Anatomy

- A Look Inside Network Address Translators

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Over the past decade there have been a number IP-related technologies that have generated some level of technical controversy. One of these has been the Network Address Translator, or NAT. This article describes the inner workings of NATs in some detail, and then looks at the issues that have accompanied the deployment of NATs in the Internet that appear to have fuelled this technical controversy. NATs are a very widespread feature of today's Internet, and this article attempts to provide some insight as to how they operate, why there is such a level of technical controversy about NATs and perhaps some pointers to what we've learned about technology and the process of standardization of technology along the way.

1. NAT Motivation

The first RFC document describing NATs was by Kjeld Egevang and Paul Francis in 1994 [RFC1631]. The original motivation behind the NAT work was based around efforts in the early 1990's associated with a successor protocol to IPv4. The overall effort of a successor protocol to IPv4 was to devise a protocol that would directly address the issues of accelerating address consumption in IPv4 that appeared to be leading to the prospect of imminent address exhaustion. While IPv4 was capable of uniquely addressing some 4.4 billion devices it was evident by as early as 1992 that the world was heading down a path of very intensive deployment of devices that included communications capabilities, and that IPv4 was not going to be able to extend across the full range of future device deployment. The objective with NAT was to define a mechanism that allowed IP addresses to be shared across a number of devices. In addition, it was intended that NATs could be deployed in a piecemeal fashion within the Internet, without causing changes to hosts or other routers. Other forms of address sharing technologies relied on intermittent connectivity, while NATs were intended to allow a collection of connected devices to share an address pool dynamically. The original RFC portrays this approach as being a measure that can "provide temporarily relief while other, more complex and far-reaching solutions are worked out."

So, as documented, the original intent of NATs were to be a possible short term response to address exhaustion while longer term solutions were being devised. NATs were also intended to be unmanaged devices that are transparent to end-to-end protocol interaction, requiring no specific interaction between the end systems and the NAT device.

A decade later NATs are attaining a status of near-ubiquitous deployment across the Internet, and while IPv6 has been defined and deployment is commencing, NATs appear to be a very well-entrenched part of the network landscape. And, for the most part, NATs continue to function as unmanaged devices. They can be transparent to some forms of protocol interaction, but, as the Voice over IP folk are finding out, they can be very obvious to the point of being highly disruptive to other forms of protocol operation.

2. NAT Operation

The operation of NATs is deceptively easy to describe in general terms. They are active units placed in the data path, usually as a functional component of a border router or site gateway. NATs intercept all IP packets, and may forward the packet onward with or without alteration to the packet's contents, or may elect to discard the packet. The essential difference here from a conventional router or a firewall is the discretional ability of the NAT to alter the IP packet before forwarding it on. NATs are similar to firewalls, and different from routers, in that they are topologically sensitive. They have an “inside” and an “outside”, and undertake different operations on intercepted packets depending on whether the packet is going from inside to outside, or in the opposite direction.

NATs are IP header translators, and, in particular, NATs are IP address translators. The header of an IP packet contains the source and destination IP addresses. If the packet is being passed in the direction from the inside to the outside, a NAT will rewrite the source address in the packet header to a different value, and alter the IP and TCP header checksums in the packet at the same time to reflect the change of the address field. When a packet is received from the outside destined to the inside, the destination address is rewritten to a different value, and again the IP and TCP header checksums are recalculated (Figure 1). The "inside" does not use globally unique addresses to number every device within the network served by the NAT. The inside (or "local") network may use addresses from private address blocks, which implies that the uniqueness of the address holds only for the site. Lets look at this using an example.

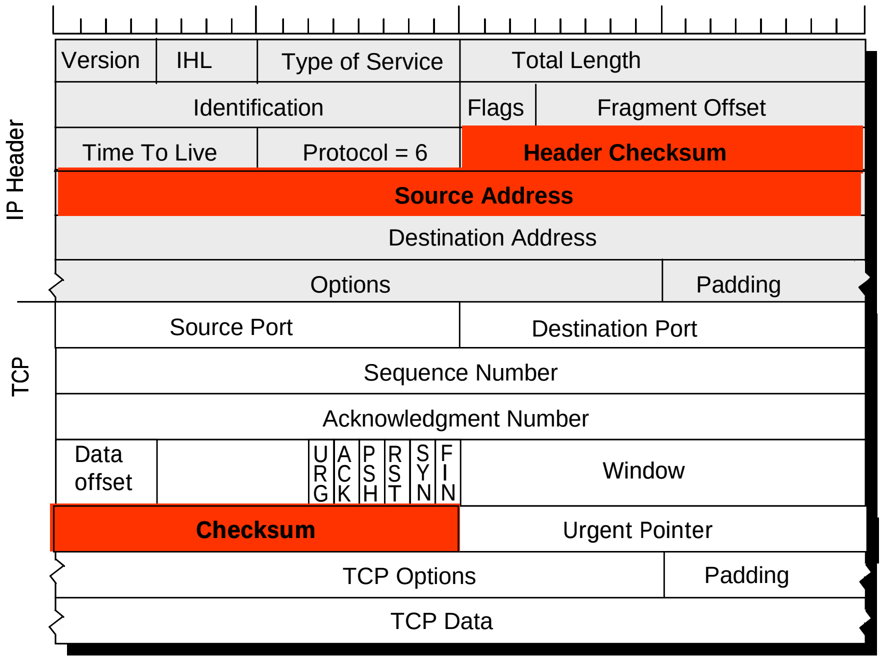


Figure 1 – TCP/IP header fields altered by NATs (Outgoing Packet)

As shown in Figure 2, how can local (private) host A initiate and maintain a TCP session with remote (public) host B? Host A will first look up the DNS to find the public IP address for B, and then create an IP packet using Host B's address as the destination address and Host A's local address as the source, and pass the packet to the local network for delivery. If the packet was delivered to Host B without any further alteration, then Host B would be unable to respond. The public Internet does not (or should not at any rate!) carry private addresses, as they are not globally unique addresses.

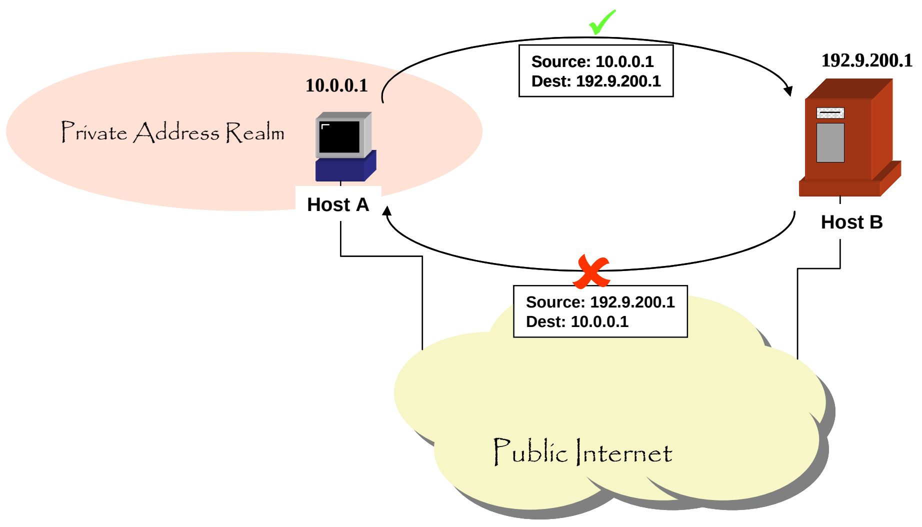


Figure 2 – Public/ Private Communication

With a NAT between Hosts A and B, the NAT will intercept Host A's outgoing packet and rewrite the source address with a public address. NATs are configured with a pool of public addresses, and when an “inside” host first sends an outbound packet, an address is drawn from this pool and mapped as a temporary alias to the inside Host A's local address. This mapped address is used as the new source address for the outgoing packet, and a local session state is set up in the NAT unit for the mapping between the private and the public addresses.

Once this mapping is made all subsequent packets within this application stream from this internal address to the specified external address will also have their source address mapped to the external address in the same fashion.

When an incoming packet arrives on the external interface, the destination address is checked. If its one of the NAT pool addresses, the NAT box looks up its translation table. If it finds a corresponding table entry the destination address is mapped to the local internal address, the packet checksums are recalculated and the packet is forwarded. If there is no current mapping entry for the destination address, the packet is discarded. The mode of operation of a NAT is shown in Figure 3. So, continuing our example, the local host at address A is directing packets to the external server host at address B. Because the NAT is in the path, the NAT has altered the packets so that address A is translated to address X. Host A is aware that it is communicating with host B, and from A's perspective this is a normal session. Host B believes that it is communicating with a host at address X, and is entirely unaware of address A. From B's perspective this is a normal session with a host at address X.

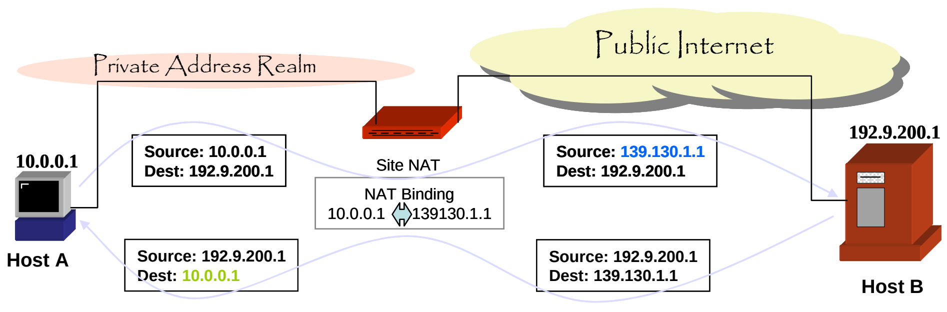


Figure 3 – NAT Traversal

Dynamically created Mapping entries (or “bindings”) are typically maintained by the NAT with a timer. If no packets that use the mapping are received by the NAT within a certain time window, then the binding is removed from the NAT and the public address is returned to the NAT pool.

2.1 NAPTs

A variant of the NAT is the Port-translating NAT (or NAPT) This form of NAT is used in the context of TCP and UDP sessions, where the NAT maps the local source address and source port number to a public source address and a public side port number for outgoing packets. Incoming packets addressed to this public address and port pair are translated to the corresponding local address and port. Again, the binding is maintained by a NAT idle timer, and upon expiration of the timer the public address and port pair are returned to the NAT's pool (Figure 4).

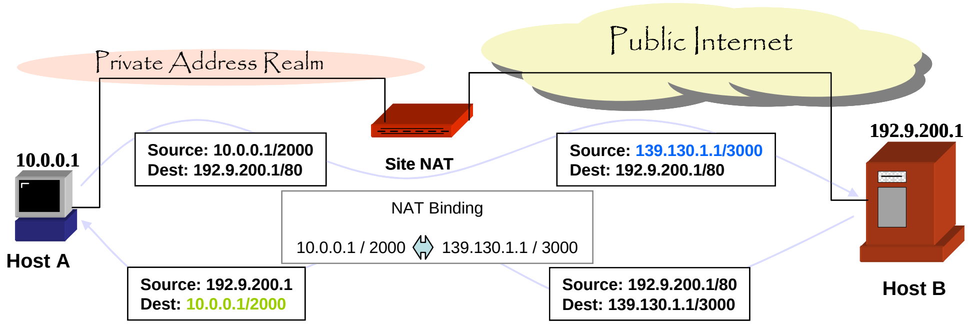


Figure 4 – NAPT Traversal

Again the NAPT is attempting to be transparent in terms of providing a consistent view of the session to each end, using a symmetric binding of as local address and port pair to an external address and port pair.

Its a reasonable question to ask as to why should NAPTs bother with port translation ? Aren't straight address translations enough? Surprisingly NATs can be relatively profligate with addresses. If each TCP session from the same local host is assigned a different and unique external pool address, then the peak address demands on the external address pool could readily match or exceed the number of local hosts, in which case the NAT could be consuming more public addresses than if there were no NAT at all! NAPTs allow concurrent outgoing sessions to be distinguished by the combination of the mapped address and mapped port value. In this way each unique external pool address may be used for up to 65535 concurrent mapped sessions.

For a while the terminology distinction between NATs and NAPTs was considered important, but this had faded over time. For the remainder of this article we'll use current terminology, and look at NATs and NAPTs together and refer to them collectively as "NATs".

3. NAT Behaviour

There are two quite basic issues about the use of NATs. One is that NATs make applications “brittle” in that NATs support a particular style of application operation, and if the application deviates in any from this style then the application no longer works. The second is much more of a concern, and that is that NATs differ from each other in quite fundamental ways. What works across one NAT may not work at all for another class of NAT. It has also been reported that NATs differ not only on a vendor-by-vendor basis, but even on a model-by-model basis within a single vendor’s range of NAT units. The implication here is that such differences of behaviour become a matter for discovery by applications rather than something applications can predict in advance. This section explores this behavioural aspects of NATs in further detail.

3.1 Symmetry and Sessions

There are a number of ways that NATs can manage address mapping, and many implementations of NATs use a form of binding termed a "symmetric" binding.

A symmetric binding is where the mapping of a local address to a public address is exclusively tied to the destination address used in the initial trigger outgoing packet for the lifetime of the binding. Incoming external packets with the mapped public address as their destination are only translated to the local address if the source address of the incoming packet matches the destination address of the original mapping. Multiple sessions to different public hosts may use the same mapped public address, or may use different public addresses for each session. This mapping is "end-point" sensitive. Symmetric NATs represent a restricted model of operation, where each NAT binding represents a window through the NAT that is only visible to the destination host (Figure 5). By comparison, a "full cone" NAT allows any external host to use this opened window, where all incoming packets addressed to the mapped external address will be translated to the mapped internal address and forwarded through the NAT. Symmetric NATs represent the most restrictive form of behaviour, while full cone NATs represent a far more permissive mode of operation.

In the context of NATs this symmetric mode of operation refers to the session state 5-tuple, made up of transport protocol, the local IP address and port number and the destination IP address and port number. When a session is opened from the local host to a remote service port on a remote host, then only that remote service can pass packets back through the NAT to the local host on that port. As with NATs, a "full cone" NAT will any remote service entity to direct packets back through the port window.

NATs can be further refined by having different behaviours for TCP and UDP transports. A NAT may behave in a symmetric manner for TCP sessions, and operate in a full cone mode for UDP transactions. The variations in NAT behaviour has lead to an exercise in categorizing NAT behaviours and developing a discovery protocol whereby a pair of cooperating systems can discover if there is one or more NATs on the network path between them, as well attempting to establish the type of NAT.

3.2 Discovering NAT Behaviours and STUN

NAT behaviour has not been the topic of any industry standardization efforts, and it should not be surprising to learn that, given that there are a range of possible NAT behaviours under certain conditions, the market contains NAT offerings that cover the full spectrum of possibilities. In the absence of common specifications or standards implementers have been placed in the position of having to make some creative guesses as to what the “right” behaviour should be under such circumstances. This is a significant problem for the application designer, given the prospect that in today's Internet any popular application must have a means of being able to function correctly in the face of one or more NATs on the path between two hosts that are communicating using the application.

One of the more pressing problems here is that NATs commonly enforce an application model where the local “hidden” host must initiate a transaction in order to create a window in the NAT to allow the remote host's packets back into the local network. Some applications may wish to undertake “referral”, where the correspondent host on the external side may want to pass the externally presented address and port details of the local host to a third party in order to commence a further part of the transaction. Other application transactions may simply want to be initiated from the external side. While this may have been thought of as a relatively obscure condition, it was brought into the forefront of attention when various forms of voice over IP and peer-to-peer applications gained popularity. In particular, the question of "how can the external side initiate a packet flow in the presence of a NAT?" has become an increasingly important question. Given that the application needs to perform some additional gymnastics in such a case there is the additional question that the application must answer, namely "how does the application learn that there are NATs in the path in the first place?"

So at this point the application is placed in the role of performing a forensic exercise of establishing whether or not its packets are being altered by one of more NATs when it attempts to establish an end-to-end packet transaction, and, if so, what types of implementation decisions have been made by the NAT in terms of the way in which packets are being systematically modified. In others words, what is the anatomy of the particular NATs that have been discovered along the path. This anatomy exercise is further complicated by the observation that NATs are silent devices, so the application cannot directly interrogate the NAT to establish its behaviour. All that is left is a somewhat unsatisfying guessing game, where the application is forced to send particular types of packets through the NAT to its counterpart on the other side, and by comparing the original packet with its address and port transformed the two ends of the application attempt to guess the nature of the systematic transforms of the NAT.

In the case of TCP it appears that the prevalent NAT behaviour is that of a symmetric NAT based on address and port bindings. This implies that when the local host opens up a TCP session with a remote host the NAT's address and port bindings for the local host are coupled with the address and port of the destination host, and only packets with a source field of the destination host can pass packets back through the NAT to the local host's TCP session. In other words, once a TCP session has been established within a NAT only the two end points of the TCP session can access the NAT bindings, and attempts by others to direct packets to the external-side presented address and port meet with the NAT's discard response. The fine-grained behaviour of NATs with respect to TCP sessions can vary according to the amount of TCP state maintained by the NAT. At a basic level the NAT can maintain a binding based on the local address and port and the remote address and port. The NAT can also keep the binding timer at a high value until a FIN exchange is observed, or until the session is reset through the RST flag being set, at which point the binding timer can be reduced to a very short interval. The NAT can also track the two sides' sequence number windows and associated window sequence number scaling values and not adjust the session’s binding timer for TCP packets with sequence numbers outside the sequence number window with their FIN or RST flags set.

These NAT behaviours are based on the explicit signalling of changes in session state within the TCP packet exchange, and the consequent ability of the NAT to track the session state and adjust the associated binding timer in response to this state information. UDP is not so straightforward, as there is no explicit session state within a UDP packet exchange, and various NATs behave differently with respect to UDP-based bindings. There are various classes of NAT behaviour that relate to how UDP bindings are managed within a NAT. These have been classified into four types of behaviours [RFC3489]:

Symmetric

We've already encountered the symmetric NAT, where the NAT mapping refers specifically to the connection between the local host address and port number and the destination address and port number and a binding of the local address and port to a public-side address and port. Any attempts to change any one of these fields requires a different NAT binding. This is the most restrictive form of NAT behaviour under UDP, and it has been observed that this form of NAT behaviour is becoming quite rare, as it prevents the operation of all forms of applications that undertake referral and handover.

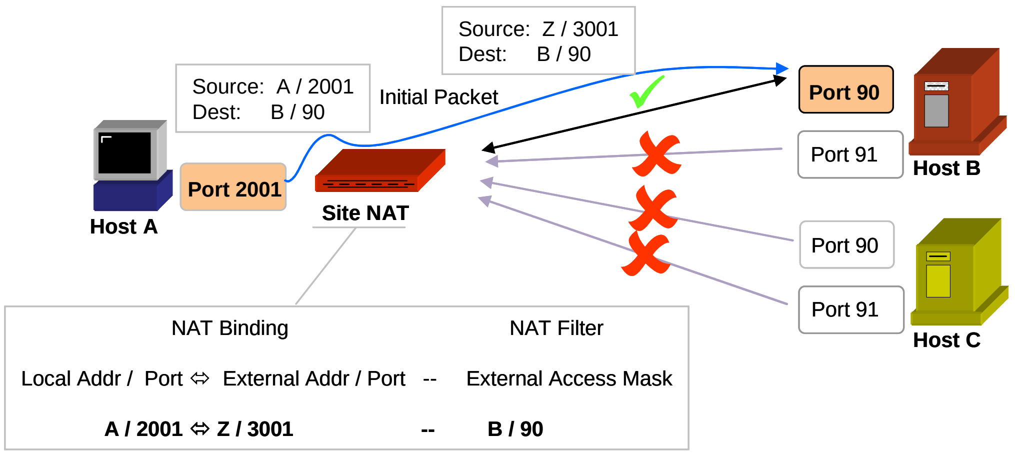


Figure 5 – Symmetric NAT

Full Cone

A full cone NAT is the least restrictive form of NAT behaviour, where the binding of a local address and port to a public-side address and port, once established, can be used by any remote host on any remote port address.

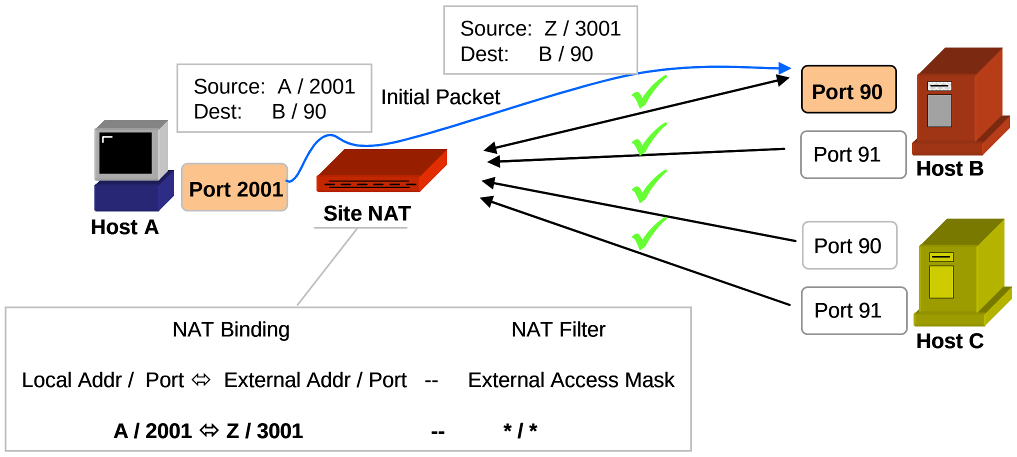


Figure 6 – Full Cone NAT

Restricted Cone

A "restricted cone NAT" is one where the NAT binding is accessible only by the destination host, although in this case the destination host can send packets from any port address once the binding is created.

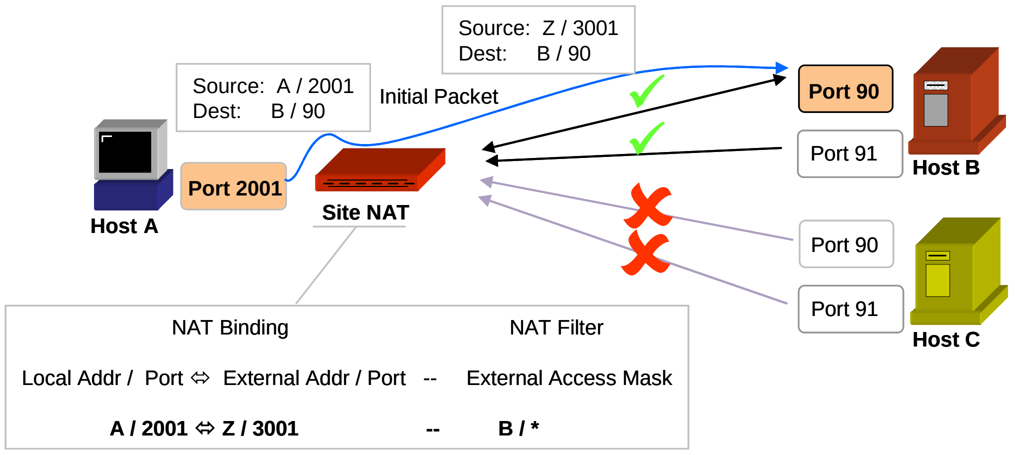


Figure 7 – Restricted Cone NAT

Port Restricted Cone

A "port restricted cone NAT" is one where the NAT binding is accessible by any remote host, although in this case the remote host must use the same source port address as the original port address that triggered the NAT binding.

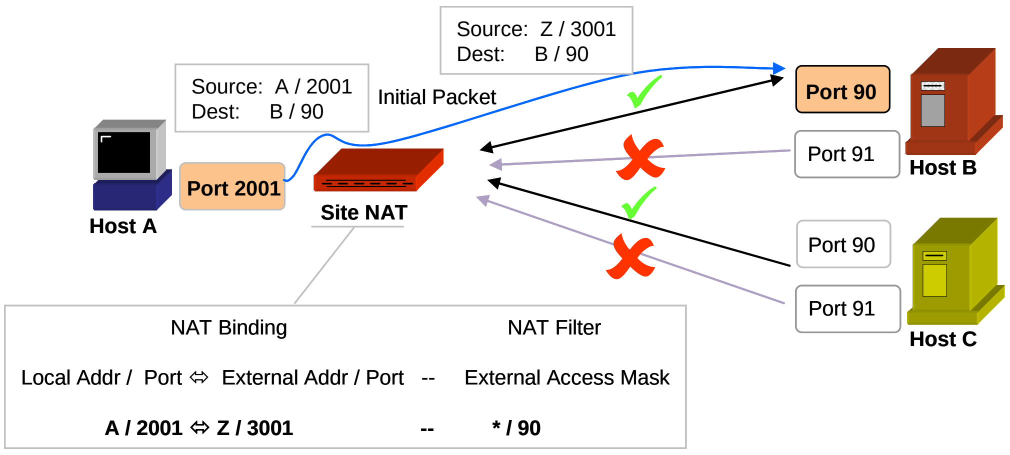


Figure 8 – Port Restricted Cone NAT

So can an application tell if there are one or more NATs in the path, and, if so, what form of behaviour the NAT is using? For this purpose the STUN (Simple Traversal of UDP through NATs) protocol has been developed [RFC 3489]. STUN is probe system that examines the interchange between a STUN client that may lie behind a NAT and a STUN server, that is positioned on the public side of the NAT. The STUN server host must be configured with two IP addresses, and the STUN itself should respond to queries on two UDP port numbers. The protocol is a simple UDP request-response protocol that uses embedded addresses in the data payload, and compares these addresses with header values in order to determine the type of NAT that may lie in the path between client and server.

The basic operation of STUN is a request response protocol, using a common request of the form: "Please tell me what the public address and port values were used to send this query to you".

STUN can be used to discover if a NAT is on the path between a client and server, and attempt to discover the type of NAT by a structured sequence of requests and responses. The client sends an initial request to the STUN server. If the public address and port in the returned response are the same as the local address then the client can conclude that there is no NAT in the path between client and the server. If the values differ the client can conclude that there is a NAT on the path. STUN then uses subsequent requests to determine the type of NAT. One critical additional item of information returned by the STUN server in the initial response is an alternate IP address and port number that can also reach the same STUN server.

The second STUN request is directed to the same address and port as the initial request, but this time the request includes a control flag that requests the STUN server to respond using its alternate source address and port values. If the STUN client receives this alternate-sourced response then it can conclude that it is behind a full cone NAT, as the initial NAT binding of the local host address to the external presentation address can evidently be accessed by third party external hosts.

If no response is received to the second request, then the STUN client sends the original probe request, but this time the request is addressed to the alternate destination address and port pair for the STUN client. If the returned address and port values relating to the new NAT binding are different to those of the first request then the client can conclude that it is behind a symmetric NAT.

If the values are unaltered then a further request can be made to determine the form of restricted cone behaviour. This fourth request includes a control flag to direct the STUN server to respond using the same IP address, but with the alternate port value. A received response indicates the presence of a restricted cone, and the lack of a response indicates the presence of a port restricted cone.

Periodic exchanges between the STUN client and server can also discover the timer used by the NAT to maintain address bindings. Additional components of STUN are intended to provide some reasonable level of integrity in the packet exchange. A flowchart of a STUN-based NAT discovery process is shown in Figure 9.

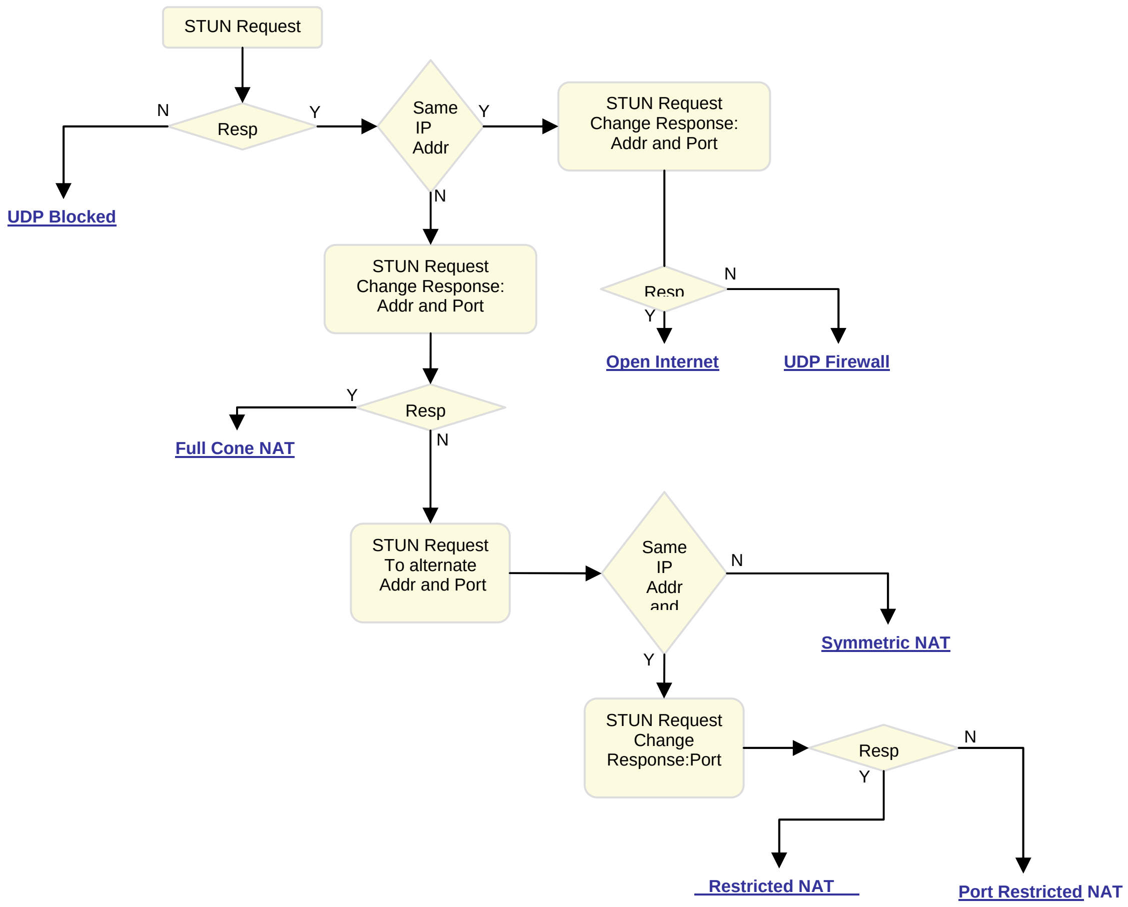


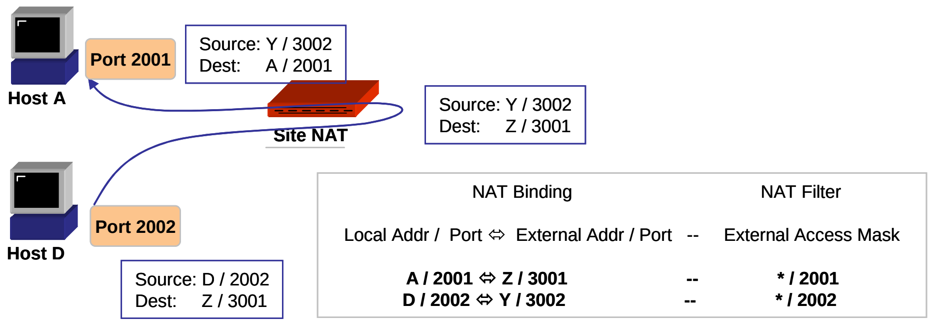
Figure 9 – NAT Discovery Process using STUN

3.3 Further Behaviours: Hairpins and Determinism

It would be good that NAT behaviour remained that simple. However, this is not the case, as some further tests on NATs reveal further differences in various NAT implementations [draft-jennings-midcom-stun-results].

The first area of difference is whether the NAT supports the so-called “hairpin” operation, where a local host directs a packet to the public address and port of an already mapped local host, or even to its own mapped address and port. If successful then the NAT supports hairpin operation, where the NAT bindings, once created, are available to either side of the NAT.

Furthermore, the NAT may generate a binding for this operation, or not, thereby presenting the hairpin packet with an external address and port, indicating that an outbound binding has been performed in conjunction with the inbound binding, or with an internal address and port, indicating that only an inbound binding is being performed.



NAT Binding		NAT Filter
Local Addr / Port ⇔ External Addr / Port	--	External Access Mask
A / 2001 ⇔ Z / 3001	--	*** / 2001**
D / 2002 ⇔ Y / 3002	--	*** / 2002**

Figure 10 – Hairpin NAT Operation

The second is in the general class of NAT determinism. Non-deterministic NATs change their binding behaviour when a binding conflict of some sort occurs in the NAT. This is further based on the classification of whether "primary", "secondary", or even "tertiary" NAT behaviours differ. To explain primary, secondary and tertiary behaviours, it is first noted that some NATs attempt to preserve the port address in the binding, so that the local source port and the externally bound port are the same whenever possible. This is the "primary" binding of the NAT. If another local host obtains a NAT binding using the same source port number, then the behaviour of the NAT for this conflicting port binding may differ from that where the port number is preserved. The first conflict of port allocations in bindings is the "secondary" binding. In some cases the primary behaviour is that of a full cone, or a restricted cone, while the NAT behaves in a symmetric fashion for the secondary instance where the port number has been mapped to a new value by the NAT. A tertiary behaviour occurs when a third binding is added to the NAT, as, again, the behaviour of the NAT may be different for this binding.

It is also possible that the NAT may elect to preserve the binding in any case, and remove the current binding and replace it with a new binding that refers to the most recent packet that the NAT has processed.

All these behaviours can all be classified as non-deterministic, in that the NAT behaviour becomes one that is determined by the order of outbound traffic. The implication is that repetitions of the same STUN test at different times may produce different classifications of the type of NAT. The inference is that if an application uses STUN to determine the type of NAT in the path, and then selects a certain behaviours based on this STUN-derived knowledge of the NAT type, non-deterministic NATs may behave differently between the STUN test and the application. The NAT response for a particular binding cannot be predicted in advance, and even once a binding state is established it may be disrupted or altered by subsequent traffic.

3.4 Another approach to classifying NATs

Further tests on NATs reveal that the various behaviours are yet more complex, and that different sequences of tests across a NAT will lead the test routine to come to different conclusions as to the type of NAT [draft-audet-nat-behave]. The key observation here is that NATs are the conjunction of two distinct behaviours sets:

- Binding, or Context-based Packet Translation:
  Detecting those packets that can be associated with a current binding and using that binding in a manner according to the packet's logical direction to perform packet header transforms.

- Filtering, or Packet Discard
  Discarding those packets that cannot be associated with current bindings and discarding them.

If a STUN-like test sequence was for a local host to send a packet to one destination and obtain a response of what NAT binding was used, and then to send a packet to a second destination and compares the results, the observation of the NAT using a different binding for each request may lead the tester to conclude that the NAT is a fully symmetric NAT. If the test sequence is for the NAT to send one packet to a destination and have the destination respond using a different source address, then the observation that the response packet is successfully delivered through the NAT back to the originating local host may lead the tester to the conclusion that the same tested NAT is some form of cone NAT.

The STUN approach classifies NAT behaviours on the basis of a single biding being established by the local host when contacting an external host, and then considers what constraints are placed on third party external hosts as they attempt to access this initial binding. An adjunct to this approach is based on the local host establishing two bindings to two distinct external hosts, and looking for any relationship between these two bindings.

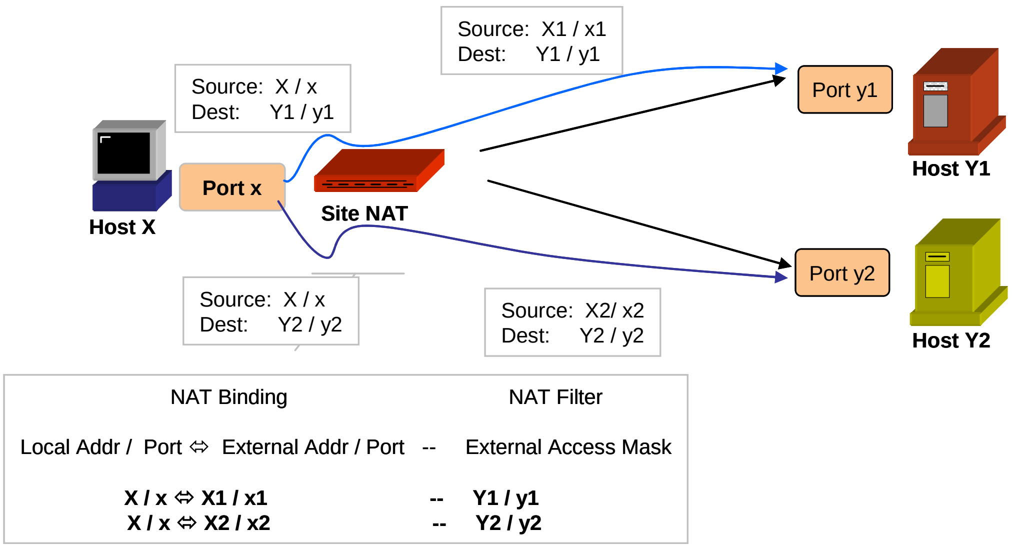


Figure 11 – Outbound connections from a common source

The behaviours of NATs under this condition can be classified under a number of behavioural aspects.

3.4.1 Binding

Binding behaviour can be seen as the amalgam of three somewhat distinct design decisions, namely the manner in which a binding is generated, the behaviour of the NAT in managing external ports used in bindings and the manner in which expiration timers that govern the continued existence of the binding are refreshed.

NAT Binding Behaviour:

Endpoint Independent
The NAT reuses the port binding for subsequent sessions initiated from the same internal IP address and port to any external IP address and port. This is analogous to a full cone NAT.

Endpoint Address dependent
The NAT reuses the port binding for subsequent sessions initiated from the same internal IP address and port only for sessions to the same external IP address, regardless of the external port. This is a looser form of symmetric NAT, where the binding is created on the basis of the external address, rather than the external address and port.

Endpoint Address and Port Dependent
The NAT reuses the port binding for subsequent sessions initiated from the same internal IP address and port only for sessions to the same external and port. This is a more precise form of UDP symmetry where the binding is available only to a single session, where a session is the 5-tuple of (protocol, source address, source port, destination address, destination port)

Port Binding Behaviour:

Port Preservation
In addition to the differences in the binding between the two cases, the NAT may attempt to preserve the local port number, if possible. The terminology proposed here is "port preservation" to describe this NAT action.

Port Overloading
Some NATs attempt to undertake port preservation at all times, so that when a different local host establishes a binding using a port that is already being preserved, the new binding will usurp the existing binding. This behaviour is proposed to be termed "Port Overloading".

Port Multiplexing
The alternative to port overloading is use of the external entity to perform the demultiplexing of the port. In this case if two local systems use the same source port to send packets to two

different external hosts, the NAT will preserve the source port in the two bindings. If the NAT is using a single external address the external view is two packets with the same source address and source port, sent to two different external addresses. The reverse packets will have the same destination address and port, The NAT will determine the appropriate binding based on the source address and port in the reserve packets. This requires an Endpoint Address and Port dependant binding behaviour. In the case where two internal hosts are directing packets to the same external endpoint using the same source port addresses, then it is necessary for one of the sessions to use a binding with an altered port number. This could be considered as non-deterministic behaviour.

Binding Timer Refresh:

Bidirectional
The NAT will not keep the binding active indefinitely, and will normally remove the binding if there are no further packets that use the binding within a certain time period. However there are variations in the classification of packets that the NAT will consider as packets that reset the timer. In a bidirectional binding timer refresh packets from either the local hosts or an external host that uses the NAT binding case the NAT binding expiration time to be reset.

Outbound
An outbound binding timer refresh NAT will only reset the expiration timer when packets pass from the local host to the external host within the context of the binding. The implication is that a local host may have to use some form of keepalive operation to maintain a NAT binding in the face of an inbound UDP unidirectional traffic flow. Additionally the expiration timer may be on a per session basis, or may be on a per binding basis in the case that multiple sessions are associated to a single binding in the NAT.

Inbound
As the name suggests, this is the opposite of the previous case, where only inbound packets case the binding's expiration timer to be refreshed.

Transport Protocol State
While the above forms are useful in the case of UDP-based sessions, when the binding is based on a transport session (such as TCP), the NAT can base its binding timer refresh on the transport session state. For TCP this would infer a binding refresh time that is refreshed by any session packet in either direction (Bidirectional), with the exception of packets with the TCP RST or FIN flags set. While it would be an option to drop the NAT's binding state when such packets are seen, this makes the NAT vulnerable to denial of service attacks by third party injection of TCP RST packets, so there is some merit in using the binding timer for TCP sessions.

3.4.2 Filtering

The second phase of the test has two external hosts directing a probe to the same binding address, and classifying the behaviours based on what packets are filtered and discardedby the NAT (Figure 12).

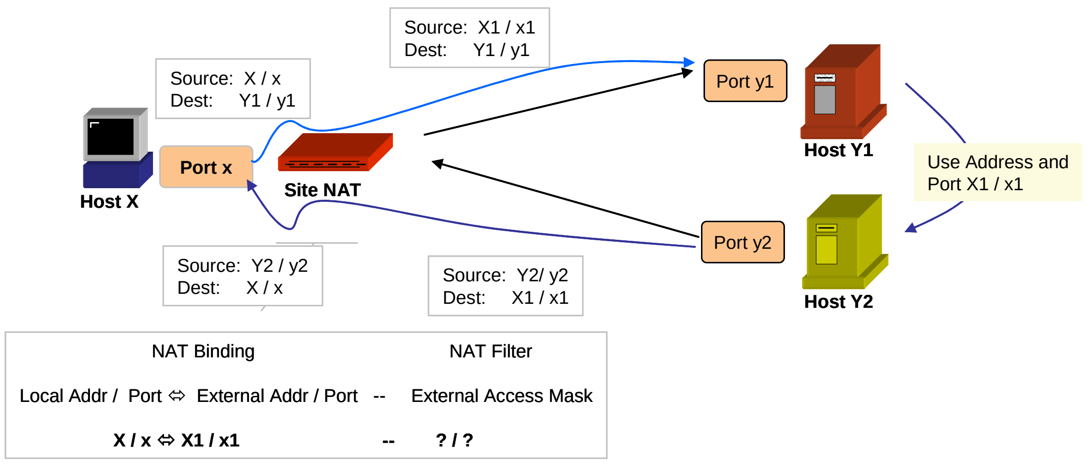


Figure 12 – Inbound test

External Filtering:

Endpoint Independent
The NAT will not filter and discard packets that are addressed to the external part of the binding, irrespective of the source values in the packet. This is analogous to a full cone NAT.

Endpoint Address dependent
The NAT will filter and discard packets that are addressed to the external part of the binding, unless the source address of the packet matches the destination address used in the binding. This is analogous to a restricted cone NAT.

Endpoint Address and Port Dependent
The NAT will filter and discard packets that are addressed to the external part of the binding, unless the source address and port number of the packet matches the destination address used in the binding. This is analogous to a port restricted cone NAT or a symmetric NAT.

External Filtering Timer Refresh

As with Binding Timers, these timers can be refreshed **bidirectionally**, **inbound** or **outbound**.

3.5 NAT Behaviours

The approach of carefully identifying the areas where NAT behaviours differ, and classifying these behavioural differences in a methodical manner is one that has the potential to at least allow us to use the same sets of words when we talk about NAT behaviours, and hopefully also refer to the same set of actual behaviours when we use the same descriptions. The original approach with the STUN work used the terms “symmetric”, “full cone”, and forms of “restricted cone” to describe variations of NAT behaviours. Experience with this form of classification has exposed further variations in NAT behaviours, and this has lead to a form of NAT classification that firstly uses a delineation of **binding** and **filtering** behaviours, and then classifying the various ways in which these bindings and filters are maintained within the NAT. Additional classification attributes include whether the NAT supports **hairpin** connections or not and whether it operates in a **deterministic** or **non-deterministic** manner.

This exercise is not another study in comparative taxonomies. A NAT has no standard way in which to advertise its presence, or any standard way in which to advise protocols or applications of the particular behaviours it will apply to packets being passed through the NAT. In the absence of such explicit advertisements of the presence of a NAT, it is left to the application to make the necessary adjustments that allow it to function in the presence of NATs. The aim of behavioural classification is to associate test sequences that expose the presence of a NAT, and to determine its behaviour. This allows applications to invoke a test procedure that exposes a NAT implementation's particular choice of behaviours, and then allows the application to invoke a mode of operation that can operate across the particular NAT.

The choices available to application environments include the use of agents as session initiation intermediaries, where the endpoints make initial contact through agents, who then assist in passing binding information to the endpoints, allowing them to directly communicate. Other forms of application behaviour need to be invoked when the NAT is Endpoint Address and Port Dependant for both binding and filtering. Different application responses are applicable when one endpoint is behind a NAT and where both endpoints are behind NATs. A typical application response in this latter case where both endpoints are behind highly restrictive NATs is for the endpoints to use agents as session intermediaries, so that the application payload is then passed through the intermediaries as an end-to-end pair of NAT bindings cannot be established.

4. Living in a NAT World

It would be a reasonable conclusion to draw from the previous sections that we are left in the somewhat unsatisfying position of observing that there is near-universal deployment in today's Internet of NAT devices that don't conform to any particular well-defined behaviour set. NAT behaviour varies across implementations, and NATs have no ability to disclose their particular behaviours to applications that are attempting to compensate for their presence in the path. It is extremely challenging for applications to reliably predict the behaviour of the NATs that lie in the path, and more so in the face of multi-party applications, such as interactive game environments, where the application is attempting to understand the level to which this silent intermediary is capable of supporting a relatively promiscuous NAT binding state in terms of external entities that wish to send packets to the local host, and communicate between themselves about the local host as a single entity.

4.1 NATs, Client-Server, Peer-to-Peer and Multi-Party Applications

NATs, as a class of devices, have strong associations with a client-server model of communications. As long as all the servers have a consistent external visibility, with stable addresses in terms of an IP address and port number, and as long as clients initiate connections with servers in a fixed two-party communications model using TCP as a transport protocol, and refraining from turning on IPSEC, then NATs generally will behave in a relatively stable and unobtrusive manner. Applications that operate conservatively in this limited mode can be unaware of the presence of NATs in their path. The relatively widespread deployment of NATs and the continued use of client-server-based applications on the Internet attests to the capability of the NAT to perform transparently and effectively within the strict confines of this particular mode of communication.

However, peer-to-peer applications are more problematical for NATs, as they have extended the model of a NAT beyond its original realm of capability. If the desire is to continue to support the NAT's dynamic binding, but also allow external parties to initiate a communication to a local host, then the NAT ceases to be transparent and unobtrusive, and in this extended environment the NAT transforms itself into an application-visible network element. It is overly presumptuous to claim that NATs have lead to the increasing deployment of multi-party applications on the Internet, but certainly multi-party applications have been seen to be useful in circumventing some of the more aggravating shortcomings of NATs in various peer-to-peer realms.

In this latter context the local party is forced to advertise its willingness to participate in a peer-to-peer realm by communicating with an external agent. The local agent performs a NAT discovery test, and then selects a mode of operation which is consistent with the discovered behaviours of a NAT that may be on the path between the client and the agent. The agent then advertises itself as the local party's intermediary to other peers within the application realm. Attempts to initiate a connection with the local party are directed to the external agent, who then undertakes to perform a rendezvous function in order to establish a session, Depending on the NATs that may exist between the two parties the rendezvous function may need to perform a convoluted handshake process, or, in some instances, may not be able to set up a peer-to-peer session at all. This topic of establishing connectivity in the face of NATs in the path is sufficiently complex to warrant a separate examination in its own right, and the various techniques and approaches will not be examined in this article other than providing some pointers as further reading.

The salient general observation is that NATs have fuelled a new generation of applications which use intermediaries and rendezvous protocols. This shift in application behaviour has implied greater attention to security frameworks for applications, as intermediaries represent an additional active element in the trust model. This, in turn, has implied that the application level has to turn to other chains of derivation of trust, as the basic Internet model of some form of persistent identity as being an attribute of an IP address is no longer a workable proposition in the face of NATs. The position we are reaching here that identity and trust need to be derived from other attributes of the end host and the application that it has invoked.

4.2 ICMP

If an ICMP message is passed through NAT, there is not only the outer IP header to consider, but also the ICMP payload. Most ICMP messages contain part of the original IP packet in the body of the message, so for the NAT to behave as transparently as possible the IP address of the IP header contained in the data part of the ICMP packet should be modified according to the NATs' binding state, as well as the IP header checksum field of this inner packet header.

4.3 NATs and IP Fragmentation

NATs that use bindings that include both address and port values do not have a clear and uniform response to fragments of an IP packet. The TCP or UDP header is only resident in the initial IP fragment, and subsequent IP packet fragments do not contain a copy of the transport layer packet header.

Some NATs attempt packet reassembly as if it were the end host, and only perform the NAT translation once the original IP packet has been reassembled. Of course the reassembled packet my be too large to be forwarded onward, and the NAT may be forced to further fragment the packet. The interplay between this behaviour and various forms of path MTU discovery become a source of frustration.

Other NAT packet fragmentation behaviours do not attempt packet reassembly, but rely on a stored packet fragment translation state that directs the translation to be performed on subsequent packet fragments once the initial packet header translation has been performed on the initial IP packet fragment. This form of behaviour has weaknesses in terms of out of order fragments, when following fragments are received by the NAT prior to the initial IP packet fragment, and in such cases the NAT often has little choice but to silently discard the out of order fragment as untranslateable.

4.4 NATs and Application Level Gateways

This brings up one of the more vexing questions regarding NAT behaviour, namely, should the NAT include knowledge of the payload of certain applications? A number of applications, including *ftp* and the domain name system's resolution protocol include IP addresses within the payload of the application. In an effort to achieve complete transparency of operation some NATs have included applications level gateway (ALG) functionality for certain applications so that this use of IP addresses in the payload can be detected and altered according to the current NAT translation bindings.

The case of ICMP represents one of the simpler forms of gateway functionality, as it can be performed in the same manner as the basic NAT transform, on a per packet with attempting to maintain retained session state. Payload transformations in the case of a TCP-based application will have implications in terms of requiring subsequent alteration of TCP sequence numbers, length fields and even the re-packetization of the payload data stream, given that the data transform required by the address change may imply a change of payload length.

Some units attempt to combine the functionality of a NAT with that of an Application Level Gateway (ALG), such that the NAT is an active intermediary in the transport session. This allows the NAT/ALG to perform “deep” inspection of the packets, and use both application protocol knowledge and per-application-session retained state in order to apply the NAT's binding transforms to the application's payload as well as to the outer IP packet header.

The most widely deployed application that can use IP addresses in the payload is *ftp*, where IP addresses are passed in the payload of the control channel in order to allow data sessions to be initiated on distinct transport sessions. The variability and reliability of *ftp* ALG support in NATs has lead to the widespread use of the passive mode of *ftp* operation, where the data flow is passed within the control session.

A related question is that of the use of IPSEC and NATs. IPSEC with Authenticated Header protection attempts to protect what it believes is the fixed part of the IP packet header, including the source and destination addresses. The NAT’s changes to the IP packet will invalidate the AH integrity check. Also the NAT will change the IP and UDP or TCP checksums, and this will disrupt the Encapsulating Security Payload (ESP) function of IPSEC. The implication is that IPSEC needs to operate upon a TCP or UDP payload, as in IPSEC operating tunnel model, or IPSEC carried as a payload within other types of tunnel operation.

Its also the case that NATs today are heavily enmeshed with the UDP and TCP transport protocols. There are other transport protocols, including the Streams Control Transport Protocol (SCTP) and the Datagram Congestion Control Protocol (DCCP), and doubtless more transport protocol offerings will follow over time. In each case it is a matter of individual choice how NAT implementations define NAT responses to such additional transport protocols. While it is tempting to propose that NATs should fall back of an address-only form of binding that was not address-and-port based this does not appear to be practical guidance. Another aspect of today's NAT deployment is that the most common scenario appears to be that of an single external address and mapping each locally-initiated session into a binding that uses this common external IP address and a variable external port number. This means that NATs need to be able to identify and transform port addresses from the transport protocol section of the IP header.

Another salient factor here is the common association of NATs and firewalls into a single unit, and the coupling of address utilization compression properties of the NAT with its associated packet filtering actions. Deploying a NAT at the external interface of a site does lead to more restrictive site filtering outcomes and a more restrictive model of application interaction, where the model attempts to impose the constraint that applications are initiated from within the site, and that unknown or unidentifiable external traffic is considered hostile and should be subject to firewall-based inspection and filtering. From this perspective there is little desire to make more permissive NATs as an isolated exercise, and there is instead a co-dependence between NAT behaviours and popularly used applications. Applications that work across today's NATs appear to enjoy popular uptake, and applications that enjoy popular uptake appear to determine what forms of traffic pass across NATs.

Popular or not, there are a class of applications that simply cannot work in a “native mode” across NATs, nor can Application Level Gateways assist here. These are applications that attempt to impose some level of end-to-end protection on the IP header fields, or use the IP address of the endpoint in a context of some form of persistant identity token. When the NAT alters the IP address, an application that uses strong forms of header validation will reject such packets as corrupted. Within this class of applications and tools, one of the more commonly referenced tools is that of IPSEC with AH. There is a certain sense of irony in the observation that NATs are often seen as part of an overall approach to site security, yet cannot support a "native mode" operation of some of the basic tools that applications could use to support secure end-to-end data transfer.

5. Views on NATs

Its certainly the case that NATs are very common in today's Internet, and it is worth understanding why NATs have enjoyed such widespread deployment with other technologies appear to be meeting some considerable resistance to widespread deployment. As the original NAT document points out:

> The huge advantage of this approach is that it can be installed incrementally, without changes to either hosts or routers. (A few unusual applications may require changes). As such, this solution can be implemented and experimented with quickly. If nothing else, this solution can serve to provide temporarily relief while other, more complex and far-reaching solutions are worked out.
>
> *Egevang & Fancis, "Network Address Translator", RFC 1631*

More generally, the positive attributes of NATs include the following considerations:

- ✓ End hosts and local routers don't change. Whether there's a NAT in place between the local network and the Internet or not, local devices can use the same software, and support the same applications. NATs don't require customized versions of operating systems or router images.

- ✓ As long as you accept the limitation that sessions must be initiated from the "inside", NATs can work in an entirely transparent fashion for a set of client-server classes of applications.

- ✓ If you accept that perspective the services and usage scenarios that are not supported by NATs are "unwelcome" or "unsafe" then NATs can be placed into a role as a component of a site's security architecture, providing protection from attacks launched from the outside towards the inside network.

- ✓ It conserves its use of public address space.

- ✓ It allows previously disconnected privately addressed networks to connect to the global Internet without any form of renumbering or host changes - and renumbering networks can be a very time consuming, disruptive and expensive operation, or, in other words, renumbering is hard.

- ✓ NAT address space is effective provider independent addressing solution with multi-homing capabilities. NATs allows for rapid switching to a different upstream provider, by renumbering the NAT address pool to the new provider's address space. In essence NATs provide the local network manager with the flexibility of using provider independent space without having to meet certain size and use requirements that would normally be required for an allocation of public provider independent address space.

- ✓ NATs allows the network administrator to exercise some control over the form of network transactions that can occur between local hosts and the public network.

- ✓ NATs require no local device or application changes. This is perhaps one of the major "features" of NATs, in that the local network requires no changes in configuration to operate behind a NAT.

- ✓ NATs do not require a coordinated deployment. There is no transition, and no "flag day" across the Internet. Each local network manager can make an independent decision whether or not to use a NAT. This allows for incremental deployment without mutual dependencies.

- ✓ These days the common theme of the public address assignment policy stresses conservative use of address space with minimum wastage. The standard benchmark is to be able to show that a target of 80% of assigned address space is assigned to number connected devices. Achieving such a very high utilization rate is a challenging task in many network scenarios, and NATs represent an alternative approach where the local network can be configured using private addresses without reference to the use of public addresses.

- ✓ NATs are very widely available and bundled into a large variety of gateway and firewall units. In many units NATs are not an optional extra - they are configured in as a basic item of product functionality.

The market has taken NATs and embraced them wholeheartedly. And in a market-oriented business environment, what's wrong with that?

Unfortunately NATs represent a set of design compromises, and no delving into the world of NATs would be complete without exploring some of NATs shortcomings. So, after enumerating what are commonly seen as their benefits, its now necessary to enumerate some of the broken aspects of the world of NATs.

> This solution has the disadvantage of taking away the end-to-end significance of an IP address, and making up for it with increased state in the network.
>
> *Egevang & Francis, "Network Address Translator", RFC 1631*

> An opposing view of NAT is that of a malicious technology, a weed which is destined to choke out continued Internet development. While recognizing there are perceived address shortages, the opponents of NAT view it as operationally inadequate at best, bordering on a sham as an Internet access solution. Reality lies somewhere in between these extreme viewpoints.
>
> *Tony Hain, "Architectural Implications of NAT", RFC 2993*

- ✗ Firstly, NATs cannot support applications where the initiator lies on the “outside”. The external device has no idea of the address of the local internal device, and therefore cannot direct any packets to that device in order to initiate a session. This implies that peer-to-peer services, such a voice, cannot work unaltered in a NAT environment.

- ✗ The workaround to this form of shortcoming is to force an altered deployment architecture, where service platforms used by external entities are placed “beside” the NAT, allowing command and control from the interior of the local network, and having a permanent (non-NAT) interface to the external network. Obviously this implies some further centralization of IT services within the NATted site.

- ✗ Even this approach does not work well for applications such as Voice over IP, where the “server” now needs to operate as some form of proxy agent. The generic approach here for applications to traverse NATs in the “wrong” direction is for the inside device to forge a UDP connection to the outside agent, and for the inside device to then establish what NAT translated address has been used, and the nature of the NAT in the path and then re-publish this address as the local entity's published service rendezvous point. Sounds fragile? Unfortunately, yes. The other approach is to shift the application to use a set of end point identifiers that are distinct from IP addresses, and use a distributed set of “agents” and “helpers” to dynamically translate the application-level identifiers into transport IP addresses as required. This tends to create added complexity in application deployment, and also embarks on a path of interdependency which is less than desirable. In summary, workarounds to re-establish a peer-to-peer networking model with NATs tend to be limited, complex and often fragile.

- ✗ The behaviour of NATs varies dramatically from one implementation to another. Consequently, it is very difficult for applications to predict or expose the precise behaviour of one or more NATs that may exist on the application's data path.

- ✗ Robust security in IP environments typically operates on an end-to-end model, where both ends include additional information in the packet that can detect attempts to alter the packet in various ways. In IPSEC the header part of the packet is protected by the Authentication header, where an encrypted signature of certain packet header fields is included in the IPSEC packet. If the packet header is changed in transit in unexpected ways the signature check will fail. Obviously IPSEC attempts to protect the packet's address fields - the very same fields that NATs alter! This leads to the observation that robust security measures and NATs don't mix very well. NATs inhibit implementation of security at the IP level.

- NATs have no inherent failover - NATs are an active in-band mechanism that cannot fail into a safe operating fallback mode. When a NAT goes offline all traffic through the NAT stops. NATs create a single point where fates are shared, in the device maintaining connection state and dynamic mapping information.

- NATs sit on the data path and attempt to process every packet. Obviously bandwidth scaling requires NAT scaling.

- NATs are not backed up by industry standardized behaviour. While certain NAT-traversal applications make assumptions about the way NATs behave, it is not the case that all NATs will necessarily behave in precisely the same way. Applications that work in one context may not necessarily operate in others.

- Multiple NATs can get very confusing with "inside" and "outside" concepts when NATs are configured in arbitrary ways. NATs are best deployed in a strict deployment model of an "inside" being a stub private network and an "outside" of the public Internet. Forms of multiple interconnects, potential loops and other forms of network transit with intervening NATs lead to very strange failure modes that are at best highly frustrating.

- With NATs there is no clear, coherent and stable concept of network identity. From the outside these NAT-filtered interior devices are only visible as transient entities.

- Policy based mechanisms that are based on network identity (e.g. Policy QoS) cannot work through NATs.

- Normal forms of IP mobility are broken when any element behind the NAT attempts to roam beyond its local private domain. Solutions are possible to this, generally involving specific NAT-related alterations to the behaviour of the Home Agent and the mobile device.

- Applications that work with identified devices, or that actually identify devices (such as SNMP and DNS) require very careful configuration when operating an a NAT environment.

- NATs may drop IP packet fragments in either direction: without complete TCP/UDP headers, the NAT may not have sufficient stored state to undertake the correct header translation.

- NATs often contain Application Layer Gateways (ALGs) which attempt to be context-sensitive, depending on the source or destination port number. The behavior of the ALGs can be hard to anticipate and these behaviors have not always been documented.

- Most NAT implementations with ALGs that attempt to translate TCP application protocols do not perform their functions correctly when the substrings they must translate span across multiple TCP segments; some of them are also known to fail on flows that use TCP option headers, e.g. timestamps.

From this perspective, NATs are a short term expediency that is currently turning into a longer term set of overriding constraints placed on the further evolution of the Internet. Not only do new applications need to include considerations of NAT traversal, but we appear to be entering into a situation where if an application cannot work across NATs than the application itself fails to gain acceptance. We seem to be locking into a world that is almost the antithesis of the Internet concept. In this NAT-based world servers reside within the network and are operated as part of the service-provider's role, while end devices are seen as "dumb" clients, who can establish connections to servers but cannot establish connections between each other. The widespread use of NATs appear to be reinforcing a re-emergence of the model of "smart network, dumb clients", while others would argue that the network is getting no smarter, its just that the number of obstacles and amount of network debris is increasing while clients are getting worse at maintaining coherent end-to-end state in the face of such changes.

However, despite their shortcomings, despite the problems NATs create for numerous applications and their users, and despite the continued grappling over a common language to understand how NATs behave, there are a lot of NATs deployed, and, at least in the IPv4 realm, NATs appear to be a firmly fixed part of the future of the Internet. NATs continue to proliferate in today's Internet.

6. Moving on with NATs

One commonly held belief is that deployment of IPv6 will eliminate the problem of NATs within the Internet. Certainly its reasonable to observe that if achieving high address utilization densities is no longer the objective, then there will be plentiful public IPv6 address space and that particular reason to deploy NATs is significantly discounted in an IPv6 realm.

That does not say that IPv6 NATs will not be implemented, nor used. Indeed IPv6 NATs are already available, and they are being used, albeit to some small extent. NATs are, rightly or wrongly considered to be part of a security solution for a site due to their filtering properties that prevents incoming packets from entering the site unless the NAT already has a permitting binding initiated from the inside. In addition, NATs allow a site to use an internally persistent naming and addressing scheme based on some form of deployment of IPv6 unique site local address, and deploy NATs at the edge to create an external view of the site that fits within a provider-based address aggregated view of the IPv6 Internet.

So it would perhaps to too enthusiastic a level of conjecture to suppose that IPv6 will drive away all forms of NAT use in IPv6. Its reasonable to predict that some use of NAT will be seen in IPv6, although many would be highly disappointed if the level of IPv6 NAT use rose to anywhere approaching that of NAT in IPv4.

However the Internet is still largely a network that uses IPv4 and NATs, and efforts continue along the lines of reducing the amount of friction and frustration in a world where NATs are prolific. One of the ways to progress here is to treat NAT boxes as yet another instance of Internet middleware, and attempt to apply the same sets of processes to NATs that appear in other instances of middleware. The work of the IETF in the Middlebox Communication Working Group uses a model that attempts to expose NATs, as well as firewalls, performance enhancing proxies, application proxies and relay agents, to the application, and allow the application to specify the policy that the middle box should apply. In the case of NATs this could allow an application to communicate to a NAT that it does not require any form of third party access, and that a fully symmetric behaviour could be applied to the binding without any loss in application functionality. Equally an application could indicate to the NAT that it expects third parties to be able to use the NAT binding, and that the binding that the NAT will set up for the application should be managed as a port restricted cone. There is much that could be achieved here that would allows applications to function with some level of determinism, rather than attempting to arm to application with a large and complex toolset of all the relevant techniques of NAT traversal that may be required by the application when confronted by various NAT behaviours.

In the meantime the NAT behaviour guessing game continues. The generic class of techniques that support this function is termed “Unilateral Self-Address Fixing” (UNSAF). This is a process where the local entity attempts to determine the address and port by which the entity is known externally, and to determine the characteristics of this association to understand in what contexts the external address may be used as a service rendezvous point for externally-initiated communication. Work in this area (RFC 3424) has exposed a number of relevant considerations, including a set of deficiencies noted in the previous section.

So, what would a NAT implementation look like if there were standards relating to NAT behaviours and the implementation were to comply with these standards? There have been numerous efforts to document various forms of network-friendly and application-friendly ways in which NATs could behave, but it would appear that such an effort will require the imprimatur of a standard in order to attain a level of general acceptance from NAT implementations. However it is possible to predict that any such effort at a “standardized” form of NAT behaviour will include the following considerations. The following set of behaviours is based on that enumerated in [draft-audet-nat-behave]:

- NATs must show endpoint independent behaviour for UDP-based bindings. This is to ensure that the NAT can support application rendezvous without the need for various multi-party relays and agents.

- NAT should not use port preservation nor port overloading, and should operate in a deterministic manner. Port preservation exposes the NATs to non-standard behaviours when port preservation cannot be enforced. In addition, NATs must have deterministic behaviour.

- A dynamic NAT UDP binding timer should be 5 minutes, and should avoid expiration timers of 2 minutes or less. This is to ensure that the timeout is long enough to avoid excessively frequent timer refresh packets.

- The NAT UDP timeout binding must use a timer refresh based on outbound traffic, and all sessions that use a particular binding should use a common refresh timer. This requirement is a security consideration, in that letting inbound traffic refresh the timer allows an external party to keep a port open on the NAT.
- The NAT filtering function should be Address Dependant. This represents a balance between security and utility.
- The NAT's UDP filter timeout behaviour must be the same as the NAT UDP binding timeout. This is intended to reduce the complexity of applications that are reliant on long-held NAT state.
- The NAT should support hairpin connections, using the external address and port.
- If the NAT includes ALG support these should be configurable in terms of being able to turn off the ALG function on a per-application basis.
- NATs should support fragmentation and forwarding of packet fragments.
- NATs must support ICMP Destination Unreachable messages, and the ICMP timeout should be greater than 2 seconds

7. Learning from NATs

There are a few very relevant lessons about NATs that we can observe at this stage.

The first is that we need standards and we rely on standards. For many years the Internet Engineering Task Force has viewed standardization of NATs and their behaviour as being an action that would encourage further deployment of a technology that was apparently considered undesireable. The result has been that NATs have been deployed for reasons entirely unconnected with the IETF and standardization, but because the original specification of NAT behaviour was at such a general level each NAT implementor has been forced into making local decisions as to how the NAT should behave under specific circumstances. We now enjoy a network with widespread deployment of an active device that does not have consistent implementations and, in the worst cases, exhibits non-deterministic behaviours. This has made the task of deployment of certain applications on the Internet, including voice-based applications, incredibly difficult. Whether NATs are good or bad, they'd be less of a collective headache today if they shared a common standard core behaviour. NATs for IPv6 may be felt to be unnecessary today, and it can be argued they represent no real value to an IPv6 site. But a collection of IPv6 NAT implantations with no common core behaviour would be a far worse of problem to application users. Standardization of technology at least eliminates some of the worst aspects of application-level guesswork out of technology deployment.

Secondly, a little bit of security is often far worse than no security. NATs are very poor security devices, and in terms of their behaviour with UDP, NATs afford only minor levels of protection. The task of securing a site from various forms of attack and disruption remains one of a careful exercise of assessment of acceptable risk coupled with detailed consideration of site management functions. NATs are not a quick way out of this effort.

In considering NATs it seems that we are back to the very basics of networking. The basic requirements of any network are "who", "where" and" how", or "identity", "location" and "forwarding". In the case of IP all these elements were included in the semantics of an IP address, and when addresses get translated dynamically we lose track of IP level identity across the network. Maybe, just maybe, as we look at the longer term developments of IP technology, one potential refinement may be the separation of end point identity to that of location, and as a potential outcome, NATs could readily manipulate location-based addresses while applications could look to a different token set as a means of establishing exactly who is the other party to the communications.

Of course if we ever venture down such a path I trust that such a move towards the use of explicit identities does not generate a complementary deployment of Network Identity Translators, or NITs, as an adjunct to the current set of NATs. Too many NITs and NATs will definitely send us all NUTs!

Further Reading

There is no shortage of material on NATs in a wide variety of sources. The following is a list of IETF-related documents, encompassing both published Requests for Comments (RFCs) and works-in-progress, that have been circulated as Internet Drafts

IETF Requests for Comment

RFC 1631
Egevang, K, and P. Francis , *The IP Network Address Translator (NAT)*, RFC 1631, May 1994.

RFC 2391
Srisuresh, P. and D. Gan, *Load Sharing using IP Network Address Translation (LSNAT)*, RFC 2391, August 1998.

RFC 2663
Srisuresh, P. and M. Holdrege, *IP Network Address Translator (NAT) Terminology and Consideration*s, RFC 2663, August 1999.

RFC 2766
Tsirtsis, G. and P. Srisuresh, *Network Address Translation - Protocol Translation (NAT-PT)*, RFCC 2776, February 2000.

RFC 2993
Hain, T, *Architectural Implications of NAT,* RFC 2993, November 2000.

RFC 3022
Srisuresh, P. and K. Egevang, *Traditional IP Network Address Translator (Traditional NAT)*, RFC 3022, January 2001.

RFC 3027
Holdrege, M. and P. Srisuresh, *Protocol Complications with the IP Network Address Translator*, RFC 3027, January 2001.

RFC3235
D. Senie, *Network Address Translator (NAT)-Friendly Application Design Guidelines*, RFC 3235, January 2002.

RFC3303
Srisuresh, P, , J. Kuthan, J. Rosenberg, A. Molitor, and A. Rayhan, *Middlebox communication architecture and framework*, RFC 3303, August 2002..

RFC 3424
Daigle, L. and IAB, *IAB Considerations for Unilateral Self-Address Fixing (UNSAF) Across Network Address Translation*, RFC 3424, November 2002.

RFC 3489
Rosenberg, J., Weinberger, J., Huitema, C. and R. Mahy, *STUN - Simple Traversal of User Datagram Protocol (UDP) Through Network Address Translators (NATs)*, RFC 3489, March 2003.

RFC 3715
Aboba, B. and W. Dixon, *IPsec-Network Address Translation (NAT) Compatibility Requirements*, RFC 3715,March 2004.

IETF Works in Progress

Internet drafts enjoy a fleeting existence, and the following documents may not be available when this read this document. In such cases its often the case that a decent Internet search will be able to locate the document, or its successor.

draft-audet-nat-behave
Audet, F, and C. Jennings, *NAT/Firewall Behavioral Requirements*, work in progress, July 2004.

draft-ford-midcom-p2p
Ford, B, P. Srisuresh and D. Kegel, *Peer-to-Peer(P2P) communication across Network Address Translators(NATs),* work in progress, June 2004.

draft-ietf-mmusic-ice
Rosenberg, J., *Interactive Connectivity Establishment (ICE): A Methodology for Network Address Translator (NAT) Traversal for the Session Initiation Protocol (SIP)*, work in progress, July 2004.

draft-jennings-midcom-stun-results
Jennings, C., *NAT Classification Results using STUN*, work in progress, July 2004.

draft-rosenberg-midcom-turn-01
J. Rosenberg, J. Weinberger, R. Mahy, and C. Huitema, *Traversal Using Relay NAT (TURN)*, work in progress, July 2004.

Other Resources:

Nat Check
Ford, B. and D. Andersen, Nat Check Web Site: http://midcom-p2p.sourceforge.net, June 2004.

STUN Client and Server
http://sourceforge.net/projects/stun, June 2004.

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