AfriNIC – Africa
- APNIC – Asia-Pacific
- ARIN – North America & Caribbean (part)
- LACNIC – Central & South America & Caribbean (part)
- RIPE-NCC – Europe, Middle East & Central Asia

These five organisations co-ordinate their activities through the Number Resource Organization (NRO) which, through an MoU with ICANN, fulfils the role of the Address Supporting Organization (ASO) in advising ICANN on number resource matters and providing global policy for the allocation of number resources [10]. Thus, the bottom-up policy making processes of the RIRs are employed to define global policy. The Internet Assigned Numbers Authority (IANA) coordinates the global IP and AS number space, and allocates blocks of that space to the five RIRs in accordance with the applicable global policies. The ICANN Board ratifies those policies [11]. The IANA function is performed under the terms of a contract between the United States government and ICANN that is in effect until September 30, 2011. IANA is directed in matters regarding the technical parameters of numbering resources by the IETF [12].

The brief history outlined above illustrates how the Internet number resource distribution function has evolved over time. Today, Internet number resource distribution is a function co-ordinated between network operators and other stakeholders under consensus agreements [13]. In addition, technology evolution has been embraced. IPv4 allocations have successfully evolved to meet the needs of the global community and IPv6 allocations, starting from a clean slate, are now able to leverage this successful global platform.

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