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DIRECTORATE FOR SCIENCE, TECHNOLOGY AND INDUSTRY
COMMITTEE FOR INFORMATION, COMPUTER AND COMMUNICATIONS POLICY

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Working Party on Communication Infrastructures and Services Policy

INTERNET ADDRESS SPACE: ECONOMIC CONSIDERATIONS IN THE TRANSITION FROM IPV4 TO IPV6

DRAFT OUTLINE

London, 24-25 May 2007

This outline was prepared as a project of the Committee for Information, Computer, and Communications Policy ("ICCP") in the context of the ICCP Committee's project on the Future of the Internet Economy, which analyses the broad trends and policies that will shape the future of the Internet and aims to identify policies to support Internet infrastructure. At its 52nd Session in March 2007, the ICCP Committee agreed that the OECD should analyse the status of Internet addressing resources; in particular, investigate issues accompanying the exhaustion of IPv4 addresses and the adoption of IPv6.

The draft outline of this report on the status of global Internet addressing resources is submitted to the Working Party on Information and Communication Infrastructures and Services Policy (CISP), in order to gather expert substantive input from the CISP Working Party through discussion under item 15 of the CISP Working Party's draft agenda.

The CISP Working Party is invited to discuss the outline and provide comments on its proposed coverage and content.

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FOREWORD

Background

1. At the 52nd Session in March 2006, the Committee for Information, Computer, and Communications Policy ("ICCP") the status of Internet addressing was raised as a potential issue for future work. In particular, the economic aspects of the "exhaustion" of the IPv4 address space, and adoption of IPv6 were highlighted in the context of the ICCP-organised Ministerial on the *Future of the Internet Economy*, to take place in Seoul, Korea in June 2008.

2. The call for greater attention to this topic stems from a workshop on the "Social and Economic Factors Shaping the Future of the Internet" co-organised by the United States' National Science Foundation and the OECD on 31 January 2007, in Washington D.C. During the workshop, a number of experts stressed that the future of IP addresses, as a key element supporting the Internet, is becoming a critical issue to be addressed as the pool of IPv4 addresses becomes fully assigned. It was suggested that the OECD conduct analysis on the economic implications of a situation in which an existing resource is nearing full assignment and IPv6 is being adopted relatively slowly. In the view of one leading expert at the NSF-OECD Workshop, IPv4 address space may be fully assigned over the next three to five years if current trends continue. This could accelerate if perceptions of scarcity create greater short-term demand.

3. In addition, policy makers recognised one of the major challenges for all stakeholders in thinking about the future of the Internet is its ability to scale, for the next several billion users and potentially far greater demand from devices and objects which may increasingly be connected to the Internet. In this context, availability of numbering space in sufficient quantities to support the growing economic and social use of the Internet is a critical enabling factor.

4. The report is expected to contribute to the background analysis to be used by OECD policy makers in recommendations for the forthcoming ICCP-organised Ministerial-level meeting in June 2008. It is presented to the Working Party in Communication and Information Infrastructures (CISP) in order to gather expert input from CISP delegates.

Objective

5. Internet addressing is one of the most important enablers for the future growth and use of the Internet. The topic involves more than technical issues. Rapid depletion of the pool of IPv4 address space available for new assignments and the relatively slow adoption of IPv6 have clear economic dimensions and policy considerations, which go beyond technical considerations. Experience shows, for example, that in any situation where scarcity exists, a market will evolve to meet demand. In the case of IPv4, a secondary market, though not officially sanctioned in today's structure for address assignments, may evolve. Indeed, anecdotal evidence suggests it already exists. If such a market develops it should have clear "rules of the game" and transparent processes developed, or, at least, "endorsed" by the Internet community. This could include, for example, maintaining the requirements created by the Internet technical community to demonstrate actual need for addresses, in order to prevent any market mechanism

allowing the trading of address assignments being misused. There is also a clear need to maintain accurate records of assignment transfers to enable contact in times of security threats to the Internet. The development of a secondary market, without transparent processes, could detract from this goal.

6. The objective of the report will be to inform all stakeholders on economic questions concerning IPv4 address space "exhaustion", address allocation management, and adoption of IPv6. This report proposes to focus on two areas in which the OECD's experience of market-based solutions which may have value, namely:

- Based on the premise of an upcoming depletion of the pool of new IPv4 address space and on the fact that the "IPv4 Internet" will need to be maintained for years to come, the report proposes to investigate options for a greater economic dimension to assignment management. This may include, for example, developing a transparent market for address trading. At present, Internet registries, under the rules created by their members, are not permitted to transfer address space through buying or selling their assignments. Assignments are not regarded as property. Parties to which address resources have been assigned are not permitted to "sell" or "lease" addresses to another party. In an environment in which a resource is scarce, potential trading options may have several advantages, if conducted through transparent mechanisms. They could allow the market to place a value on address space, which could entice those with assignments, in excess of their requirements, to free them up for other players. Any options for change would, however, need to carefully consider whether the benefits of a new system would outweigh the costs associated.

- The IPv6 standard, established in 1998, is a new version of the Internet protocol. This report will discuss the main economic variables that currently determine adoption of IPv6 by different actors on the Internet: Internet Service Providers (ISPs), governments, technology developers etc. Analysis will draw on trends in related information and communication technology markets, such as new requirements generated by the deepening penetration of the Internet worldwide, the shift from a one PC per person paradigm to a multi-device environment, wireless developments, fixed-mobile convergence, or the development of RFID and sensor networks.

Scope of the report

7. The report will take into account existing data and short to medium term considerations. It will look at proposals, such as the proposal submitted by Japan Network Information Center (JPNIC) to several regional Internet registries (RIRs) in 2007: "IPv4 countdown proposal".

8. It will note long-term academic or basic networking research initiatives such as the Global Environment for Networking Innovations (GENI) facility planned by the United States National Science Foundation or the Future Internet Research and Experimentation (FIRE) initiative being undertaken by the European Commission. The paper will not, however, address any new forms of addressing and traffic routing or technical issues surrounding IPv4 or IPv6 unless they have an economic dimension.

Structure of the report

- The Introduction will briefly explain why IP addresses matter for the future of the Internet.

- Section I will provide an overview of the major initiatives that have taken place in Internet addressing to date.

- Section II will describe three major trends taking place in parallel today; in particular *i)* efforts towards more efficient allocation of remaining IPv4 addresses (approximately 20%); *ii)* developments in the area of Classless Interdomain Routing (CIDR) and Network Address Translators (NATs); and *iii)* factors that influence IPv6 adoption, drawing on available data. The focus of this section will not be on technology. Instead, it will consider the economic dimensions of such initiatives.

- Section III will sum up public policy issues raised and present options for a greater role for economic considerations to be taken into account by the Internet technical community. This could include market design options to take into account the continuing availability of IPv4 addresses for network operators in developing countries. It could also include economic considerations related to the adoption of IPv6 in networks, in server applications, or in user systems.

Main issues

1. IPv4 address exhaustion

9. Business continuity and continued growth of the Internet requires network addresses. At the same time, the pool of available IPv4 addresses available for new assignments is being rapidly depleted. Assuming consumption of IPv4 addresses continues at the current rate, or increases, the situation requires near-term attention to issues that are not only the technical but also economic. Technical or transition solutions such as Network Address Translators (NATs) may no longer be sufficient and may create unintended consequences of their own, such as increasing the Internet’s complexity and costs of operation.

2. Lack of incentives to adopt IPv6

10. At present there appears to be a lack of customer driven demand for the adoption of IPv6. Without demand from customers it is unlikely that the take-up of IPv6 will occur in a timely manner to address the depletion of the pool for new assignments of IPv6.

3. Address allocation distribution

11. An additional issue warrants attention. Due to historical factors, a great majority of IPv4 addresses have been allocated to network infrastructure operators in developed countries. Meanwhile, high growth is expected in developing countries in the coming years. To date, the Internet community has done an excellent job in ensuring that all networks have IPv4 addresses sufficient to meet their needs. Ensuring availability of enough IPv4 addresses in the transition to IPv6 could be challenging if the available pool for new assignments rapidly dwindles. An economic mechanism which assists in this process may be worth consideration. A question to be considered is how market mechanisms can be utilised positively to take into consideration concerns such as ensuring a level-playing field for new entrants and/or for operators in developing countries (*e.g.* a trading mechanism could allow those with large existing assignments to donate IP address blocks for use in developing countries).

4. Necessary coordination and cooperation

12. From a policy perspective, an orderly transition from IPv4 to IPv6 would be desirable. Indeed, a key challenge is in changing the Internet in a co-ordinated way to achieve long-term goals, such as through IPv6 integration rather than through short-term-patches, without disruption of on-going Internet operations. However, the process of IPv6 take-up is proving to be slow. For orderly protocol migration to happen IPv4

address space needs to be managed as efficiently as possible. During this period an effective worldwide upgrade to IPv6 needs to be undertaken.

13. The Regional Internet Registries (RIRs) in charge of address space distribution have developed IPv6 allocation policies. Some RIRs also seem to be tightening their IPv4 address allocation policies, in view of the upcoming depletion of the pool of IPv4 address space for new assignments, in particular through closer enforcement of their needs-based allocation policies. Moreover, in an environment in which market-based secondary trading appears, the basis of the current address allocation function requires careful review, because the potential for unintended consequences of two systems operating in parallel is very high. In addition, the potential impact of trading IP addresses on the routing table by increasing or decreasing its size needs to be considered and potential means to minimise strains on the routing system considered. The databases containing Internet addresses and their allocation, that are published publicly using the IP Whois protocol, needs to accurately reflect assignments if a secondary market develops.

14. Any "rules of the game" for a secondary market for IPv4 Address space should be developed, principally by the Internet community, in consultation with all other stake-holders. This would enable operational and technical concerns to be taken into account in respect to the design of any economic mechanism, should an economic mechanism be thought beneficial.

15. In terms of the IPv6 business case, policy makers could benefit from a better understanding of where and why IPv6 investments are made. This information will help policy makers in understanding the mechanisms available to them to help shape market incentives in view of an industry transition to Ipv6. A leading issue for the future will be more effective co-ordination activities; *i.e.* finding ways to bring together equipment vendors, Internet providers, researchers, economists, academics, and public policy analysts to collectively discuss options to support future Internet growth.

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INTRODUCTION TO INTERNET ADDRESSING

Contextual background: the importance of addressing in the overall functioning of the Internet.

16. Each device connected to the Internet has a unique numeric identifier: its Internet Protocol (IP) address—in simpler terms, a network address. IP addresses need to be attributed to each network on the Internet, in function of the network size, for network managers to in turn allocate to each device. IP addresses identify devices and enable them to communicate with each other on networks using the Internet Protocol standard (IP). Any participating network device—including routers, computers, servers, printers, Internet fax machines, and IP phones—can have its own unique IP address.

17. The IPv4 address space is limited by its 32-bit address scheme, which limits the address space to 4,294,967,296 (2^{32}) possible unique addresses, and as the number of addresses available is consumed, an IPv4 address shortage seems inevitable. Moreover, in addition to legacy allocations (~1.6 billion addresses), some portions of the space are unavailable because they are reserved for special purposes such as private networks (~16 million addresses) or multicast addresses (~270 million addresses), reducing the number of addresses that can be allocated as public Internet addresses.

Brief history and role of various actors / institutions: ICANN/IANA, RIRs, network operator groups

18. Allocating IP resources and disseminating new standards such as IPv6 requires continued wide-spread collaboration, including by the Internet Engineering Task Force (IETF) from a standards perspective, by the Internet Corporation for Assigned Names and Numbers (ICANN), by the Regional Internet Registries (RIRs) and the Number Resource Organisation (NRO), by root server operators, and by many others.

19. The IANA (Internet Assigned Names and Numbers) registry services that ICANN performs consist in assigning IP addresses to Regional Internet Registries (RIRs). ICANN’s Address Supporting Organization (ASO) coordinates IP address policies for the RIRs: Réseaux IP Européens-Network Coordination Centre (RIPE-NCC), the American Registry for Internet Numbers (ARIN), the Asia Pacific Network Information Centre (APNIC), the Latin America and Caribbean Network Information Centre (LACNIC), and the African Network Information Centre (AfriNIC). RIRs, in turn, allocate IP addresses to national Internet registries (NIRs) or, in countries without a NIR, to local Internet registries (LIRs), to in turn allocate to Internet service providers (ISPs) who assign IP addresses to enterprises and end-users.

20. Each Regional Internet Registry (RIR) is allocated blocks of IP address space from IANA. Each RIR is responsible for maintaining a database containing information on the allocation and use of IP address space within their region. Information includes the IP address space, the Autonomous System (AS) number, organisation name, and points of contact.

SECTION I: OVERVIEW OF MAJOR INITIATIVES IN INTERNET ADDRESSING TO DATE

21. The purpose of section I will be to show how addressing in the Internet context has been revised over the years to support remarkable expansion in the global use of Internet, with over one billion Internet users connected in 2007 and increasingly pervasive IP-based supporting infrastructure.

- As the Internet continues to grow, more IPv4 addresses are requested for new devices and applications. Studies predict an exhaustion of new IPv4 address space between 2009 and 2015.
- The combination of Classless Inter-domain Routing (CIDR) or Network Address Translators (NATs) has helped slow down the exhaustion of the address space. However, because NAT breaks the end-to-end model of the IP protocol, some consider that it places limitations and complexity on other Internet protocols.
- IPv6 was developed by the IETF in 1998. Characteristics of IPv6 include, first and foremost, a widely-expanded address space. In addition, IPv6 proponents claim that it can provide better support for always-on and real-time services, and mobility. Some claim that IPv6 can also provide better end-to-end security support, while others claim that the level of support is not different from that provided in IPv4. Overall, business adoption of IPv6 has been slow, to date.

1) IPv4 addresses and allocation policy

Legacy IPv4 address allocations

IPv4 allocation principles e.g. aggregation, conservation, registration

2) "Buying time" through the development of CIDR or of private addressing through NAT

22. This section will briefly explain how the Internet Engineering Task Force (IETF) took on the task of finding several short-term measures e.g. by introducing the "Classless" address architecture, also known as Classless Interdomain Routing (CIDR) to allow for more efficient use of remaining IPv4 space and by devising Network Address Translation (NAT). NATs enable a single device, such as a router, to act as an agent between the public Internet and a local private network. Thereby, an entire group of computers and other connected devices become "clients" (as opposed to both clients and servers in the "end-to-end" model that characterised the early Internet) and need only a single, unique IP address.

3) The development of IPv6

23. This section will relate the introduction of a new network level protocol called Internet Protocol version 6 (IPv6) in the early 1990s and the advantages that IPv6 offers over the current standard, IPv4. IPv6 has been an ongoing effort since 1993 and is often viewed as a technical strategy that might provide potentially useful solutions to current problems. The section will focus on the means for coexistence of the two protocols, IPv4 and IPv6, since the two protocols are not "interoperable" and it is expected that IPv4 will be supported alongside IPv6 for the foreseeable future.

SECTION II: CURRENT TRENDS

24. Section II will examine three significant trends that are taking place in parallel, and that appear likely to remain in the foreseeable future.

TREND 1: Efforts to mitigate effects of IPv4 address exhaustion

25. This section will investigate whether there are any visible efforts directed to mitigation of the effects of the looming IPv4 address exhaustion. By way of background, some working definitions of concepts such as that of "IPv4 address exhaustion" (i.e. exhaustion of the IANA pool, of the RIRs' pools, of the LIRs' pools) will be provided.

IPv4 address exhaustion forecasts

26. This section will detail several analyses of IPv4 address consumption rates and lifetime projections. Experts predict that, if current allocation rates prevail, IANA will exhaust all available IPv4 space sometime between 2008 and 2016. Most notable are Geoff Huston's "IPv4 Address Space Report", Tony Hain's "A Pragmatic Report on IPv4 Address Space Consumption" and KC Claffy's analysis of IPv4 consumption rates.

27. It needs to be noted that estimates of an exhaustion date assume no major technology or policy changes. Therefore, any change in the distribution system or any "land rush" on IPv4 addresses may cause disruption.

Tightening allocation criteria

28. This section will detail whether the RIRs are considering any substantive new address policies, which could impact on the exhaustion of the IPv4 address space (e.g. the lowering of the IPv4 allocation size, making the allocation criteria stricter etc.). Timeline estimates will be provided, *e.g.* timelines for an open policy process to be developed by a RIR, and different possible scenarios will be investigated.

Reclaiming unused IPv4 address space

29. This section will discuss potential mechanisms for reclaiming unused IPv4 address space (in the early days of the Internet, large blocks of IP addresses were allocated to individual entities and it is sometimes suggested that these allocations, when these entities no longer exist or addresses are not used, could be reclaimed by the IANA and reissued). So far, the prevailing view has been that addresses are not assets, and have no monetary value: under this regime, attempts to reclaim address space have been largely ineffective. Therefore, the question of interest in this section will be whether assigning a realisable value to IP addresses through market operation, *i.e.* "monetising" the "asset", would assist in any reclamation process by creating impetus for address redistribution.

Fairness and security issues with grey and black IPv4 address trading markets

30. This section will discuss the concept of address uniqueness and the reason for which uniqueness is critical for the operation of the Internet. A "black" market for IP addresses is deemed to exist today, raising issues about concealment of the title of an address block. In addition to creating the opportunity for anonymous use of addresses, it also creates the potential for the same address to be "sold" multiple times, thereby destroying the uniqueness of the address. In such a black market, it is difficult for a buyer to establish that addresses offered for sale are indeed unique addresses, that these are the legitimate property

of the seller, and once the transaction is concluded, to have the “title” of the address block transferred over. This section will also detail the security concerns that such a market raises, e.g. as an enabler for spammers, and will look into the additional security risks posed by a black market in a situation in which there are no “new” IPv4 address resources available.

Structuring and stabilising a market for trading IPV4 addresses

31. This section will show that exhaustion of the unallocated IPv4 address pool does not imply unavailability of IPv4 address resources to industry players and that there is reason to believe the Internet industry will continue to use IPv4 as a base protocol long after IPv4 address exhaustion. After exhaustion of “new” addresses, in the absence of external controls, conventional economics would predict the emergence of various forms of trading markets for address space. Within a market-based pricing dynamic, address pools that are not routed (i.e. not advertised in the routing table), poorly utilised address pools and other address holdings could be resold. This section will focus on necessary rules of the game in such a market, various elements put in place from an institutional perspective such as the RIRs’ role, potential scarcity premium, and the likelihood or otherwise of potential behaviour such as hoarding and speculation. Security and universal uniqueness concerns will be discussed. The global nature of such a market and consequent challenges for imposing regulation outside of any individual national regulatory framework will be considered. In addition, possible alternative options will be noted and discussed.

TREND 2: Broad deployment of Network Address Translators (NATs)

32. This section will briefly discuss the widespread deployment of NATs, their perceived benefits (*e.g.* low cost, perceived security, low usage of IP addresses) and perceived problems (*e.g.* complexity of networks, asymmetry between clients and servers, interference in peer-to-peer applications, blacklisting, potential competition policy issues vis-à-vis Internet Service Providers).

- Impact of NAT deployment on conservation of the IPv4 address space

- Issues caused by Network Address Translators (NATs) and limitations of NAT to support global Internet growth. It may also be worth considering what further refinements are likely in the NAT model, particularly as they relate to the interaction of NATs with the DNS and with applications.

TREND 3: Drivers of, and challenges to, IPv6 adoption

33. This section aims to examine the current status of IPv6, with regards to rollout, policy, technology and applications.

Current status of IPv6 deployment

34. The aim of this section of the report is to provide an overview of IPv6 deployment worldwide. It is expected that data will be segmented by region and country, as well as by actor in the Internet value chain:

- Implementation status: support by operating systems (*e.g.* Windows Vista, Linux), by hardware (*e.g.* routers), by key Internet technologies (*e.g.* BIND, DNS, DNS root zone transport), by public domain applications, by commercial applications.

- IPv6/IPv4 traffic ratio, traffic ratio at Internet exchanges.

- IPv6 allocations by region/country: Japan, South Korea, Taiwan, China, North America, Europe, India, Latin America, Australia, the Middle East and Africa.

IPv6 allocation criteria (e.g. aggregation, conservation, registration, single prefix)

Drivers of IPv6 adoption

35. This section of the report will seek to understand how and why IPv6 is adopted, by addressing some of the following questions:

- To date, who has registered IPv6 addresses? Where are they located geographically? What portion of IPv6 routing appears in the routing table?

- What category of organisation, e.g. Internet Service Providers, or enterprise network operators, can be considered as critical adopters?

- What are the factors that prompt certain organisations to be adopt IPv6? In particular:
    - What, if any, comparative advantage is provided by adoption?
    - What, if any, role for regulation and public procurement mandates?
    - What potential for new service markets such as “smart buildings”, “smart traffic control”, consumer devices, or identification tags? What, if any, is the importance of “killer applications”?

- What factors characterise early adopters/late adopters, i.e. what organisational characteristics and market conditions influence the timing of the adoption decision?

- What are incentives to migrate, for ISPs, hardware providers, software providers, consumer electronics vendors e.g.?
    - A reachable IP address for peer-to-peer applications, e.g. VoIP, innovative applications
    - The potential for scaling that IPv6 provides
    - Strategic long-term advantage
    - Avoidance of opportunity costs of staying with IPv4
    - Public sector mandates *e.g.* US Office of Management and Budget (OMB) mandate, E.U. mandate

- What are some demand-side considerations, e.g.:
    - Support of wireless: mobile phones, personal digital assistants (PDAs) etc.?
    - Other devices?
    - Next generation networks (NGN) and Session Initiation Protocol (SIP)?
    - Other e.g. Defence, GRID, Car-2-Car applications, Space programs, Satellite and HDTV sectors?

Challenges to adoption: backwards compatibility, cost, lack of customer demand, lack of competitive advantage

36. This section will focus on the challenges to IPv6 adoption. Because IPv6 is not backwards compatible with IPv4, the costs of deployment are close to those of a Greenfield deployment (a “brownfield” deployment, in contrast, upgrades or adds to an existing network using legacy components), but without the usual opportunities of Greenfield opportunities.

Transition / co-existence techniques

37. This section will look at other initiatives that may provide industry alternatives. For example, could further technical effort create the impression of backwards compatibility using network middleware? Has the potential of application level gateways been fully explored? Can NATs play a different role? Are there alternatives in NATs and DNS?

SECTION III: POLICY IMPLICATIONS AND ISSUES FOR CONSIDERATION

38. This section will sum up public policy issues raised. The report will consider areas in which international public policy cooperation may be needed when the IPv4 unallocated address pool is exhausted, to ensure continued growth of the Internet. In addition, the most appropriate ways of supporting the future of the Internet, such as acquiring experience with IPv6 in networks, in server applications, and in user systems, will be considered.

Anticipated timeline

Policy approaches taken

39. This section will look into:

- The technical community's approach to IPv4 address shortage and to IPv6 deployment
- Countries' approach to IPv4 address shortage, to IPv6 and the role of public policy (e.g. mandates)

International public policy co-operation requirements

40. To deal with IPv4 address shortage and slow private sector deployment of IPv6, this section will look into areas in which policy makers could benefit from cooperating internationally in areas such as:

- A potential secondary trading market for IPv4 addresses and concepts of global distribution fairness
- Identifying drivers for IPv6 adoption in developing and developed countries, and determining to what extent this is a policy question, to what extent this is a technology question and to what extent this is a research and development opportunity.