IPv6 study: General Background

1 Introduction

1.1 Critical resources

1. The Tunis Agenda for the Information Society[1] invited the Secretary-General of United Nations to convene a new forum for multi-stakeholder policy dialogue called the Internet Governance Forum (IGF) (paragraph 67). The mandate of the IGF (paragraph 72) includes discussing, *inter alia*, issues relating to "critical Internet resources" (item j). The management of critical Internet resources is one of the five specific areas of the discussion during IGF meetings.

2. While many are considering the term "critical Internet resources" as the administration of the Domain Name System (DNS) and Internet Protocol (IP)[2], in the report of the Working Group on Internet Governance (June 2005)[3], critical Internet resources are defined as :

> *Issues relating to infrastructure and the management of critical Internet resources, including administration of the domain name system and Internet protocol addresses (IP addresses), administration of the root server system, technical standards, peering and interconnection, telecommunications infrastructure, including innovative and convergent technologies, as well as multilingualization. These issues are matters of direct relevance to Internet governance and fall within the ambit of existing organizations with responsibility for these matters.* (paragraph 13 a)

3. The term "critical resource" would appear to be used—at times—in the discussions summarized above in a sense that is similar to the use of the term "essential facility" in anti-trust law. In particular, US courts have held that a facility is "essential" if companies need it in order to compete in a given market[4]. For example, a particular bridge over a river was held to be an "essential facility" with respect to competition in the railroad business. In other cases, electrical power transmission lines were held to be "essential facilities", as were local telephone exchanges.

4. It is clear that, in this sense, IP addresses are "essential facilities" as are other resources that are required in order to offer telecommunication services, such as frequencies (for mobile telecommunications), E.164 numbers (for telephony), Q.708 resources (for fixed network switching), E.212 resources (for mobile telephony).

5. In some countries, use (or abuse) of essential facilities might be within the scope of anti-trust law and/or competition authorities. For example, if a company (or group of companies) has monopoly control over an essential facility, and competitors cannot practically or reasonably duplicate the facility, and the company (or group of companies) denies use of the facility to competitors, then the authorities might order some remedial actions.

6. In some countries, certain essential facilities might be identified *ex ante* or *ex post* and regulations might be established to ensure access to those facilities by competitors on reasonable financial terms. For example in the telecommunications sector, many countries have local loop unbundling provisions, or intervene, at the request of new entrants, to set interconnection prices for facilities owned by an incumbent operator.

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[1] Available at: http://www.itu.int/wsis/docs2/tunis/off/6rev1.html

[2] See page 12 of "Chairman's summary of Third Meeting of the Internet Governance Forum" (2008) available at: http://www.intgovforum.org/cms/hydera/Chairman%27s%20Summary.10.12.2.pdf

[3] Available at: http://www.wgig.org/

[4] See page 45 of A. Michael Froomkin and Mark A. Lemley, "ICANN and Antitrust", University of Illinois Law Review (2003), available at: http://osaka.law.miami.edu/~froomkin/articles/icann-antitrust.pdf

7. Much of the electromagnetic spectrum is considered *ex ante* to be an essential facility, whose allocation is governed by the government through methods such as beauty contests, auctions, etc.

8. As we will see below, governments have historically been involved in the allocation of telecommunications naming, numbering and addressing resources (with the exception of Internet resources), because there has been an implicit *ex ante* determination that such resources are "essential facilities" or "public resources" and that the role of governments is to ensure that all competitors can have access to these facilities and resources on an equal basis, so as to favour competition.

9. The IP address space is commonly considered to be *"a public resource that must be managed in a prudent manner with regards to the long-term interests of the Internet"*[5].

1.2 History of allocation of critical telecommunications resources

10. The history of international telecommunications started in 1865, when a number of countries agreed the Paris International Telegraph Convention. In that treaty, the signatories agreed to a certain provisions whose purpose was to facilitate international communications by telegraphy.

11. Article 58 of the 1865 Convention provided that an official map of telegraphic connections (that is, telegraph lines or circuits) would be established and published by the French government. Article I of the Regulations of the International Service, which completed the Convention, provided details on how international lines should be shown on the map.

12. In the 1872 version of the Convention, the responsibility for producing the map was given to the International Bureau, an organization created in 1869 to perform certain tasks related to the Convention.[6]

13. Thus, starting in 1872, an intergovernmental organization had the task of publishing the lines/circuits/routes available for international telecommunication. The ITU still publishes the Operational Bulletin, which is the successor the information published since 1872, but the Operational Bulletin no longer includes detailed information on lines/circuits/routes. That information is exchanged bilaterally between interconnected operators.

14. Telecommunication naming and addressing resources were initially alphabetical strings corresponding to physical addresses, for example "23 This Street, This City, This Country". And this because telegrams were physically delivered to the end-user.

15. Allocation of machine-readable strings for names and addresses used for telecommunication became necessary (or at least desirable) when automatic routing and switching equipment was installed. The allocation of such machine-readable naming and addressing resources was originally performed by each operator, without reference to other operators, because interconnection between operators was a manual operation, and the instruction "this telegram goes to Paris, France" or "to operator X" or was sufficient to allow the switch operator to establish the requisite connection to allow the international transmission to take place.

16. Automatic routing of telegram messages was initiated during the 1930s[7], at which time operators developed numbering plans for their respective networks. The system was known as Telex; it became common around the world during the 1960s.

17. As automatic routing and switching became prevalent, it became necessary to establish international machine-readable names and addresses. The first significant international

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[5] See for example 3.1 of the joint APNIC, ARIN and RIPE NCC *IPv6 Address Allocation and Assignment Policy*, at: http://www.ripe.net/ripe/docs/ipv6policy.html

[6] See Article 60 of the 1872 Convention and Articles I and XXXIV of the Regulation.

[7] See http://en.wikipedia.org/wiki/Telegraphy#Telex

standardization of this type was the approval in 1960 by CCITT of Recommendation E.29, which contained a list of international telephone country codes. Not all countries were assigned a number in that initial list. International standardization of country codes for telegraphy and telex soon followed, with the approval by CCITT in 1964 of Recommendations F.96 (later renumbered F.32), F.68 and F.69.

18. The use of international direct automatic dialling grew rapidly, and eventually all countries requested, and received, international country codes for telephony, telegraphy, and telex. In addition, technological developments such as signalling systems and mobile telephony generated requirements for additional international naming and addressing resources.

19. As a result, at present, a number of telecommunications naming and addressing resources are allocated by ITU (and specifically, ITU-T) at the international level[8]. Those allocations are performed in accordance with relevant ITU-T Recommendations, in particular E.164 and E.164.1 for telephone numbers, Q.708 for International Signalling Point Codes (ISPCs) and E.212 for International Mobile Subscription Identities (IMSIs).

20. Resources are allocated to countries by ITU. Each country then allocates resources at the national level using methods that are determined nationally.

21. Prior to liberalization and deregulation, allocation of national telecommunications naming, numbering and addressing resources was primarily performed by the monopoly operator, which was usually a government-controlled entity. As liberalization was introduced, a number of governments recognized that it was important to ensure that names, numbers and addresses were allocated so as to foster competition, and the task of name, number and address allocation was assigned to newly-created independent regulators. A good summary of this development is provided by the European Union Directive 2002/21 of 7 March 2002 on a *Common Regulatory Framework for Electronic Communications Networks and Services (Framework Directive)*[9]. That Directive states at *whereas* (20):

> *Access to numbering resources on the basis of transparent, objective and non-discriminatory criteria is essential for undertakings to compete in the electronic communications sector. All elements of national numbering plans should be managed by national regulatory authorities, including point codes used in network addressing.*

22. Article 8.2(d) of the cited Directive provides that:

> *The national regulatory authorities shall promote competition in the provision of electronic communications networks, electronic communications services and associated facilities and services by* inter alia … *ensuring the effective management of radio frequencies and numbering resources.*

23. However, the cited Directive excludes IP addresses from its scope, because the cited *whereas* (20) also states: "*The provisions of this Directive do not establish any new areas of responsibility for the national regulatory authorities in the field of Internet naming and addressing.*"

24. As another example, the North American Numbering Plan was created and instituted in 1947 by AT&T[10]. However, since 1995, the North American Numbering Council (NANC) (a Federal Advisory Committee to the Federal Communications Committee (FCC)) has advised the FCC and made recommendations concerning this plan, so as to that foster efficient and impartial number

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[8] See http://www.itu.int/ITU-T/inr/index.html

[9] See also Article 5.2 of the European Union Directive 2002/20 of 7 March 2002 on the *Authorisation of Electronic Communications Networks and Services (Authorisation Directive).*

[10] See http://en.wikipedia.org/wiki/North_American_Numbering_Plan#History

administration[11]. The NANC is composed of representatives of telecommunications carriers, regulators, cable providers, VoIP providers, industry associations, vendors and consumer advocates.

25. Similarly, in the United States, Q.708 ISPCs were initially assigned by AT&T. That task was taken over by the FCC in 1987.

26. According to a survey conducted by ITU-T Study Group 2 in 2004, approximately 65% of the responding countries stated that the regulator would have authority to impose obligations on operators with respect to opening access to international numbering resources allocated by the ITU[12].

27. Thus, in summary, it can be said that—except for Internet resources—telecommunication naming and addressing resources are allocated at the international level by the ITU and at the national level by independent regulators—and this in order to promote competition and to ensure that all entities have equal access to required naming and addressing resources (which may be considered to be "essential facilities" or "critical resources" or "public resources").

1.3 Spectrum/orbit management by ITU

28. ITU is mandated by its Constitution to allocate spectrum and register frequency assignments, orbital positions and other parameters of satellites to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum.

29. The main principles of efficient use of and equitable access to the spectrum/orbit resources laid down in No. 196 of the ITU Constitution (Article 44), which stipulates that:

> "*In using frequency bands for radio services, Members shall bear in mind that radio frequencies and the geostationary-satellite orbit are limited natural resources and that they must be used rationally, efficiently and economically, in conformity with the provisions of the Radio Regulations, so that countries or groups of countries may have equitable access to both, taking into account the special needs of the developing countries and the geographical situation of particular countries*".

30. As indicated in the above provision, further detailed regulations and procedures governing orbit/spectrum use are contained in the Radio Regulations (RR), which is a binding international treaty (No. 31 of the ITU Constitution). The international spectrum management system is therefore based on regulatory procedures for frequency notification, coordination and registration[13].

31. The efficient, rational and cost-effective utilization of spectrum/orbit was implemented through a "first come, first served" and "coordination before use" procedure. This procedure is based on the principle that the right to use a satellite position is acquired through negotiations with the administrations concerned by actual usage of the same portion of the orbital segment. If applied correctly (i.e. to cover genuine requirements), the procedure offers a means of achieving efficient spectrum/orbit management; it serves to fill the gaps in the orbit as needs arise and results, in principle, in a homogeneous orbital distribution of space stations. On the basis of the RR, and in the frequency bands where this concept is applied, Member administrations designate the volume of orbit/spectrum resources that is required to satisfy their actual requirements. It then falls to the national administrations to assign frequencies and orbital positions, to apply the appropriate procedures (international coordination and recording) for the space segment and earth stations of their (governmental, public and private) networks, and to assume continuing responsibility for the networks.

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[11] See http://www.fcc.gov/wcb/cpd/Nanc/nancback.html

[12] See http://www.itu.int/ITU-T/2001-2004/com02/surveys_E164.html

[13] This and the following two paragraphs are from "Spectrum-Orbit coordination procedures" (1999) by N. Malaguti, available at: http://www.itu.int/ITU-R/conferences/seminars/cuba-99/docs/08-spec-orbit.doc

32. The progressive exploitation of the orbit/frequency resources and the resulting likelihood of congestion of the geostationary-satellite orbit prompted ITU Member States to consider more and more seriously the question of equitable access in respect of the orbit/spectrum resources. This resulted in the establishment (and introduction into the ITU regulatory regime[14]) of frequency/orbital position plans in which a certain amount of frequency spectrum is set aside for future use by all countries, particularly those which are not in a position, at present, to make use of these resources. These plans, in which each country has a predetermined orbital position associated with the free use, at any time, of a certain amount of frequency spectrum, together with the associated procedures, guarantee for each country equitable access to the spectrum/orbit resources, thereby safeguarding their basic rights.

1.4 Comparison of telephony and Internet naming and addressing resources

33. It is useful to distinguish names from addresses:

a) A **name** is a location independent string with respect to both a source and a destination. If a string is the name of a destination, it remains unchanged if the destination moves. It is valid regardless of the source attempting communication with the destination.[15]

b) An **address** is a string of symbols that is valid regardless of the location of the source but changes if the destination moves. An address is used for the purpose of routing.[16]

34. Given those definitions, it is useful to compare the management of various currently used naming and addressing resources as shown in Table 1.

Table 1: names and addresses

	Name	Address
Internet	Domain name	IP address
Fixed telephony	E.164 number	Q.708 ISPC
Mobile telephony	E.164 number	E.212 IMSI

35. As noted above, naming and addressing resources for telephony are allocated by the ITU-T at the international level: each country receives one or more resources in accordance with the relevant ITU-T Recommendations. Each country then establishes its own methods for allocating naming and addressing resources at the national level. Both the international allocations and the national allocations are published[17] by the ITU-T.

1.5 History of IP address allocation

36. Unlike previous telecommunication technologies such as telephony, IP-based networks relied on machine-readable naming and addressing resources from their inception. At first, those resources were centrally allocated. Later, regional management of IP addresses was introduced, see section 1.4 below.

37. When the TCP/IP architecture for the Internet was designed in the first half of the 1970s, a 32-bit address space was then believed to be adequate for all time. Since the Internet – and TCP/IP – are designed around the notion of a "network of networks", rather than a single, seamless, network, that 32-bit address space was originally structured to permit a relatively small number of networks (roughly 256), with a large number of hosts (around 16 million) on each. It rapidly became clear that there would be a larger-than-anticipated number of networks, of varying sizes, and the

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[14] See *Appendix 30B of Radio Regulations*, http://www.itu.int/publ/R-REG-RR/en

[15] ITU-T Recommendations G.807/Y.1302 (01), 3.13; G.8081/Y.1353 (04), 3.2.26

[16] ITU-T Recommendations G.807/Y.1302 (01), 3.1; G.8081/Y.1353 (04), 3.2.2

[17] See http://www.itu.int/ITU-T/inr/index.html

architecture was changed to support three important "classes" of networks (there was a fourth class, but it is not relevant to this discussion): 128 Class A networks, each accommodating up to 16’777’215 hosts, 16 384 Class B networks, each accommodating up to 65’535 hosts, and around 4 million Class C networks, each accommodating up to 255 hosts. Some of the Class A blocks were allocated to early adopter of TCP/IP, including research institutions and universities.[18]

38. The distinction between networks and hosts on a network was, and remains, very important because Internet routing is closely tied to the separation of routing within a network and routing between networks. Using the division of an address into a network number and a host number, a given host can determine whether a packet is to be routed locally (on the same network), using some sort of "interior" protocol or whether it must be routed, typically through a gateway (although there are actually slight differences in meaning, the term "router" is often used interchangeably with "gateway" or, more precisely, "network-level gateway"), to another, "exterior" network. Exterior routing protocols use only information about networks; they pay no attention to what goes on inside a network.

39. The network-based approach described above has very significant limitations as far as utilization of the address space is concerned. This design nonetheless appeared reasonable for the early Internet, since the network was built around the assumption of relatively large, time-sharing hosts, each with large numbers of users.

40. However, the subsequent appearance of small and inexpensive desktop computers changed the situation. Fairly quickly, the assumption that an enterprise or department would consist of a few large computers with attached terminals – with the terminals using a different protocol to communicate with the computers than the computers used to communicate with each other – evolved to a vision of networks as consisting of machines, interconnected with TCP/IP, and hence needing addresses whose numbers were roughly proportionate to the number of people, rather than the number of departments. Increasing modem speeds, combined with protocols that supported dial-up use of TCP/IP with adequate authentication and management facilities for commercial use, made dial-up networks and general home use of Internet connections plausible. As a result of this combination, Internet growth, spurred on by the introduction of the web and graphical interfaces to it, exploded. Several techniques were developed to reduce the rate of address space consumption below the rate of "Internet growth" (measured by the number of computers that were ever connected).

41. For the purposes of this study, the most significant development was the abandonment of the classes and their fixed boundaries, replacing them in 1993 with a classless system – Classless Inter-Domain Routing (CIDR). CIDR permitted the use of a variable-length network portion in the address, so that the remaining address space could be used more efficiently than the class-boundary network sizes permitted. An enterprise or network that needed, say, 500 addresses, could be allocated a network block with capacity for 511 or 1’023 hosts, rather than requiring a full Class B network and "wasting" the remaining sixty-four thousand (or so) addresses. When very small networks became common a few years later, such as for home or small office networks using cable television or digital subscriber line (DSL or xDSL) connections, CIDR also permitted address allocations to be made in blocks considerably smaller than the original Class C (up to 255 host) ones.

42. In summary, the Internet enables and relies on a dynamic routing environment in which network topology changes can be accommodated automatically and at reasonable speed. It must be noted, however, that today's routing technology will allow changes at the level of networks rather than individual users, and that such changes cannot be processed in real time. In today's Internet an

[18] This paragraph and the following five paragraphs are from Attachment 8 of “A Handbook on Internet Protocol (IP)-Based Networks and Related Topics and Issues” (ITU, 2005), available at: http://www.itu.int/ITU-T/special-projects/ip-policy/final/index.html

ISP's global routing table will contain some 180'000[19] entries, and while that number is growing at a steady rate, it is generally felt that major increases in routing table size would degrade dynamic routing on many routers, to the extent that smaller Internet Service Providers (ISPs) would lose global visibility of the Internet, resulting in unpredictable service and/or the need to select manually the routes that they were able to carry. [20]

43. That management of IP addresses therefore involves not only the conservation of address space, but also the conservation of "routing space" through the avoidance of excessive address space fragmentation. Accordingly, the principle of "provider-based" addressing has been generally applied, in which the recipients of IP addresses are the ISPs who are able to utilize large blocks of address space and allow those address ranges to be reached through a minimal number of routing announcements. From the addressing point of view, it has been said that the "geography" of the Internet involves the ISP as the primary subdivision, with frontiers corresponding to interconnections across which global routing information is exchanged.

44. A further consequence is that Regional Internet Registries (RIRs) must make allocations not only in accordance with demonstrated needs of ISPs, but also in such a way as to limit the number of discrete, independent allocations that are made. The value of the resource is due not only to the relative scarcity of IPv4 addresses, but also to the need to maximize aggregation and limit routing table growth. Thus, there would be a need to carefully manage the assignment of IPv6 addresses also.

1.6 History of Regional Internet Registries[21]

45. Initially, IP addresses were allocated by Jon Postel, one of the people originally involved in the design and implementation of the Internet[22]. As the network grew beyond its initial stage—which was an experimental project, interconnecting a small number of research networks—it became clear that the allocation of various resources should be formalized. This was done through the Internet Assigned Names Authority (IANA), which operates under a contract with an agency of the United States government. The first mention of an agreement between an agency of the US government and Mr Postel appears to occur in January 1983[23]. The first mention of the term IANA appears to occur in March 1990[24], but the function was established well before that[25]. There have been formal contracts by the US government concerning the IANA function since 1988[26].

46. In 1992, the IETF recommended that IP addresses be managed regionally[27]. The main reason given for this recommendation was:

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[19] The value of 180'000 was provided in April 2002. In January 2009, the routing tables held nearly 300'000 entries, see Figure 1 of "BGP in 2008" by Geoff Huston at http://www.potaroo.net/ispcol/2009-03/bgp2008.html

[20] This paragraph and the following two paragraphs are from 2.4.5.3 of "A Handbook on Internet Protocol (IP)-Based Networks and Related Topics and Issues" (ITU, 2005), available at: http://www.itu.int/ITU-T/special-projects/ip-policy/final/index.html

[21] Parts of this section are based on the history available on the NRO website, at: http://www.nro.net/archive/news/rir-history.swf and on information available on the RIR websites.

[22] See IETF RFC 349 of 30 May 1972.

[23] See IETF RFC 820 of January 1983.

[24] See IETF RFC 1060 of March 1990.

[25] IETF RFC 1174 of August 1990 states: "Throughout its entire history, the Internet system has employed a central Internet Assigned Numbers Authority (IANA) for the allocation and assignment of various numeric identifiers needed for the operation of the Internet."

[26] The contracts since 2000 can be found at: http://www.ntia.doc.gov/ntiahome/domainname/iana.htm

[27] See IETF RFC 1366 of October 1992.

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.

47. The Regional Internet Registries (RIRs) emerged to undertake the regional management of IP addresses. The RIRs were created as follows:

Réseaux IP Européens Network Coordination Centre (RIPE NCC): 1992

Asia Pacific Network Information Center (APNIC): 1993

American Registry for Internet Numbers (ARIN): 1997

Latin America and Caribbean Internet Address Registry (LACNIC): 2002

Africa Network Information Center (AfriNIC): 2005

48. The American Registry for Internet Numbers (ARIN) formerly covered all of North and South America and part of Africa. At present, subsequent to the creation of other regional registries, ARIN covers Canada, the United States, and countries in the Caribbean area.

49. The RIRs are non-profit organizations whose membership includes Internet Service Providers (ISPs), telecommunication organizations, large corporations and industry stake-holders including end-users. The RIRs operate as industry self-regulatory bodies. Their operating structures are designed to support consensus-driven, bottom up decision-making processes. The RIRs believe that they have provided a numbering allocation system that is "effective, stable, open and fair; and that has been critical for development of Internet in the past and will ensure its stability into the future"[28].

50. At roughly the same time CIDR was proposed (1993, see above), the Regional Internet Registries (RIR) adopted much more restrictive policies toward allocating space for those who requested it[29]. The approval of CIDR reinforced this space-conserving trend, which some enterprises considered excessive at the time. Applicants were required to document plans for space utilization and to justify, in fairly specific terms, the amount of space they would need. The intent was not to prevent anyone from getting needed space, but to slow the rate of allocations and ensure that space was used as densely as possible.

1.6 Analysis of IP addresses allocation data

51. Table 2 shows the recent evolution of IPv4 address number allocated to each region and IANA's pool.

Table 2: IANA IPv4 Address Space Registry [/8][30]

	Afri NIC	AP NIC	ARIN	RIPE NCC	LAC NIC	Legacy	IANA Reserved	IANA Unallocated	Total
As of June 2008	1	28	29	26	6	92	35	39	256
As of December 2008	2	30	31	26	6	92	35	34	256
As of August 2009	2	34	31	28	6	92	35	28	256

[28] See Section 2.1.2 of C09/INF/10 Section 3 document "Economic Factors in the Allocation of IP Addresses" by prof. Milton Mueller.

[29] See http://www.ripe.net/training/e-learning/rir-history.html

[30] This table is generated using the IANA data available at http://www.iana.org/assignments/ipv4-address-space/ . In the data, the designation of 'Legacy' includes address space indicated 'various' in the above provision and /8 address blocks assigned directly to an organization prior to the establishment of the current RIR system.

52. As for the evolution in the number of IPv4 allocation from RIRs to organizations, the last three-year trends worldwide were presented in "NRO Response to ITU-TSB Questionnaire"[31]. Charts derived from that data are presented in Section 4 of C09/INF/10. It can be seen that the top 10 countries holding highest numbers of IP addresses account for about 83% of the total allocated IPv4 addresses, thus the rest of the world share about 17 % of the total as of May 2009. Among the top 10 countries, the US occupies more than half of the total IPv4 addresses.

53. The trends show that about a dozen /8s IPv4 addresses are distributed to economies each year, of which a constant proportion of about a quarter has been granted to the US over the last three years. Another notable point in the trends is a large increase in IPv4 allocation to China, which represents almost a 2.5 times increase in the total holdings of China in the last three years. The rate of the increase in IPv4 allocation to China in 2008 might be about to overtake the USA's[32]. However, China's increasing allocation rate is not enough to bridge the gap in IPv4 allocation at present. The trends also show that other 'early adopters' are getting comparatively larger address space than 'late adopters'.

54. However, the available data on IP address allocation does not conclusively support (or invalidate) either the hypothesis that a historical geographical imbalance persists, or the opposing hypothesis that the historical geographical imbalance has been corrected over time.

55. On the one hand, at the world level, the average number of IPv4 addresses per Internet user is about 2, while the average numbers if the US is removed is about 1. Indeed, the US has over 6 IPv4 addresses per Internet user, which is the highest number per capita. Most, but not all, of the countries which have above average per capita allocations are developed countries that were early adopters of Internet.

56. On the other hand, some developing countries have per capita allocations that are above average. And an analysis of the number of IPv4 addresses per Internet subscriber (as opposed to Internet user[33]), yields somewhat different results. The US does not have the highest number per subscriber, and a number of developing countries have very high per capita allocations in terms of subscribers. Further, a statistical analysis[34] of the data indicates that the number of IPv4 addresses allocated to a given country is proportional to the number of subscribers in that country.

57. But this says nothing about causality: it could be that addresses are allocated as a function of subscribers, or it could be that the number of subscribers is limited by a lack of availability of addresses.

58. Furthermore, it is not clear that all IP addresses allocated to a given country are indeed used in that country. On the contrary, it is clear that, in some cases, addresses assigned to a given country are used elsewhere. For example, when a multinational company receives a block of addresses, they often use addresses from that block in all their operating companies around the world.

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[31] Available at http://www.nro.net/news/nro-response-to-itu.html

[32] China received 2.7 [/8s] IPv4 addresses while the US received 3.2 [/8s] in 2008.

[33] The ITU publishes statistics both on "Internet users" and on "Internet subscribers". The data are provided to ITU by national authorities. Presumably the data on subscribers are more accurate, since they could be based on reports from ISPs, while the data on users are typically based on surveys. In 2008 there were about 5.2 hundred million Internet subscribers worldwide and about 1.5 billion Internet users. For comparison, there were about 1.3 billion fixed telephone lines and about 4 billion mobile subscribers.

[34] In technical terms, the regression of the logarithm of number of IPv4 addresses against the logarithm of number of subscribers has an R-Squared of nearly 0.9 and a slope very close to 1.

2. Current methods of IP address allocation

59. As noted before, IP addresses are managed regionally and in a hierarchical manner. ICANN, as part of its IANA functions, allocates[35] IP address space from the pools of unallocated address space to the RIRs according to their needs as described by its global policy[36]. Each RIR currently obtains /8s IPv4 address space and /12s IPv6 address space from the IANA pool. RIRs allocate IP address space to their memberships such as Local Internet Registries (LIRs) or National Internet Registries (NIRs)[37] according to their needs as described by each regional policy. The minimum IPv4 allocation sizes from RIRs depend on each regional policy, which vary from /22 to /20, while the minimum IPv6 allocation size from RIRs is generally fixed as /32[38]. These delegated address spaces are allocated or assigned to their members such as ISPs or end-users. In some cases, RIRs assign address space to end-users, such as allocations for multi-homed network purposes.

60. While end-users are assigned variable-length portions of IPv4 address blocks, a procedure that was made possible due to CIDR, they are assigned equally /48s IPv6 address blocks from their upstream organizations.

61. RIRs allocate IP addresses to NIRs, LIRs including ISPs, and end-users who request Provider Independent address assignment directly from RIRs. The number of entities receiving IP addresses directly from RIR pools was (as of May 2009) more than 20'000 in the case of IPv4 and about 2'000 in the case of IPv6 (as of May 2009). As the number of entities directly downstream from the RIRs increases, it becomes more difficult it is for RIRs to allocate contiguous IP address blocks to an entity in any subsequent allocation requested by that entity. This creates fragmentation of the routing tables. Thus, in terms of IP address aggregation issues, this fragmentation of IP address blocks at relatively high level of the address distribution hierarchy might influence the Internet core routing table.

62. The number of entities that receive addresses directly from an RIR varies widely by country. The US has about 4300 such entities for IPv4 and 700 for IPv6, while countries having 10 or fewer such entities account for more than 50% of the world in the case of IPv4 and more than 80% in the case of IPv6.

63. As IP addresses are considered as public resources, those who use distributed IP addresses are considered as "custodians" rather than "owners" of the resource. If the distributed addresses become invalid[39], then the address space must be returned to the appropriate Internet Registry. Distribution fees serve to cover operational costs incurred by Internet Registries (IRs) and IANA, they are not a price to be paid for the addresses themselves. The fees of the RIRs are described in their respective websites.

64. Each RIR has been allocated variable sizes of IPv6 address space until the current global policy[40] was applied in July 2006. This global policy requests that the minimum IPv6 allocation from IANA to an RIR is a /12, and that each current RIR with less than a /12 unallocated address

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[35] The terms 'allocate' and 'assign' must be distinguished. To 'allocate' means to distribute address space to Internet Registries or other organizations for the purpose of subsequent distribution by them, while to 'assign' means to delegate address space to an ISP or end-user, for specific use within the internet infrastructure they operate.

[36] See "Policy for Allocation of IPv4 Blocks to Regional Internet Registries" http://www.aso.icann.org/docs/aso-001-2.pdf and "Global Policy for Allocation of IPv6 Address Space" http://www.aso.icann.org/docs/aso-global-ipv6.pdf

[37] National Internet Registries (NIRs) exist only in Asia Pacific and Latin America areas.

[38] These minimum allocation sizes are described in each regional policy which are summarized in "RIR Comparative Policy Overview" by NRO, available at http://www.nro.net/documents/comp-pol.html

[39] An allocation of address space becomes invalid if it is made for a specific purpose that no longer exists or based on information that is later found to be false or incomplete.

[40] Available at http://www.icann.org/en/policies/proposed-ipv6-policy-14jul06.htm

space shall receive an IPv6 allocation from IANA. Also, it stipulates that any new RIR shall, on recognition by ICANN receive an IPv6 allocation from IANA. Thus, each RIR has respectively a /12 block and some small blocks[41], in other words, each RIR holds the equivalent of approximately 2100 /23s blocks as shown in Table 3.

Table 3: Cumulative numbers of allocated IPv6 address space [as of March 2009]

Numbers of allocated IPv6 address space	AfriNIC	APNIC	ARIN	RIPE NCC	LACNIC
To RIRs [/23s][42]	2,049	2,084	2,053	2,114	2,049
From RIRs [/32s][43]	68	24,355	14,902	33,374	186

3. Concerns raised by countries regarding IP address allocation

65. Differing points of view have been expressed with respect to IP address allocation. Some take the view that the current IP address management has been worked well and there is no need to change it; on the other hand, others have argued for the need to review the current system because of the rapid increase of demand and use of the Internet, in order to "*ensure equitable distribution of resources and access for all into the future*"[44]. In response to that position, some have argued that any changes in the allocation mechanism would result in technical risks such as disruption of the current routing aggregation.

3.1 IP address allocation policy development

66. The Internet policy development process is perceived as being open. However, some participants believe that developing countries are under-represented in the process, because of various reasons, such as budget limitations in certain countries. Some developing countries feel left out of existing governance structures and that, with their limited human and financial resources, they find great difficultly in making their voices heard. They see the various institutions dealing with the Internet as being dominated by developed countries and feel marginalized. "*What is more, due to the complex and fragmented nature of the various mechanisms that run the Internet, they have difficulty in finding out what is going on and in identifying which institution is dealing with what aspect and what possibilities they would have to make meaningful input into ongoing processes*"[45].

67. As an example, GAC (Governmental Advisory Committee) statistics show that developing countries have a relatively low representation and participation in GAC as reported to the Council Working Group on the World Summit on the Information society[46]:

> *106 countries/territories are registered members of GAC and this is close to just half of the number of countries/territories recognized within the framework of the Internet. Many of the countries without representation are developing or least developed. […] [T]he percentage of countries in the Regional Internet Registry (RIR) that are GAC members, also reflects their low representation. […] 52% of ITU Member States are GAC members […]. The participation of ITU Member States in GAC meetings is also minimal.*

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[41] See http://www.iana.org/assignments/ipv6-unicast-address-assignments/

[42] See also http://www.iana.org/assignments/ipv6-unicast-address-assignments/

[43] See http://www.nro.net/statistics/index.html

[44] See Paragraph 85. of "Background Report" of WGIG http://www.wgig.org/

[45] Markus Kummer, *Internet Governance and the Need for an Inclusive Multi-Stakeholder Dialogue* (2007), available as http://www.oecd.org/dataoecd/60/53/37985809.pdf

[46] Internet Governance-Background Document, available at http://www.itu.int/council/groups/wsis/dedicatedgroup.html

68. Their point of reference is the world of telecommunications, where the International Telecommunication Union (ITU) provides a central clearing house for policy discussion of international matters of interest to governments[47]. The Tunis Agenda for the Information Society[48] recognized *"that all governments should have an equal role and responsibility for international Internet governance"* (paragraph 68). The Background report of WGIG (2005) mentions this point:

> *"There is a lack of a global mechanism for participation by Governments, especially from developing countries, in addressing multisectoral issues related to global Internet policy development."*
>
> *[t]here is currently limited involvement of either governments or civil society in the policy making or practical management of IP addresses, although generally RIRs encourage such groups to participate in RIR policy development. Some governments have the position that the allocation of IP numbers, or some subset of these numbers, should be under the sovereignty of national governments and should be managed via a national Internet registry (NIR).*[49]

69. Further, it has been considered by some that allocation at the national level would better meet the needs of users. Indeed, the major reason given for regional allocation as opposed to central allocation could be seen as arguing in favour of national allocation as opposed to regional allocation. That reason, as stated in Request for Proposals (RFC) 1366 of the Internet Engineering Task Force (IETF) was:

> *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.*

70. However, it has also been stated that the current regional allocation scheme is the maximum (and optimum) level of decentralization: any further decentralization would have negative effects, in particular with respect to routing[50].

3.2 Imbalances in IPv4 Allocation

71. It is widely recognized there are imbalances in IPv4 allocation. In the words of Number Resource Organization (NRO), these imbalances are due to historical reasons:

> *During the 1980s and early 1990s, early adopters of the Internet were able to receive IPv4 address space under the allocation policies that existed at the time. These early adopter organizations were allocated and often still hold many more addresses than they would be allocated under present allocation principles, placing them in a relatively advantaged position today. This enduring imbalance is not a result of the current principles but rather a reflection that different allocation principles were in place in the past.*[51]

72. Although the current system of IP address administration "on a fair and equal basis to all users"[52] has been introduced, as noted at 2.1 in this document, the number of allocations to the US has constantly been accounting for about a quarter of the total allocation each year. This large address space allocation to the US is actually based on the current distribution system, and not on

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[47] Markus Kummer, *Internet Governance and the Need for an Inclusive Multi-Stakeholder Dialogue* (2007), available as http://www.oecd.org/dataoecd/60/53/37985809.pdf

[48] http://www.itu.int/wsis/docs2/tunis/off/6rev1.html

[49] See also Paragraph 85 of the Tunis Agenda for the Information Society.

[50] See *A Fine Balance: Internet Number Resource Distribution and De-Centralization* (Internet Society, 2009)

[51] See http://www.nro.net/documents/nro17.html

[52] See http://www.nro.net/documents/nro17.html

historical reasons. This trend might continue until the exhaustion of the IPv4 address pool, which is projected to take place in about two years, meaning that the difference in the number of IPv4 allocations between the US and the other economies might be getting larger.

73. According to the NRO[53], the current allocation policy is based on the immediate needs of users. The above fact shows the current mechanism may be favorable to early adopters (some of whom may have already mature network infrastructures and relatively big budgets). Thus, the allocation mechanism based on the immediate needs would tend to maintain the historical imbalances and especially affect developing countries. As an evaluation of potential needs in the future is difficult at best, the current mechanism may contain certain risks.

3.3 IPv4 Depletion and IPv6 Address Management

74. Since the 1980s it has been apparent that the number of available IPv4 addresses is being exhausted at a rate that was not initially anticipated. It is now projected by some experts[54] that, if the current trend continues, the unallocated IPv4 address space will run out by 2011-2012, as only 10.9% (28/256) of the total IPv4 address space remained unallocated by IANA in August 2009.

75. In 1990s, an Internet Protocol version 6 (IPv6) was developed primarily to solve the IPv4 depletion problem. IPv6 has a much larger (128-bit) address format (about 3.4×10^{38} addresses), which was considered by many to be ‘practically infinite’. IPv6 addresses are also allocated based on the ‘first come, first served’ and ‘demonstrated need’ principles and through the RIR mechanism as for IPv4 addresses.

76. Although implementation of IPv6 is still in the very early stage and very slow, there have been calls to conserve IPv6 address space in order to avoid premature exhaustion. Indeed, some countries may share a concern expressed by certain experts, namely that *“From a public policy perspective, there is a risk to create, yet again, an early adopter reward and a corresponding late adopter set of barriers and penalties”*[55]. As a consequence, there has been some tightening in IPv6 allocation policies.

77. Because of those concerns mentioned in 3.1 and 3.2 above, further studies in IPv6 address management have been suggested, as well as for other related topics. The report of the Working Group on Internet Governance (June 2005)[56] stated :

> *“In the light of the transition to IPv6, some countries feel that allocation policies for IP addresses should ensure balanced access to resources on a geographical basis.”* (paragraph 22)
>
> “*Transition to IPv6 should ensure that allocation policies for IP addresses provide equitable access to resources.”* (paragraph 77)
>
> *“[e]nsuring more balanced use of the IPv4 space, correcting the unbalanced distribution of IP numbers and sustainable transformation of the IP addressing system to IPv6.”* (paragraph 105)

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[53] *“IP addresses are allocated according to immediate need wherever that need is demonstrated, in accordance with well-known allocation principles”* http://www.nro.net/documents/nro17.html

[54] Geoff Huston, http://www.potaroo.net/tools/ipv4/index.html

[55] Millet & Huston (2005) http://mailman.apnic.net/mailing-lists/sig-policy/archive/2005/08/msg00005.html

[56] http://www.wgig.org/