Scarcity in IP addresses: IPv4 Address Transfer Markets and the Regional Internet Address Registries

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We are running out of Internet addresses. This paper evaluates address transfer policies that Internet governance agencies are considering as a response to the depletion of the IPv4 address space. The paper focuses on proposals to allow organizations holding IPv4 addresses to sell address blocks to other organizations willing to buy them. This paper analyzes the economics of the proposed transfer policies, and conducts a systematic comparison of the policies proposed in the three main world Internet regions. It concludes that:

- *Address transfer markets offer a pragmatic solution to the problem of reclaiming a substantial amount of unused IP address space and of re-allocating addresses to their most efficient uses*
- *The risks of instituting well-designed address transfer policies are small when compared to the potential benefits. The change is less radical than it appears.*
- *A failure to legitimize address transfer markets would create substantial risks of the institutionalization of gray or black markets in IPv4 address resources, leading to a deterioration of accurate registration and administration of the legacy address space. This could have severe negative implications for Internet security.*
- *One should not prevent IPv4 address transfers in order to push organizations into IPv6. If migration to IPv6 is beneficial, a transfer market could only prolong the transition, it could not stop it. We do not know how long it will take the global Internet to transition to IPv6, or even whether such a migration will succeed. Given the uncertainties surrounding dual stack implementation, a longer transition period may turn out to be very helpful.*
- *The proposed address transfer policies being considered by RIPE and APNIC are more liberal than ARIN's. Most of the legacy IPv4 address space is in North America; thus, the policies ARIN adopts have the most importance and should be formulated with the good of the global Internet in mind. RIPE, ARIN and APNIC should strive to harmonize their transfer policies and (in the longer term) make inter-regional transfers possible.*

Introduction and background

What happens when the Internet addresses run out? That question has been generating growing concern among Internet operators and policy analysts. The problem is fundamental to the future of the Internet.

The Internet we know is based upon a data communication protocol known as Internet Protocol version 4 (IPv4). IPv4 is a software procedure that moves data packets from one unique numerical address to the other.[1] The 1981 standard that defined

[1] RFC 791, Internet Protocol, DARPA INTERNET PROGRAM PROTOCOL SPECIFICATION, September 1981. See also RFC 790, Assigned Numbers, Jon Postel, September 1981.

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Internet Protocol created a fixed address field of 32 bits, which creates a mathematical possibility of about 4 billion unique addresses.

Because of continuing Internet growth, IPv4 addresses have become scarce and valuable resources. Put simply, we are running out of them. At the middle of 2008, the last remaining stash of unused address blocks – the so-called "unallocated address number pool" – had dwindled to only 39 blocks. In recent times, these blocks of addresses have been distributed to regional address management entities at a rate of about 12 per year, which means we have only about a three year supply left. Demand may accelerate as exhaustion of this pool approaches, but even if it doesn't the end of the unallocated pool is within sight.[2]

The problem of address scarcity is as severe for the Internet economy as the oil shocks and gasoline shortages of the 1970s were to the industrial economy. Address shortages could act as a brake on the growth of the Internet. Emerging Internet economies in Africa, Asia and Latin America are just beginning to fulfill their potential level of Internet development.

In principle, a new Internet standard, IPv6, solves the problem of address scarcity because it has a very large address space (2^{128} addresses). But the new Internet standard is not compatible with the old one. Thus, anyone who implements IPv6 and throws away their IPv4 capabilities is going to be isolated, cut off from the vast majority of communication partners, web sites and services associated with the old Internet. One must think of the transition from IPv4 to IPv6 as the (possibly temporary) co-existence of two distinct "Internets."[3] One way to keep the two Internets universally interconnected is for adopters of the new standard to run both versions of Internet protocol. This is known as running "dual stacks." Another way is to use Network Address Translation – Protocol Translation (NAT-PT).[4] Both methods require IPv6 users to use IPv4 addresses during the transition period. During the migration to IPv6, users will not engage in simple substitution of IPv6 addresses for IPv4 addresses. IPv4 address resources will continue to be in demand.[5]

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[2] A 2005 study by Cisco's Tony Hain projected depletion of the IANA pool by 2010. Tony Hain, "A Pragmatic Report on IPv4 Address Space Consumption," *The Internet Protocol Journal*, Volume 8, Number 3. http://www.cisco.com/web/about/ac123/ac147/archived_issues/ipj_8-3/ipv4.html Another respected computer scientist who, in 2003, projected that the IPv4 address space would last "another three decades or so" now projects the depletion date of the IANA pool at January 2011, and the depletion of the regional subpools at November 2011. See Geoff Huston, "IPv4 Address Report" http://www.potaroo.net/tools/ipv4/ . For Huston's earlier study see Geoff Huston, "IPv4: How long do we have?" *The Internet Protocol Journal* Volume 6, Number 4.

[3] The value of networks depends on who else is on the same network. Because of this network externality, users who abandon a network that already reaches a large segment of the population are penalized. Network externalities create "inertia" that must be overcome by very strong economic or technical advantages of a new standard. See Farrel, J. and Saloner, G. 1987. "Competition, Compatibility and Standards: The Economics of Horses, Penguins and Lemmings." In Gabel, ed. *Product Standardization and Competitive Strategy*. Amersterdam: Elsevier.

[4] See RFC 2766 (2000), "Network Address Translation - Protocol Translation," http://www.ietf.org/rfc/rfc2766.txt

[5] See the blog post of Dave Piscietello, Feb. 11, 2008: If 'NAT will save us' is the war cry of the IPv6 averse part of the community, then 'dual stack will save us' is the counter-cry of the IPv6 advocates who've left the hard nuts in deployment for someone else to crack." http://www.securityskeptic.com/catRant.htm

How long is that transition period likely to be? No one knows for sure, but efforts to model this problem do not yield encouraging results. One group of academics applied mathematical diffusion models to IPv6 adoption and projected that the overlap period under the most favorable assumptions could take no less than 6 years, and might take up to 70 years.[6] There are still Internet technical people who openly claim that IPv6 will *never* succeed in reaching the critical mass needed to replace the IPv4 Internet.[7] Another recent economic assessment of the incentives to migrate also came up with pessimistic conclusions.[8] Thus, it would be unwise for IP addressing policy to be based on the assumption that a global migration to IPv6 is inevitable. Sound address management should be designed to conserve and reclaim IPv4 resources and ensure that they are assigned to their most important, highly valued uses.

What should be done? This paper evaluates transitional policies that Internet governance agencies are considering as a response to the depletion of the IPv4 address space. In particular, the paper focuses on proposals to allow organizations holding IPv4 addresses to sell address blocks to other organizations willing to buy them. IP *address transfer markets*, as they are called, have been proposed as a pragmatic way to extend the life of the IP address space. One important benefit of such a policy is to provide incentives for existing holders of addresses to release unused address resources. Another possible benefit is the way it might rationalize and make more transparent an underground economy in address resources. Transfer markets also increase the autonomy of Internet users by providing an alternative to the centralized administrative processes that currently control address allocations. Fairly liberal address transfer market proposals are being considered in the European and Asia-Pacific regions. A more restrictive transfer proposal is also under consideration in North America.

This paper analyzes the economics of the proposed transfer policies, and conducts a systematic comparison of the policies proposed in the three main world Internet regions. It concludes that:

- Address transfer markets offer a pragmatic solution to the problem of reclaiming a substantial amount of unused IP address space and of re-allocating addresses to their efficient uses
- The risks of instituting well-designed address transfer policies are small when compared to the potential benefits. The change is less radical than it appears.
- A failure to legitimize address transfer markets would create substantial risks of the institutionalization of gray or black markets in IPv4 address resources, leading

[6] Elmore, H., L. Jean Camp and Brandon Stephens. 2008 "Diffusion and Adoption of IPv6 in the ARIN Region." Paper presented at the 2008 Workshop on the Economics of Information Security, June 25-28, Tuck School of Business, Dartmouth College, Hanover NH. http://weis2008.econinfosec.org/papers/Elmore.pdf

[7] J.H. Woodyatt is one of many. See his interesting blog post of March 2008 http://jhw.vox.com/library/post/the-future-without-ipv6.html

[8] Benjamin Edelman, 2008. "Running Out of Numbers: The Impending Scarcity of IP Addresses and What To Do About It." Unpublished paper draft, http://www.benedelman.org/publications/runningout-draft.pdf

to a deterioration of accurate registration and administration of the legacy address space. This could have severe negative implications for Internet security.

- IPv4 address transfers should not be prevented as part of an attempt to push organizations into IPv6. If migration to IPv6 is beneficial, a transfer market could only prolong, not stop, the transition. We do not know how long it will take the global Internet to transition to IPv6, or even whether such a migration will succeed. Given these uncertainties, a longer transition period may turn out to be very helpful.
- The proposed address transfer policies being considered by RIPE and APNIC are more liberal than ARIN's. All three could be improved in various ways. Most of the legacy IPv4 address space is in North America; thus, the policies ARIN adopts have the most importance and should be formulated with the good of the global Internet in mind. RIPE, ARIN and APNIC should strive to harmonize their transfer policies and over the longer term make inter-regional transfers possible.

The significance of this issue goes beyond a narrow assessment of transfer markets as a policy. The creation of address transfer policies both reflects and reinforces the growing importance of the Regional Internet Address Registries in global Internet governance. Thus, this paper supports a broader conclusion which will be explored in greater detail in a future IGP paper:

- For transfer markets to work properly, the registration and enforcement functions of the RIRs will need to be strengthened. As the address allocation process becomes more institutionalized, we will need stronger public policy frameworks for RIRs to operate within. These policy frameworks should retain and respect the RIRs' status as independent self-regulatory entities, but also ensure that their policies are constrained by basic human rights protections regarding freedom of expression, privacy and due process, as well as economic policies regarding competition.

The IP Address Governance Regime

To understand the controversy surrounding IPv4 address depletion and transfer markets, some description of current institutional arrangements around address management is necessary. Address assignments are made in a hierarchical fashion. At the top of the hierarchy is ICANN, whose IANA function distributes large blocks of 16,777,216 addresses (known as /8's) to one of five regional Internet address registries (RIRs). The RIRs then accept applications from organizations with networks that need addresses within their territory. Some larger blocks may be assigned directly to end user organizations, but most will go to Internet service providers who will then re-assign them to their customers. (An "allocation" is an address block given to an Internet service provider for intermediate use in selling internet service to other users. An address "assignment" is a block given to end users for their own use; e.g., corporations or universities with private networks.)

RIRs were created in the 1990s as the Internet protocols began to be widely adopted.[9] The first Regional Internet Registry, RIPE-NCC, was created in 1991 to serve the European region. In 1995 APNIC was created as the RIR to serve the Asia Pacific region. Both were incorporated as private sector nonprofits. In 1997, parallel to the creation of ICANN, the address administration functions performed by several U.S. government contractors were privatized and placed in the hands of a new nonprofit entity known as the American Registry for Internet Numbers (ARIN). All three of the RIRs rely on a private sector-based, contractual model of governance.

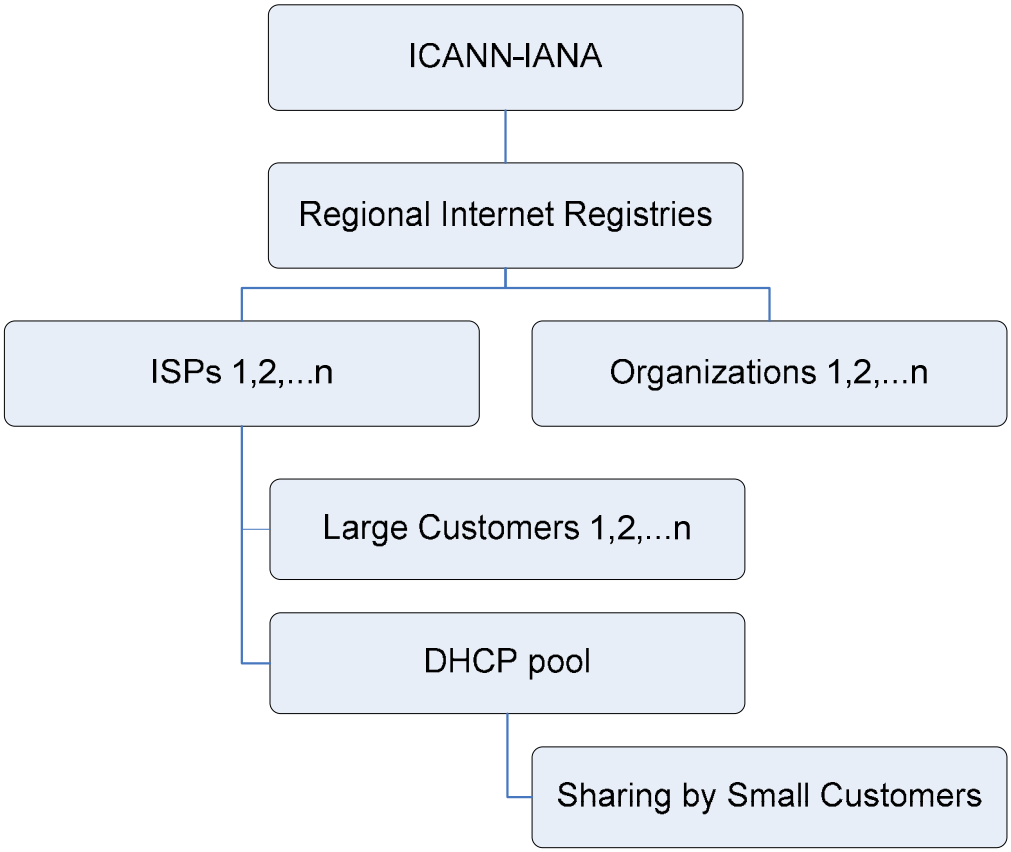

Figure 1: Address Block Delegation

The creation of the RIRs led to tighter and more formalized address allocation and assignment policies, and more careful registration and tracking policies. Before they were created, however, a large portion of the IPv4 address space had already been

[9] See RFC 1174 (1990) and RFC 1466 (1993) for the earliest documents documenting the rationale for creating Regional Internet Registries.

assigned or allocated, perhaps as much as half. Many of these "legacy allocations" made before 1997 are still held without any contractual obligations.[10]

A Common Pool Model?

The RIRs have developed a consistent ideology about address management policies, which are codified in their own policy documents.[11] Address resources are considered a "shared public resource" and the RIRs are considered their "stewards." Addresses are said to be "loaned" to private users, not sold, and users are not supposed to gain any property rights in an address block they are granted.[12] Although RIRs finance themselves via address-related fees and membership charges, they insist that members are not "buying" addresses but are merely paying the RIR for services associated with administering the address space and its registry. The RIRs formally prohibit assignees from reselling or transferring the addresses directly to other private users. But the line between permitted and not-permitted transfers is gray, not bright and clear. Internet service providers who hold address allocations sell services commercially to their customers, and among these services are fixed IP addresses, with specific charges associated with addresses. Also, when companies with IP address allocations or assignments are merged or acquired, RIRs allow the address resources to be transferred along with ownership of the company.

The RIR ideology of resource stewardship has some similarities to the economic model of a common pool resource.[13] The common pool model is used to govern natural resource use in other contexts, such as unlicensed radio spectrum, forests, water or marine fisheries. Common pool governance is typically employed when two conditions are met: consumption of the resource is rival (i.e., one person's use or consumption prevents another person from also using/consuming it), and it is difficult to exclude people from appropriating the resource (which makes the model of markets based on private property rights difficult to apply). The task for a governance agency is to regulate appropriation of the resource in a way that maintains its value.

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[10] Like many processes associated with the Internet, the distribution of IPv4 addresses began very informally in the early 1980s, when the Internet was basically a research project. A computer scientist at the University of Southern California handed out big swaths of the available space to members of the American military-industrial-university complex: MIT, Stanford, Hewlett Packard, Motorola, General Electric, Halliburton, Defense Department agencies, etc.

[11] See the general APNIC FAQ, http://www.apnic.net/info/faq/apnic_faq/obtaining.html; the *ARIN Number Resources Policy Manual* http://www.arin.net/policy/nrpm.html; and the RIPE *IPv4 Address Assignment and Allocation Policies for the RIPE NCC Service Region* http://www.ripe.net/ripe/docs/ipv4-policies.html

[12] For the seminal document contrasting the "address ownership" policy with an "address lending" policy and arguing that only the lending model was consistent with the need for hierarchical route aggregation, see RFC 2008, "Implications of Various Address Allocation Policies for Internet Routing" Y. Rekhter, T. Li. (1996). It is important to emphasize that this important policy document did not argue against address ownership policies or private transfers on equity grounds, nor did it justify "needs based assessment" of address requests. It simply noted that for the Internet to continue growing that routes needed to be aggregated under providers, so when private users switched providers they would have to give up their addresses.

[13] For a sampling of the institutional economics literature, see Elinor Ostrom, 1990. *Governing the Commons: The evolution of institutions for collective action* Oxford University Press; Elinor Ostrom, Roy Gardner, James Walker, 1994. *Rules, Games, and Common-pool Resources*. University of Michigan Press; Anderson, Terry L., Grewell, J. Bishop (2000) "Property Rights Solutions for the Global Commons: Bottom-Up or Top-Down?" In: Duke Environmental Law & Policy Forum, Vol. X, No. 2, Spring 2000

Under certain conditions, common pool governance has very good economic and social properties. Simple, collectively applicable limits on the number of trees one can cut or fish one can remove, for example, conserves the resource pool while maintaining easy access to the resource and very low transaction costs. In the case of unlicensed spectrum, anyone who wants to offer service in an unlicensed wireless band can enter freely without prior permission from regulatory authorities. Appropriation is governed by technical limits on transmission power and protocol specifications, which prevent any single transmitter from hogging too much of the spectrum resource.

Despite the appealing ideology of common resource stewardship that appears to underlay RIR policies, there are major failings in the application of the common pool model to IP address resources. Address consumption is rival, but it is not that difficult to exclude unauthorized people from using them. Under the RIR regimes, appropriation from the common pool is not based on a simple and uniformly applicable appropriation limit, but on complex, expensive, case-by-case administrative procedures. In order to get resources from the address pool, applicants must individually request resources from the RIR and demonstrate their "need." The RIR bases its decision on engineering studies of the applicant's plans. This is more like a central planning regime than classical common pool governance. Under conditions of intense scarcity, such a process is not only costly but inherently inaccurate because of the asymmetry of information between the requestor and the granting agency.

Another crucial difference between the RIR regime and what we normally think of as common pool management is that when IP addresses are not used by those to whom they have been allocated, they do not automatically return into the common pool for use by others. Those who have been allocated or assigned address resources retain exclusivity over an address block regardless of whether they are using the resources. Cumbersome administrative processes are required to move resources from a nonuser to a prospective user. In a true common pool model, the IP address space would work like a gigantic DHCP address pool.[14] Organizations would grab addresses (like catching fish) only when they were actually using them, and as soon as they were not using them the addresses would be released back into the common pool for use by others.

That is not how things work now. Organizations that have been given IP addresses retain them until they choose to give them up, and users have very weak incentives to return addresses to RIRs.[15] If they don't give them back, nothing bad happens. If they do give them back, they incur both administrative costs (the cost of altering their records and interacting with the RIR) and opportunity costs (the cost of

[14] DHCP stands for Dynamic Host Configuration Protocol, and defines mechanisms through which clients can be assigned a network address for a finite lease, allowing for serial reassignment of network addresses to different clients when one client ceases using an address. See RFC 2131.

[15] In principle APNIC allocates addresses on an "annually renewable" basis. In practice it seems to rely primarily on the organization's initiative to reclaim addresses.

foregoing future use of the addresses). RIRs' ability to monitor the actual usage of assignments is limited. Even if they did have perfect information about actual usage and "needs" of applicants, their enforcement powers are weak. They cannot impose financial penalties on organizations; they can only terminate a service contract and threaten never to assign the organization any more addresses. Even this does not directly deprive the users of addresses; it only signals to Internet service providers that the organization is not the legitimate holder of the address block, which *may* lead ISPs to refuse to route packets to those addresses.[16] Another crucial limitation on ARIN specifically is the large number of *legacy address allocations* which are held without any contractual obligations. Legacy allocations were made before the RIRs existed, and RIRs lack the authority to recover them until and unless the holders of the address resources voluntarily choose to sign "Legacy Registry Service Agreements."[17]

In sum, the RIR regime captures only half, possibly less, of the standard benefits associated with common pool management. It regulates appropriation effectively, but it raises the cost of access and does a very poor job of facilitating reclamation and reuse.

Latent markets and Unused Resources

Given the major imperfections in the realization of common pool objectives, it is not surprising to discover latent markets for address resources and underground transfers taking place. In June 2008, for example, a private sector participant stated publicly on the ARIN Public Policy Mailing list, "I have been aware of people ...buying, selling and using subterfuge to obtain IP allocations for as long as I have been in the industry (the past 8 years)."[18] The examples provided by this person are worth quoting at length:

> a. Three companies merged into one. For many months after they merged they continued to interact with ARIN as separate entities, obtaining far more IP allocations than they would have been able to as a single entity. Even today, this single entity (which has now recently merged again), interacts with ARIN using two separate, but related entity names and two separate ORG IDs.
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> b. Every month I run into people who are willing to sell me their /18, /19, /20 for a fee. It is my understanding that such transactions are usually structured so that other [usually worthless] assets or an entire shell entity are included in the

[16] The primary regulatory leverage the RIRs have comes from their maintenance of IP address registries and their associated Whois service. The whois service allows Internet connectivity providers to look up the identity of organizations that hold address blocks. ISPs will usually not issue route announcements for address blocks unless they first check IP address Whois to see that these blocks have some relation to their client. Transfers of IP addresses that bypass the RIR registry, therefore, might have trouble being routed or carried by ISPs. When RIRs revoke an address allocation or assignment, another user could be given those addresses. Other ISPs may cease to carry route announcements for the prior address block holder.

[17] ARIN's new Legacy RSA contracts, http://www.arin.net/registration/legacy/index.html, bring uncontracted legacy address resource holders into the contractual system but promise not to reclaim unused resources.

[18] Jay Sudowski, Handy Networks LLC. Posting to ARIN Public Policy Mailing List June 20, 2008.

sale to pass ARIN scrutiny.

c. For a time, I did work for an entity that had previous bad blood with ARIN… and managed to obtain 3 /18s on the after market. From what I gather, this is not all that unusual.

d. There are consultants out there who, for a fee, guarantee you will get an IP allocation from ARIN. They are able to accomplish [this] because they control a large amount of IP space for entities that they work for, and they SWIP out space from those entities to the entity paying them for the direct allocation. …

e. ARIN members continue to report IP usage by customers that have long since left their network, inflating their actual need and utilization percentages, allowing them to obtain unnecessary allocations from ARIN.

As our analysis of incentives above suggested, reclamation of unused IP addresses should be a weak point in the regime. Empirical evidence supports this expectation. There are strong reasons to believe that a very large part of the allocated IPv4 address space is unused, and thus eligible to be transferred. This is especially true in the North American region. An OECD report cited Geoff Huston, Chief Scientist at APNIC, that 90% of RIR-allocated space is routed while only 40% of legacy space is routed.[19] The same OECD report cites surveys that examine the population of visible IPv4 Internet hosts, and find that "only a low percentage of advertised addresses respond, which could mean that even among routed address space, significant address space is unused." One study finds that only 3.6% of allocated addresses are actually occupied by visible hosts.[20]

In the legacy allocations especially, it is well known that large swaths of unused address blocks are so underutilized that they can be surreptitiously taken over by spammers, illegal pornographers, or other Internet malefactors with a need to operate under cover. An antispam website from 2004 maintains a long list of hijacked IP address blocks, which includes an entire /8 originally allocated to Halliburton in the 1980s.[21] An article by Ronald F. Guilmette documents how two /16 address blocks, containing tens of thousands of IPv4 addresses, were hijacked from NASA and a small software company and used to facilitate spamming.[22] In these two cases, the address blocks were essentially abandoned, as their delegated users had completely lost track of their status and were not even aware of their appropriation by a third party.

[19] OECD Report p. 26-27.
[20] Ibid.
[21] Google cache of The Complete Whois web site, retrieved 10 June 2008, http://completewhois.org/hijacked/hijackers.htm
[22] http://www.47-usc-230c2.org/ 47-usc-230c2, A web site maintained by Ronald F. Guilmette.

When the Free Pool Runs Out

The model of common pool resource management assumes that there are free, unallocated resources in the wild, and the task of the resource manager is to set appropriation rules. The appropriation rules of the RIRs were based on a "justified need" criterion where assessments of "need" were based on simple engineering studies.

As the IPv4 free pool runs out, the justified need approach to IPv4 address management loses its relevance. As the number of unallocated blocks approaches zero, IPv4 addresses can only be acquired through *transfers* from one holder of address resources to another, not through initial appropriation from a free pool. Traditional need assessment methods are of no relevance in this situation. In the post-free pool world, engineering plans that "justify" the use of a certain number of addresses may or may not justify taking addresses away from someone else. To allocate the resource under these new circumstances, an RIR would have to decide which plan was more important or more valuable, and remove addresses from one user to give them to another. To justify transferring address resources from one user to another, one must make judgments about *relative* need and the social value of the resource in alternate uses.

The only feasible way to discover how valuable the address resources are in alternate uses is to institute competitive bidding for them.[23] The only alternative to competitive bidding is a central planning regime; i.e., ongoing "beauty contests" in which a centralized agency tried to assess the relative merit of every internet-related business in their region. In addition to more closely scrutinizing existing uses and users, RIRs would also have to give themselves more power to take away resources from parties they decided didn't really need them, or were needed more by someone else. Such a policy would make RIRs into dictators of who could enter the Internet economy and which business plans were more valuable than others. RIRs lack both the authority and the knowledge to judge relative need and aggressively re-allocate address resources across an entire world region. Also, RIR decisions to take away addresses from one party and give them to another would likely become ensnared in controversies and litigation. Future resource allocation must rely on decentralized judgments about the value of resources by the actual holders of address resources. RIRs should act more as title agencies than resource managers.

Transfer Policies as a Response to IPv4 Depletion

To the credit of the RIRs and their associated communities, the problem of IPv4 address depletion has led to some innovative policy proposals. Each of the three largest RIRs is considering proposals to permit market-based address transfers. In the temporal order of their introduction, they are:

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[23] This was the conclusion of the famous "socialist calculation debate" of the 1920s and '30s, which nearly all modern economists recognize as proving that a price system based on trading is needed to efficiently allocate resources across a wide variety of alternative uses and users. For a good summary of this debate see Vaughn, Karen. 1980. Economic Calculation under Socialism: The Austrian Contribution. *Economic Inquiry* 18:535–54.

- Asia-Pacific region: prop-050-v002: IPv4 address transfers (Huston)
- European region: RIPE 2007-08, "Enabling Methods for Reallocation of IPv4 Resources." (Titley and van Mook)
- North America region: ARIN: Policy Proposal 2008-2 IPv4 Transfer Policy Proposal

The transfer proposals would allow organizations willing to release address resources to benefit monetarily by selling them to another organization who wants them, subject to the record keeping requirements and contractual regulations of the RIRs. The premise of this policy is that once all the free IPv4 address blocks have been distributed, the only way to get more of them is to shift addresses away from users who no longer need or want them to users who do need them. By allowing the recipients of address blocks to pay the existing holders to give them up, market transfers will create an incentive to release unused IPv4 resources. The emergent price system will also clarify the economic tradeoffs associated with the use of IP addresses.

The market transfer policy has another, equally powerful motivation. As noted before, addresses are already being transferred privately or even hijacked and used without authorization. There is a fear that once scarcity increases, a black market will evolve and the RIR's registries will no longer accurately reflect which organization holds which address blocks. A breakdown in the accuracy and universality of the RIRs' databases would have severe consequences for the security and orderly management of the Internet's technical infrastructure.

The proposals vary significantly. In general, the RIPE proposal is the simplest and most liberal. The APNIC proposal is similar to the RIPE proposal but attaches a few more restrictions and costs onto the transacting parties, and has some structural flaws. The ARIN proposal, on the other hand, is the most restrictive and complicated policy. As the most regulatory of the three, the ARIN proposal nominally legalizes transfers but does so in a way that is virtually guaranteed to insure that they never take place.

The next section conducts a systematic analysis of the proposals according to five key dimensions: 1) Trigger Date; 2) Territorial restrictions; 3) Eligibility restrictions/speculation controls; 4) Fees; and 5) Route Aggregation. The similarities and differences among the proposals are summarized in Table 1.

Trigger Date

The ARIN proposal says that the transfers it authorizes only start "when IANA allocates its last unallocated unicast IPv4 address block." The RIPE and APNIC proposals have no trigger date. The economic rationale for a tying the beginning of a transfer policy to the depletion of the IANA free pool is weak. If a party is willing to part with address space now and someone else wants it, there is no social benefit to be gained from requiring that person to wait for IANA's last unallocated address block to be

dropped, and no harm by allowing them to sell it earlier. Indeed, the person buying the address block is leaving free space available for others to take, which seems desirable.

One might see a trigger as necessary to prevent people who received "needs-based" allocations for free from turning around and reselling them. But if RIRs can really determine whether organizations "need" IP addresses as they claim to be able to do, a trigger time should be unnecessary. An organization that really needs the address blocks they have been assigned will not sell them. Another rationale that has been advanced for the ARIN trigger date is that if addresses are still available "for free" from ARIN, then organizations that don't qualify for space under current policy would be able to get addresses. But this argument reveals a fundamental confusion. It is an attempt to preserve the effects of pre-scarcity policies under the new conditions of IPv4 scarcity. As noted before, engineering-based "needs assessments" make no sense once the free pool is depleted. A transfer market allows the transacting parties to determine which party has the greater need. The potential to eliminate burdensome and expensive needs assessments is one of its primary virtues.

Territorial Restrictions

This is one of the most interesting and difficult problems associated with address transfers. In principle, an address transfer market should be global (subject to the need to maintain route aggregation) and allow resources not used in one region to be transferred to another region where it is needed more. This aspect is most relevant to developing countries, which may need to "import" IPv4 addresses from regions such as North America which are rich in unused legacy IPv4 addresses.

RIPE and APNIC would allow organizations in different geographic regions to transfer addresses between them, as long as they are both members of the same RIR. The RIPE and APNIC policies would thus permit inter-regional transfers, with some suggesting that the RIRs would become "competing title agencies." The ARIN policy on the other hand is designed to prohibit interregional transfers. The ARIN policy requires both that the transferring parties be members of ARIN *and* that the addresses transferred would be used within the ARIN region exclusively. The purpose of this restriction is to retain the regional exclusivity of the RIR and avoid competition with other registries.

Eligibility Restrictions/Speculation control

None of the RIRs are eager to encourage speculative accumulation and rapid resale of address resources. The policy goal is to encourage one time transfers of allocations and assignments from organizations that do not need them to organizations that do need them. If organizations stockpile address resources purely for their resale value it could make the IPv4 supply situation less stable and predictable given the operational need for IPv4 addresses and the tight supply. Thus the structuring of

transfers to discourage speculation makes sense. The three proposals vary significantly, however, in how they handle this:

1. RIPE's policy is applicable only to Internet service providers, not end users. This makes it the most limited in scope. Aside from that limitation, it provides for the most sensible restriction on speculation. It posits that buyers of transferred addresses cannot transfer complete or partial blocks of *the same address space* for 24 months. This simple and direct limitation eliminates the possibility of acquiring addresses in order to quickly "flip" them in a secondary market. The RIPE policy recognizes that there is no need to regulate the selling party to achieve this goal. The RIPE policy also does not prevent the recipient from engaging in reasonable and graduated stockpiling of addresses that they might need over time in order to accommodate risk and uncertainty. Nor does it impinge on what these entities do with other address resources not involved in the transfer.
2. APNIC allows any organization that has been assigned addresses to transfer them. With regard to speculation, the APNIC policy imposes a blanket restriction on the selling party, who cannot receive any IPv4 address allocations or assignments from APNIC for a period of 24 months. This regulation is not as well designed as the RIPE provision. The restriction on future requests might make potential sellers think twice about whether they should give up their current address holdings, regardless of whether they have any intention of being involved in speculation. Also, this aspect of the policy still does not prevent the buying party from quickly reselling its newly received address resources the first time it receives some through the new transfer process. True, the restriction on receiving more resources from APNIC would catch speculators *after* they sell the resources, but limiting their ability to request additional resources from APNIC would miss the target. True address speculators would be more likely to get new addresses from the secondary market, not from APNIC.
3. The ARIN proposal, like the APNIC proposal, allows both end user organizations and ISPs to transfer addresses. But it imposes severe restrictions on both the selling party and the buying party. It requires purchasers of address resources to "pre-qualify" for addresses by subjecting themselves to a traditional ARIN "needs assessment" process. Any prospective buyer who does this will discover that ARIN will assess not only their request for a transfer, but *all* of their existing allocations. This could deter many potential buyers from applying for fear that ARIN might take away addresses rather than authorizing them to get more. The releasing party cannot have received any IPv4 addresses, either from ARIN or from transfers, in the past 24 months, and cannot request any for the next 24 months. So anyone who sells resources must remove themselves from the ARIN allocation/assignment process for a total of four years. This restriction is punitive and ignores the need to *encourage* legacy address holders to release resources they could learn to do without. The restrictions seem to be motivated more by an ideological desire to reassert its legacy principle of needs-based address allocation, than by an attempt to encourage efficiency-enhancing reclamation. In

the new environment of address scarcity and relative need, ARIN should not care whether an organization that wants to release addresses acquired them from ARIN two years ago, one year ago, or 20 years ago. The point is that they have too many addresses and want to sell them, and that someone else needs them and wants to buy them. ARIN policy should concentrate more on making sure that releasers of address resources are the legitimate and valid holders of the resources, and not attempt to punish them for participating in the market. To discourage gaming and speculation, after an organization sells addresses into the market, it should of course not be able to go immediately to an RIR and ask for free assignments. A one year "time out" after a release/sale is a reasonable requirement. But as time passes it is unlikely that there will be any free IPv4 address blocks for ARIN to distribute, anyway.

Route aggregation.

If address blocks released into the transfer market are subdivided into many parts, address transfers could lead to more de-aggregation of routes. All three of the transfer policies attempt to limit the impact of transfers on route aggregation, although in different ways:

1. RIPE and APNIC propose simple rules that set a minimum size of the blocks to be transferred. For RIPE, a /21 (a little more than 1,000 contiguous addresses) is the minimum size address block. For APNIC, a /24 (a little more than 250 contiguous addresses) is the minimum size.
2. As usual, ARIN adopts the most detailed and prescriptive policy. It also considers a /24 the minimum size, but imposes on releasing parties detailed regulation of the way in which larger address blocks can be cut up into smaller ones.[24] Without a much longer and more detailed study it is difficult to assess the economic and technical impact of ARIN's attempts to control the impact of transfers on route aggregation. Strictly speaking, ISPs are not obligated to route addresses simply because RIRs have allocated them. Smaller address blocks that enter into the transfer process might not be routed if ISPs reach the limit of what their routers can bear. Thus, in a true transfer market, one would expect the price of addresses to reflect their quality, with routability being a critical aspect of quality. Smaller blocks with a low probability of being routed should be devalued relative to larger ones. Deaggregation could cause an increase in the costs of ISPs; but at the same time, some ISPs might willingly bear those costs if it meant additional customers. It is not clear whether ARIN's detailed prescriptions are needed. The assembly of contiguous blocks by aggregators of address resources for leasing by third parties could also overcome this problem.

[24] See ARIN Policy sections 8.3.3 and 8.3.6. "The transferor may retain one contiguous address range out of their original allocation or assignment for their own use, and transfer the other contiguous address range. If the address range to be transferred consists of multiple non-aggregatable CIDR blocks, each may be transferred to a different transferee. The retained address range may not be further subdivided or transferred for a period of 12 months. Notwithstanding the preceding, the block may be subdivided as provided in section 8.3.6."

Fees

In the ARIN and APNIC proposals, the buyer pays a "transfer fee" in addition to the normal fees associated with holding and servicing address resources. In the RIPE proposal, no transfer fee is mentioned; re-allocated blocks are considered to be no different from the allocations made directly by the RIPE NCC. If the purpose of the policy is to encourage efficient transfers, then the transfer process should not create costs that normal address holdings don't incur, which the RIPE policy does. Although address transfers do create costs for the RIRs to update their registrations and records, the same costs are incurred when any other changes take place in RIR's records. This may or may not be a significant problem, depending on the size of the fees and the costs associated with updating records and verifying the authenticity of the parties involved in the transfer. A small, one-time transfer fee probably would not create a strong disincentive to engage in transfers.

Summary

There are important variations in the address transfer market policies of RIPE, APNIC and ARIN. The most important differences pertain to eligibility and the approach to regulating speculation. For reasons that are not clear, RIPE's policy does not permit end user organizations to transfer addresses, while the other ones do. RIPE would regulate resale by a buyer (which we believe is the correct approach). APNIC's policy regulates the post-transfer address requests of the seller of addresses, and does not regulate the buyer at all (a mistake). ARIN over-regulates both sides of the transaction. A common structural approach should be adopted by all three. We suggest that both end user organizations and ISPs be eligible. We suggest that buyers of address resources not be allowed to resell them for two years, and that sellers not be allowed to request IPv4 address resources from an RIR for one year after the sale. These restrictions should be globally applicable. We suggest that ARIN dispense with the pre-qualification of buyers and concentrate on identifying and verifying the authenticity of sellers. On the issue of route aggregation, transfer policies should retain a common minimum size. They should also make it explicit that an RIR's role in recording and facilitating address transfers carries no guarantee of routability. The price of the address blocks should reflect the risks associated with attempting to use them, and the ISPs themselves should decide how many additional route announcements they can carry.

	ARIN	RIPE	APNIC
Trigger for starting	Last IANA block allocated	No trigger	No trigger
Relationship to RIR	Both seller and buyer must be resident in ARIN territory, and the addresses must be used in that territory.	Address space may only be re-allocated from a RIPE NCC member to another member of the RIPE NCC.	The address block must be administered by APNIC and allocated or assigned to a current APNIC account holder.
Eligibility	Any ARIN member	Only LIRs; end users are not eligible	Any APNIC member
Trafficking restrictions	Seller cannot have received any IPv4 addresses from ARIN or from transfers in the past 24 months. Seller cannot request any for the next 24 months. ARIN decides how much supply the buyer gets.	Buyer cannot re-allocate complete or partial blocks of the same address space for 24 months.	Seller cannot receive any IPv4 addresses from APNIC for a period of 24 months. Future requests to APNIC must be justified.
Need assessment of recipient	Buyer must "pre-qualify" to be eligible. Buyer must justify both existing allocations and the amount transferred.	None	No need assessment unless additional requests for IPv4 addresses made
Fees	Buyer pays a transfer fee in addition to normal fees associated with all addresses held	No transfer fee mentioned. Re-allocated blocks no different from the allocations made directly by the RIPE NCC	Buyer pays a transfer fee in addition to normal fees associated with all addresses held
Aggregation	/24 minimum. Detailed regulation of way in which address blocks are downsized	A /21 is the minimum size	A /24 is the minimum size

Table 1: Comparison of RIR IPv4 Address Transfer Policies

In the short term, it is wise to keep the transfer markets regionally segregated in order to reduce the complexity of policy implementation and to limit the scope of any mistakes or problems that are discovered. But in the longer term policies should seriously explore modifications that would allow inter-regional transfers. Because of the

concentration of IPv4 resources in North America and the faster growth rates of developing countries, there are likely to be a major need for moving resources globally. ARIN in particular might want to find a way to authorize the one-way export of address resources from its region to poorer countries.

Issues and Debates around Address Transfers

This section reviews some of the argumentation that has emerged around transfer policies. A great deal of the debate on this question has been emotional and somewhat irrational. Many of the arguments against transfer markets are based on a hidden assumption that the free pool will not be depleted. They tend to compare an idealized version of the way things worked in the past to the unknown risks and problems of a transfer market. This is not the comparison we need to make. Some kind of change is unavoidable. The driver of change is the depletion of the IPv4 pool of unallocated addresses, which is something no one can stop. The only valid policy debates revolve around different ways of adjusting to that new reality. In this context, a transfer market with simple barriers to rapid speculation is less radical than the only other two alternatives. One alternative is to push people into IPv6 adoption by adopting the brick wall approach; i.e., telling the world that there are no more IPv4 addresses and turning away all applicants. This is a radical and potentially disruptive policy. The other alternative to transfer markets is an aggressive IPv4 reclamation program that allows a centralized authority to audit organizations' usage on their own initiative and unilaterally take away addresses from one organization to move them to another. This, too, is a far more dramatic change from current practice than a transfer market.

Transfers and the migration to IPv6

Some critics argue that a transfer market would slow down or harm the transition to IPv6. A transfer market, they say, might encourage organizations to consider purchasing more IPv4 addresses instead of firmly committing themselves to an IPv6 migration strategy.

Note that this argument implicitly concedes that a transfer market would work. Transfer markets would cause organizations to defer their IPv6 migration plans only if the transfers succeeded in facilitating reclamation and use of a significant stock of unused IPv4 addresses. In effect, those who make this argument are saying that we should maintain *artificial limits* on the availability of IPv4 addresses in order to *force* organizations and ISPs to migrate to IPv6 more quickly.

That policy seems like a dangerous one. The depletion of the free pool of IPv4 addresses could trigger a coordinated movement to IPv6 only if IPv6 was backwards compatible. But it is not. We know that IPv4 addresses will be needed for some time to maintain compatibility between the two Internets as the migration takes place. Unfortunately, many of the compatibility issues associated with large-scale dual stack implementation and NAT-PT are not well understood. The transition could turn out to be

more complicated, costly and difficult than anticipated, and we don't know how long it will last. If we try to use an address shortage to force ISPs into making the transition before they are ready, we could develop damaging gaps in connectivity due to shortages of address resources and compatibility problems.

There are really only two possibilities: *either* 1) address scarcity in the IPv4 space makes migration to IPv6 inevitable, *or* 2) migration to IPv6 is not inevitable, and Network Address Translators and other workarounds can keep IPv4 alive indefinitely.

If a migration to IPv6 is inevitable, a transfer market could only prolong the transition slightly, it could not stop it. A transfer market can only shift address resources from organizations who are not using them to active use, and from lower-valued uses to higher-valued uses. Transfers do not create more addresses. Given the uncertainties surrounding the costs, duration, and technical problems of the transition, extending the time horizon for decisions to migrate to IPv6 seems like a good idea. It is certainly a less risky strategy than creating an abrupt shortage.

If migration to IPv6 is *not* inevitable then any attempt to force people into IPv6 by preventing more efficient use of remaining IPv4 addresses could simply fail, and even backfire badly. Organizations might respond to the artificial shortage with an intensified NAT strategy, or find ways to acquire the IPv4 address resources they needed via subterfuge and underground transactions.

Ultimately, the real impetus to switch to IPv6 is that it can deliver applications and capabilities that IPv4 can't – including the ability to do things that require larger amounts of address space. When the special applications and capabilities of IPv6 reach critical mass and organizations can realize network externalities by switching to it, a bandwagon effect will start and a complete migration will take place. Since no one can predict when, or even whether, that will happen, we must prioritize efficient and flexible management of the IPv4 address pool. We should not gamble with the fate of the Internet we have in order to push people into one that doesn't exist yet.

What happens if no transfers are allowed?

We need to focus more on the central question: If the IPv4 free pool is exhausted and we *don't* institute a transfer policy, what is likely to happen? The most probable result would be:

- The intensification and spread of black or gray transfer markets
- Strengthening the market power of incumbent telephone companies and ISPs
- Inefficient or wasted utilization of large swaths of the existing IPv4 address space

By preventing firms and organizations from trading address blocks, ARIN would simply push the supply and demand pressures surrounding address scarcity into different channels. One likely result is address hoarding. In an IPv4-depleted world

without transfers, holders of address resources will do everything in their power to justify their continued possession of them. They might need it some day, and they might be able to sell it on the black market or increase their value in an acquisition. Unless the power of RIRs to reclaim addresses from assignees is significantly strengthened, it is difficult to see any plausible scenario in which major unused blocks of the address space come back to an RIR.

A second response to increased scarcity would be underground transfers. We already know that these are taking place as a response to the relatively minor economic barriers created by the ARIN application process. Imagine the pressure once the free pool is gone. The long term implications of fostering an address economy outside the accurate registration and contractual administration facilities of the RIRs are pretty disturbing. Indeed, we may already be too late. One of the most accurate and troublesome criticisms that could be made of a transfer market is that it might do nothing. Would the incentives generated be strong enough to pull unused resources out? Are the complexities of getting transferred address resources into the routing table too great? We should be more concerned about the possibility that such a market wouldn't have any impact than we should be about the remote possibility that it will destabilize the Internet economy.

Yet another channel through which suppressed demand and supply forces will flow is the acquisition of firms and their assets. Since it is already "legal" to acquire addresses by acquiring the firms that hold them, creative legal and corporate structures will be set up to transfer addresses by making it look like a corporate acquisition or a shift of assets internal to a corporation or holding company. And of course the simplest and most legitimate way to gain IPv4 address resources in the absence of a transfer market will be by simply taking over an incumbent address holder. Take this logic a little further, and it seems plausible to conclude that the absence of a transfer market will encourage greater consolidation of the ISP industry than we would have otherwise. Industry consolidation in communications networks is already a source of great concern to antitrust authorities and public interest groups. Anything that encourages it is not a desirable policy.

Incumbents and developing countries

Some commentators have claimed that a transfer market will favor incumbents. But the incumbents themselves say something different. The European telephone companies are staunch opponents of address transfer markets.[25] This may be nothing more than conservatism. But ETNO and similar established ISPs also may know that if there is nowhere else to go for addresses, Internet users will have to come to them to draw on their existing stocks, which can be leveraged as an appreciating asset like Rembrandt paintings. The rigidity of a transfer-less IPv4 market strengthens their

[25] European Telecommunications Network Operators Association. 2008. "IP Addressing in a post IPv4 World – Principles." ETNO Expert Contribution EC097, 2008/05 (May).ETNO Report

market power. Large incumbents are also in the best position to gain additional address resources through acquisitions.

Likewise, some have asserted that developing countries would be harmed by a transfer policy because IPv4 address resources would become more expensive. But this argument is fallacious because it assumes that free addresses will continue to be available to developing countries. They won't. Once the free pool is depleted, there are no addresses to hand out to developing countries – or anyone else. So unless addresses are transferred among existing users, latecomers to the Internet, such as ISPs in less developed economies, simply will not be able to get IPv4 addresses. Since developing countries by definition start with fewer addresses than developed countries and are likely to generate more demand in the future, anything that facilitates transfers is in their interest.

Short-term, the two RIRs in developing country regions would probably run out of addresses a lot later than the three developed regions, because the utilization levels of their already assigned blocks are actually lower there. Post-depletion, a transfer market is more likely to succeed in shaking loose new blocks of unused IPv4 addresses that could be transferred to developing country ISPs. Unless there is an open and globally integrated transfer market, IPv4 depletion will make ISPs in developing countries more dependent on large-scale incumbent ISPs in the North, because that is where the addresses currently are. Growing developing economies can and do successfully bid against the developed world for critical resources and industrial inputs, such as oil. There is no reason to assume that they cannot acquire address resources, too.

To conclude, the Internet community needs to lay aside irrational fears of the unknown and adopt sensible, well-designed IPv4 address transfer policies. These policies could be instituted immediately; there is no economic justification for waiting for the exhaustion of the free pool.