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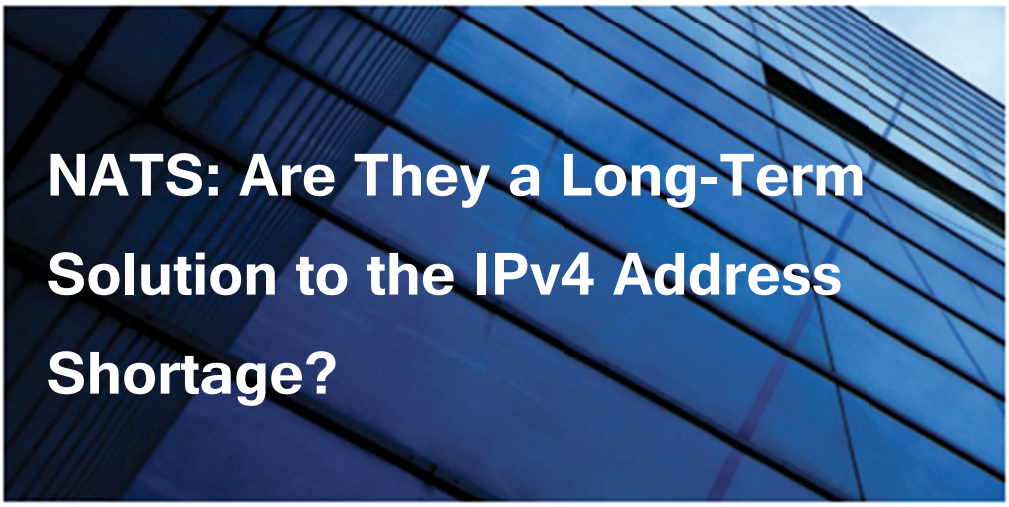

NATS: Are They a Long-Term Solution to the IPv4 Address Shortage?

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As the world approaches an acute global shortage of IPv4 addresses, an important debate has arisen regarding how effective Network Address Translation (NAT) systems are as a solution to serve the growing mobile user base of the Internet. NATs have been used for approximately 10 years, and the technology is familiar to Internet service providers (ISPs). The usage of NATs has increased significantly in recent years in order to efficiently utilize the dwindling pool of IPv4 addresses. Carrier-grade NATs have been very helpful in reducing the demand for IPv4 addresses, but can one expect them to continue to be a reliable solution? Many experts take the position that NAT systems will have a very limited and reduced capacity to effectively service the active users of the Internet. In light of the fact that the transition to IPv6 protocol is expected to take anywhere from several years to more than a decade, the limited pool of dedicated IPv4 addresses will remain the preferred option to serve active Internet users, and therefore the value of these IPv4 addresses is expected to increase significantly in the near future. This article takes a closer look at one's ability to rely on NATs as an acceptable alternative or substitute for a dedicated IPv4 address.

Network Address Translation Systems: What They Are

A NAT is a technological tool that enables multiple devices to use a single dedicated Internet protocol (IP) address. Many users have some familiarity with this tool because it is commonly employed in homes, since it is relatively expensive for a homeowner to have more than one dedicated IP address. Home gateway routers allow the user to connect multiple devices to a dedicated IP address made available by its broadband ISP.

NATs have been used successfully for approximately ten years. NATs allow home and business networks to use private Internet addresses that are not registered for intranet connections; those private addresses are non-routable. When such users need to access the Internet, these private addresses are directed to routers designed to work with NATs through a *single* registered public IPv4 address.

Despite the fact that some users have embraced the notion that a NAT is an acceptable solution, or alternative, to the pending shortage of IPv4 addresses, a NAT is probably ***not*** a viable substitute for acquiring additional IPv4 addresses to meet long-term expected demand. It is fair to say that except for users that rely on the Internet only for relatively simple telecommunication—voice communication and texting, email, and Web-searching—the majority of users will eventually encounter the technological

limitations of a NAT. Moreover, because users continue to utilize more sophisticated applications over time, it is likely that important applications, such as those related to financial transactions or real-time video streaming, will not perform at optimal levels due to the limitations of a NAT. Therefore, from a commerce standpoint, given a choice between Internet functionality based on a NAT or a dedicated IPv4 address, consumers will most assuredly select the latter. In the long run, this means that a NAT is only a "close" substitute in the very limited circumstances of rudimentary telecommunication, email, and Web-searching. Importantly, as major technological advancements occur that enable users to employ advanced applications in video streaming and financial transactions, a NAT will become a much more limited substitute than it has been to date.

Carrier-Grade NATs

The substantial increase in current demand for IPv4 addresses can be attributed to the remarkable growth in the use of smartphones, tablets, portable computer game consoles, laptops-notebooks, netbooks, and machine-to-machine devices.[1] Carrier-grade NATs are considered a temporary solution to the pending shortage of IPv4 addresses. Carrier-grade NATs will delay the full effect of the pending shortage of IPv4 addresses, and in certain circumstances will enable service providers to employ a single IPv4 address for a considerable number of users, in some cases up to 5,000 subscriber households or more.[2]

The distinction between a NAT and a carrier-grade NAT is that carrier-grade NATs are owned and operated by ISPs and can accommodate a significantly larger scale and with added performance. Carrier-grade NATs connect large-scale private IPv4 networks to a much smaller number of public IPv4 networks.

Tests of NAT Systems Indicate Unreliability in Transferring Data

In July and August 2010, members of the Network Working Group of the Internet Engineering Task Force (IETF) performed a series of studies that tested the impact of NAT444 on common Internet applications. The scientists involved in the testing worked for CableLabs, Time Warner Cable, Rogers

[1] Netbooks are small, lightweight, inexpensive laptop computers that do not include floppy drives or other devices normally included in laptop-notebook computers. Machine-to-machine devices use the wireless network to communicate with other devices or networks such as vending machines, automobiles, alarm systems, and remote sensors.

[2] Doyle, Jeff, "Can Large Scale NATs save IPv4?" *Network World* (October 4, 2010), accessed at: http://www.networkworld.com/community/blog/can-large-scale-nat-save-ipv4

Communications, and the University of Colorado. The purpose of these studies was to "evaluate the user experience over the public Internet using NAT444…"[3]

From June to October 2011, CableLabs conducted additional testing of NAT444 and added tests of dual-stack architectures. Dual-stack architectures are a transition technology in which devices have both IPv4 and IPv6 addresses, allowing the devices to communicate in both environments. This is necessary because IPv4 has been, and will continue to be, the prevailing address architecture for the foreseeable future.

The testing revealed that services such as Web browsing and email "worked normally and as expected."[4] However, initial tests also revealed that the functions of many other applications either failed or were degraded. The Network Working Group "worked with the vendors involved to confirm the specific issues and explore workarounds."[5] Despite these additional efforts, many increasingly common applications used by ISP subscribers continued to fail. In particular, the study revealed:

- **Peer-to-Peer Gaming Sessions** between two users of Xbox 360s through a single ISP could not be connected.[6, 7]
- **Internet Protocol Telephone Calls** from one subscriber to another could be neither initiated nor received.[8]
- **Capacity of Routers** to download files or stream media was degraded in cases where streaming functioned.[9]
- **Large File Transfers** were "markedly slower."[10]

Of course, tens of thousands of applications are on devices connected to the Internet, and the Network Working Group could only properly test a handful. Nevertheless, the study demonstrates that

[3] Donley, C., L. Howard, V. Kuarsingh, J. Berg, and J. Doshi, "Assessing the Impact of Carrier-Grade NAT on Network Applications," Internet Draft of the Network Working Group of the Internet Engineering Task Force, p. 2 (November 15, 2011).
[4] Ibid., p. 12.
[5] Ibid.
[6] Xbox Live allows individuals to play games with other Xbox users over the Internet. As of August 2011, Xbox Live had 35 million subscribers, and new subscribers were being added at a rate of approximately 1 million per month. The Network Working Group did not test interactive PlayStation or Wii functionality.
[7] Donley et al. (2011), pp. 12–13.
[8] The IP calls that were tested used Session Initiation Protocol, signaling protocol established by the Internet Engineering Task Force. In addition to controlling voice and video calls over IP, it is used for video conferencing, streaming media, instant messaging, file transfer, and online games.
[9] Donley et al. (2011), p. 14.
[10] Ibid.

carrier-grade NATs, or NAT444, will likely be unacceptable to a considerable number of users. In economic terms, given a choice and all other things being equal, consumers would select a dedicated IPv4 address without limitations over a solution that cannot be viewed as an acceptable substitute because of performance limitations, such as a NAT.

Another commentator on NAT performance, Geoff Huston, noted that the projected failure rate for NATs, depending on the application, was as high as 35 percent due to network complexity and fragility. Huston noted that "really simple transactions in a restricted application environment will still function, but not much else can be assumed to work."[11] In a future where the amount of information being transferred will increase dramatically, NATs will likely become an unworkable solution. This future is now.

Bandwidth Usage and Transparency are Problematic under NATs

As the Internet expands and moves toward more complex applications that use more bandwidth, reliance on a NAT would be a significant technological step backward and provide an inferior user experience. ISPs are expected to compete based on offering faster speeds, such as 4G and LTE, and by employing dedicated IPv4 addresses. Indeed, recent consumer studies have found that faster speed is the most important factor in consumers' purchase decisions. The typical applications that need increased bandwidth include real-time video sharing, peer-to-peer file sharing, and video gaming.

Another area where NATs are problematic involves transparency between IPv4 addresses and the ability to identify a user by IP address. Placing a private network or individual behind a NAT makes it more difficult to identify specific users of an IP address. This type of network structure leads to problems including:[12]

Malicious Hacking: When an individual engages in offensive, fraudulent, or other illegal behavior on the Internet, the tool of choice to block that individual's behavior and preclude further harm is to block his or her IP address.[13] If the individual's ISP employs a carrier-grade NAT, the entire network of individuals, which may exceed 5,000 in number, sharing the same IP address on the NAT is also blocked.

[11] Kosters, M. and G. Huston, *CGNs in IP: What are you going to do about it?* (January 16, 2013), accessed at: http://www.potaroo.net/presentations/2013-01-16-cgn-kosters-joint-techs.pdf
[12] See Doyle (2010).
[13] Barring individuals based on their usernames is ineffective because these can be changed with ease.

Law Enforcement and Homeland Security: Centralized address and port translation within a NAT presents challenges to compliance with lawful intercept requirements under federal wiretapping laws. Under certain NAT architectures, the government's ability to identify and wiretap specific individuals behind a NAT structure would be made more difficult and complex. This would compromise the ability of the government to conduct surveillance of individuals involved in illegal conduct.

Banking and Other Commercial Transactions: An ever-increasing volume of financial and commercial transactions take place on desktops, laptops, smartphones, tablets, and the like. The lack of transparency caused by the NAT structure could adversely impact the efficiency and transparency of private transactions with banks and other commercial enterprises. A bank that wants to track suspicious transaction activity for an individual may have difficulty performing this task if the individual is situated behind a NAT structure. This would result in increased costs to the banking institutions and commercial enterprises in managing transactions, and in decreased reliability and integrity of performing such transactions over the Internet.

Consumer Research: Companies that track the purchasing behavior of consumers in order to identify potential customers could also be disrupted by the structure of the NAT. Once again, the lack of transparency between the public Internet and private addresses behind the NAT wall will make it more complicated and difficult for companies to identify and track specific consumer behavior and target potential customers. As a result, market research covering consumer-purchasing behavior would be more costly and potentially produce inaccurate results. Under certain circumstances, it would not be feasible. In addition, the ability for companies to perform specific, targeted advertising would be compromised.

Additional Performance Issues with NATs

Performance Reduction: With a NAT structure, each translation requires additional computing time. As the IPv4 address exhaustion reaches an acute stage, a further migration to NATs at an accelerated rate is inevitable. The corresponding degradation in performance will become more obvious to users. In a world where users place considerable importance on speed, a reduction in speed would place economic value on regaining lost performance. Indeed, users would be keen on any enhanced performance attributable to dedicated IPv4 addresses. [14]

Security Protocols: Some security protocols are intended to identify changes and modifications. Employing a NAT precludes one's ability to make such distinctions. IPSec is one such system.[15] "IPSec is a security protocol from the IETF that provides authentication and encryption over the Internet."[16] One objective of IPSec is to protect data confidentiality, authenticate the sender, and ensure the integrity of the data by confirming that the data has not been altered during transmission.[17] This principal cannot be maintained since a NAT precludes end-to-end connectivity. One of the basic principles established during the nascent stage of the Internet was for users to have end-to-end connectivity.

Lack of Public Addresses, Access, and Compatibility Issues: When multiple users employ a single user address, certain functions will fail to perform because the user does not communicate through a genuine or dedicated IPv4 address.[18] For the most common and widely used applications, "application layer gateways," and other applications, solutions have been developed to address this problem. One of the better-known applications is VoIP, an inexpensive and sometimes free application that enables users to make telephone calls utilizing a computer.

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[14] Kozierok, Charles M., "IP Network Address Translation (NAT) Protocol," *The TCP/IP Guide*, page 5 of 5 (2005), accessed at: http://tcpipguide.com/free/t_IPNATOverviewMotivationAdvantagesandDisadvantages-5.htm

[15] Ibid.

[16] Answers.com, Definition of "IPsec," accessed at: http://www.answers.com/topic/ipsec. IETF is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of Internet architecture and the smooth operation of the Internet. Accessed at http://www.IETF.org/about/

[17] Shinder, Deb, "NAT Traversal (NAT-T) Security Issues," WindowSecurity.com (June 23, 2005), accessed at: http://www.windowsecurity.com/articles/nat-traversal-security.html

[18] Kozierok (2005).

New Usage Trends for Mobile Devices Highlight Additional Problems with NATs

Another trend in the mobile device market is that usage patterns evolve rapidly. Based upon the 2013 Consumer Electronics Show, which concluded in January 2013, the mobile device industry expects smartphones to continue to be important for telecommunication—voice and text, email services, and Web searching. However, the usage allocation is expected to shift dramatically before the end of 2013, where users will begin to rely on mobile devices—smartphones, tablets, and netbooks, as well as personal computers, laptops, and notebooks—as a major vehicle for watching video real-time television programming, such as news and sporting events, recorded television, and movie programming.

The consequence of this paradigm shift in usage will highlight the limitations of carrier-grade NATs and NATs in general. It is clear that NATs reduce the public demand for Internet addresses as long as the user focuses on rudimentary telecommunication, email services, and Web searching. As users begin to employ their mobile devices for video streaming, computer game play, and financial and business transactions, the inherent limitations and weaknesses of NATs will become clear to consumers. Eventually, consumers will seek ISPs that offer dedicated IPv4 addresses to ensure or limit encountering such performance issues. Geoff Huston recently expressed concerns over a heavy reliance on carrier-grade NATs: [19]

> This points to a mobile Internet that is almost completely reliant on NATs, and this, in turn, points to some longer term elements of concern for the continued ability of the Internet to support further innovation and diversification in its portfolio of applications and services.

The investments made by private industry to bring ultra-high-definition imaging to mobile devices are unprecedented. Private industry envisions mobile devices serving a much larger role in delivering premiere video streaming to consumers. Consequently, NATs may no longer be an acceptable alternative or substitute to a dedicated IPv4 address. It is important to know that most consumers, even if they do not intend to use video streaming and related features frequently, would prefer to have the feature. While a price reduction may suffice sometimes, it is unlikely to be the solution often. One thing is certain: NAT limitations will become a much bigger issue in 2013 and in the foreseeable future.

[19] Huston, Geoff, "Addressing 2012 – Another One Bites the Dust," *The ISP Column* (January 2013), accessed at: http://www.potaroo.net/ispcol/2013-01/2012.html

Increased Data Traffic and Continued Reliance on Carrier-Grade NATs:

As discussed above, smartphones will continue to be the major source of demand for Internet addresses in 2013. Consumers continue to place considerable importance on speed, imaging, and online financial transactions together with related security. One of the major buzzes at the 2013 Consumer Electronics Show related to Qualcomm's "high-end mobile-friendly chipsets, together with their Snapdragon 800" processors.[20] These chipsets coupled with the Snapdragon 800 or 600 processors are considered significant technological advancements, and the resulting video images will change the way consumers view their smartphones. As a result of these attributes, smartphone users will experience enhanced speed and connectivity as well as increased quality of video and audio downloads.

The overall market effect of Snapdragon processors will allow users to download large amounts of data at much faster speeds. This new development directly addresses a key trend in the mobile device market—increased use of mobile devices to download larger amounts of content from the Internet. In a November 15, 2012, presentation, Qualcomm pointed out the dramatic increase in global data traffic over the Internet. From 2010 to 2011 global data traffic doubled, and by 2016 the Internet content entering the home is expected to triple. Additionally, in its latest annual Visual Networking Index, Cisco predicted that by 2017 the average American will use 6.2 GB of data on their mobile devices each month. This figure compares to an average of 752 MB of data per month in 2012.[21] This Cisco projection, therefore, predicts an eight-fold increase in data downloads over the next five years.

In future years, the video capabilities of smartphones, tablets, and digital media players are expected to make a significant jump in capabilities and performance of video features that require larger and larger data downloads. In this environment, it is likely that carrier-grade NATs will not be able to serve as an acceptable substitute for dedicated IPv4 addresses to the extent that they have up to now. It is also reasonable to conclude that carrier-grade NATs will continue to diminish in a number of circumstances as an acceptable substitute for dedicated IPv4 addresses. Consequently, in this mobile, data-driven environment, prices for IPv4 addresses are expected to significantly increase.

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[20] Eichelberg, Amy, "Qualcomm Introduces Next Generation Snapdragon Premium Mobile Processors, Promises Up To 75% Better Performance," *The Unlockr* (January 8, 2013), accessed at: http://theunlockr.com/2013/01/08/qualcomm-introduces-the-next-generation-of-800-and-600-mobile-processors-promises-up-to-75-improvement/#ItmFwXtOA5D1JS3j.99

[21] Goldman, David, "AT&T Wants to Bill You for Everything," CNN Money (February 25, 2013), http://money.cnn.com/2013/02/25/technology/mobile/att-bill/index.html

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