NAT Port Mapping Protocol (NAT-PMP)

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Abstract

This document describes a protocol for automating the process of
creating Network Address Translation (NAT) port mappings. Included in
the protocol is a method for retrieving the external IP address of a
NAT gateway, thus allowing a client to make this external IP address
and port number known to peers that may wish to communicate with it.
This protocol is implemented in current Apple products including Mac
OS X, Bonjour for Windows, and AirPort wireless base stations.

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1. Introduction

Network Address Translation (NAT) is a method of sharing one public
internet address with a number of devices. This document is focused
on what "IP Network Address Translator (NAT) Terminology and
Considerations" [RFC 2663] calls "NAPTs" (Network Address/Port
Translators). A full description of NAT is beyond the scope of this
document. The following brief overview will cover the aspects
relevant to this port mapping protocol. For more information on
NAT, see "Traditional IP Network Address Translator" [RFC 3022].

NATs have one or more external IP addresses. A private network is

set up behind the NAT. Devices behind the NAT are assigned private
addresses and the private address of the NAT device is used as the
gateway.

When a packet from any device behind the NAT is sent to an address on the public Internet, the packet first passes through the NAT box. The NAT box looks at the source port and address. In some cases, a NAT will also keep track of the destination port and address. The NAT then creates a mapping from the internal address and internal port to an external address and external port if a mapping does not already exist.

The NAT box replaces the internal address and port number in the packet with the external entries from the mapping and sends the packet on to the next gateway.

When a packet from any address on the Internet is received on the NAT's external side, the NAT will look up the destination address and port (external address and port) in the list of mappings. If an entry is found, it will contain the internal address and port that the packet should be sent to. The NAT gateway will then rewrite the destination address and port with those from the mapping. The packet will then be forwarded to the new destination addresses. If the packet did not match any mapping, the packet will most likely be dropped. Various NATs implement different strategies to handle this. The important thing to note is that if there is no mapping, the NAT does not know to which internal address the packet should be sent.

Mappings are usually created automatically as a result of observing outbound traffic. There are a few exceptions. Some NATs may allow manually-created permanent mappings that map an external port to a specific internal IP address and port. Such a mapping allows incoming connections to the device with that internal address. Some NATs also implement a default mapping where any inbound traffic that does not match any other more specific mapping will always be forwarded to a specific internal address. Both types of mappings are usually set up manually through some configuration tool.

Without these manually-created inbound port mappings, clients behind the NAT would be unable to receive inbound connections, which represents a loss of connectivity when compared to the original Internet architecture [ETEAISD]. For those who view this loss of connectivity as a bad thing, NAT-PMP allows clients to operate much more like a host directly connected to the unrestricted public Internet, with an unrestricted public IP address. NAT-PMP allows client hosts to communicate with the NAT gateway to request the creation of inbound mappings on demand. Having created a NAT mapping to allow inbound connections, the client can then record its external IP address and external port number in a public registry (e.g. the world-wide Domain Name System) or otherwise make it accessible to peers that wish to communicate with it.

2. Conventions and Terminology Used in this Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in "Key words for use in RFCs to Indicate Requirement Levels" [RFC 2119].

3. Protocol and Packet Format

NAT Port Mapping Protocol runs over UDP. Every packet starts with an 8 bit version followed by an 8 bit operation code.

This document specifies version 0 of the protocol. Any NAT-PMP gateway implementing this version of the protocol, receiving a packet with a version number other than 0, MUST return result code 1 (Unsupported Version), indicating the highest version number it does support (i.e. 0) in the version field of the reply.

Opcodes between 0 and 127 are client requests. Opcodes from 128 to 255 are server responses. Responses always contain a 16 bit result code in network byte order. A result code of zero indicates success. Responses also contain a 32 bit unsigned integer corresponding to the number of seconds since the NAT gateway was rebooted or since its port mapping state was reset.

This protocol SHOULD only be used when the client determines that its primary IPv4 address is in one of the private IP address ranges defined in "Address Allocation for Private Internets" [RFC 1918]. This includes the address ranges 10/8, 172.16/12, and 192.168/16.

Clients always send their Port Mapping Protocol requests to their default gateway, as learned via DHCP [RFC 2131], or similar means. This protocol is designed for small home networks, with a single logical link (subnet) where the client's default gateway is also the NAT translator for that network. For more complicated networks where the NAT translator is some device other than the client's default gateway, this protocol is not appropriate.

3.1. Requests and Responses

NAT gateways are often low-cost devices, with limited memory and CPU speed. For this reason, to avoid making excessive demands on the NAT gateway, clients machines SHOULD NOT issue multiple requests simultaneously in parallel. If a client needs to perform multiple requests (e.g. on boot, wake from sleep, network connection, etc.) it SHOULD queue them and issue them serially one at a time. Once the NAT gateway responds to one request the client machine may issue the

next. In the case of a fast NAT gateway, the client may be able to
complete requests at a rate of hundreds per second. In the case of

a slow NAT gateway that takes perhaps half a second to respond to
a NAT-PMP request, the client SHOULD respect this and allow the
NAT gateway to operate at the pace it can manage, and not overload
it by issuing requests faster than the rate it's answering them.

To determine the external IP address or request a port mapping,
a NAT-PMP client sends its request packet to port 5351 of its
configured gateway address, and waits 250ms for a response. If no
NAT-PMP response is received from the gateway after 250ms, the client
retransmits its request and waits 500ms. The client SHOULD repeat
this process with the interval between attempts doubling each time.
If, after sending its 9th attempt (and then waiting for 64 seconds),
the client has still received no response, then it SHOULD conclude
that this gateway does not support NAT Port Mapping Protocol and
MAY log an error message indicating this fact. In addition, if the
NAT-PMP client receives an "ICMP Port Unreachable" message from the
gateway for port 5351 then it can skip any remaining retransmissions
and conclude immediately that the gateway does not support NAT-PMP.

As a performance optimization the client MAY record this information
and use it to suppress further attempts to use NAT-PMP, but the
client should not retain this information for too long. In
particular, any event that may indicate a potential change of gateway
or a change in gateway configuration (hardware link change
indication, change of gateway MAC address, acquisition of new DHCP
lease, receipt of NAT-PMP announcement packet from gateway, etc.)
should cause the client to discard its previous information regarding
the gateway's lack of NAT-PMP support, and send its next NAT-PMP
request packet normally.

When deleting a port mapping, the client uses the same initial 250ms
timeout, doubling on each successive interval, except that clients
may choose not to try the full nine times before giving up. This
is because mapping deletion requests are in some sense advisory.
They are useful for efficiency, but not required for correctness;
it is always possible for client software to crash, or for power to
fail, or for a client device to be physically unplugged from the
network before it gets a chance to send its mapping deletion
request(s), so NAT gateways already need to cope with this case.
Because of this, it may be acceptable for a client to retry only once
or twice before giving up on deleting its port mapping(s), but a
client SHOULD always send at least one deletion request whenever
possible, to reduce the amount of stale state that accumulates on
NAT gateways. A client need not continue trying to delete a port
mapping after the time when that mapping would naturally have expired
anyway.

3.2. Determining the External Address

   To determine the external address, the client behind the NAT sends
   the following UDP payload to port 5351 of the configured gateway
   address:

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Vers = 0      | OP = 0        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   A compatible NAT gateway MUST generate a response with the following
   format:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Vers = 0      | OP = 128 + 0  | Result Code                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Seconds Since Start of Epoch                                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| External IP Address (a.b.c.d)                                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   This response indicates that the NAT gateway implements this version
   of the protocol and returns the external IP address of the NAT
   gateway. If the result code is non-zero, the value of External IP
   Address is undefined (MUST be set to zero on transmission, and MUST
   be ignored on reception).

   The NAT gateway MUST fill in the "Seconds Since Start of Epoch" field
   with the time elapsed since its port mapping table was initialized on
   startup or reset for any other reason (see Section 3.6 "Seconds Since
   Start of Epoch").

   Upon receiving a response packet, the client MUST check the source
   IP address, and silently discard the packet if the address is not the
   address of the gateway to which the request was sent.

[3.2.1](). Announcing Address Changes

   When the external IP address of the NAT changes, the NAT gateway MUST
   send a gratuitous response to the link-local multicast address
   224.0.0.1, port 5350 with the packet format above to notify clients
   of the new external IP address. To accommodate packet loss, the
   NAT gateway SHOULD multicast 10 address change notifications.
   The interval between the first two notifications SHOULD be 250ms,
   and the interval between each subsequent notification SHOULD double.

   Upon receiving a gratuitous address change announcement packet,
   the client MUST check the source IP address, and silently discard
   the packet if the address is not the address of the client's
   current configured gateway. This is to guard against inadvertent
   misconfigurations where there may be more than one NAT gateway
   active on the network.

   IMPLEMENTATION NOTE: Earlier implementations of NAT-PMP used port
   5351 as the destination both for client requests (address and port
   mapping) and for address announcements. NAT-PMP servers would listen
   on UDP 5351 for client requests, and NAT-PMP clients would listen on
   UDP 5351 for server announcements. However, implementors encountered
   difficulties when a single device is acting in both roles, for
   example a home computer with Internet Sharing enabled. This computer
   is acting in the role of NAT-PMP server to its DHCP clients, yet at
   the same time it has to act in the role of NAT-PMP client in order to
   determine whether it is, itself, behind another NAT gateway. While in
   principle it might be possible on some operating systems for two
   processes to coordinate sharing of a single UDP port, on many
   platforms this is difficult or even impossible, so for pragmatic
   engineering reasons it is convenient to have clients listen on UDP
   5350 and servers listen on UDP 5351.

[3.3](). **Creating a Mapping**

To create a mapping, the client sends a UDP packet to port 5351
of the gateway's internal IP address with the following format:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Vers = 0      | OP = x        | Reserved (MUST be zero)       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Internal Port                 | Requested External Port       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Requested Port Mapping Lifetime in Seconds                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Opcodes supported:
1 - Map UDP
2 - Map TCP

The Reserved field MUST be set to zero on transmission and MUST
be ignored on reception.

The Internal Port is set to the local port on which the client is
listening.

If the client would prefer to have a high-numbered "anonymous"
external port assigned, then it should set the Requested External
Port to zero, which indicates to the gateway that it should allocate
a high-numbered port of its choosing. If the client would prefer
instead to have the mapped external port be the same as its local
Internal Port if possible (e.g. a web server listening on port 80
that would ideally like to have external port 80) then it should set
the Requested External Port to the desired value. However, the
gateway is not obliged to assign the port requested, and may choose
not to, either for policy reasons (e.g. port 80 is reserved and
clients may not request it) or because that port has already been
assigned to some other client. Because of this, some product
developers have questioned the value of having the Requested External
Port field at all. The reason is for failure recovery. Most low-cost
home NAT gateways do not record temporary port mappings in persistent
storage, so if the gateway crashes or is rebooted, all the mappings
are lost. A renewal packet is formatted identically to an initial
mapping request packet, except that for renewals the client sets the
Requested External Port field to the port the gateway actually
assigned, rather than the port the client originally wanted. When a
freshly-rebooted NAT gateway receives a renewal packet from a client,
it appears to the gateway just like an ordinary initial request for
a port mapping, except that in this case the Requested External Port

is likely to be one that the NAT gateway *is* willing to allocate
(it allocated it to this client right before the reboot, so it should
presumably be willing to allocate it again).

The RECOMMENDED Port Mapping Lifetime is 3600 seconds.

After sending the port mapping request, the client then waits for
the NAT gateway to respond. If after 250ms, the gateway doesn't
respond, the client SHOULD re-issue its request as described above
in Section 3.1 "Requests and Responses".

The NAT gateway responds with the following packet format:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Vers = 0      | OP = 128 + x  | Result Code                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Seconds Since Start of Epoch                                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Internal Port                 | Mapped External Port          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Port Mapping Lifetime in Seconds                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The 'x' in the OP field MUST match what the client requested. Some
NAT gateways are incapable of creating a UDP port mapping without
also creating a corresponding TCP port mapping, and vice versa, and
these gateways MUST NOT implement NAT Port Mapping Protocol until
this deficiency is fixed. A NAT gateway which implements this
protocol MUST be able to create TCP-only and UDP-only port mappings.
If a NAT gateway silently creates a pair of mappings for a client
that only requested one mapping, then it may expose that client to
receiving inbound UDP packets or inbound TCP connection requests
that it did not ask for and does not want.

While a NAT gateway MUST NOT automatically create mappings for TCP
when the client requests UDP, and vice versa, the NAT gateway MUST
reserve the companion port so the same client can choose to map it
in the future. For example, if a client requests to map TCP port 80,
as long as the client maintains the lease for that TCP port mapping,
another client with a different IP address MUST NOT be able to
successfully acquire the mapping for UDP port 80.

The client normally requests the external port matching the internal
port. If that external port is not available, the NAT gateway MUST
return an available external port or return an error code if no ports
are available.

The source address of the packet MUST be used for the internal
address in the mapping. This protocol is not intended to facilitate
one device behind a NAT creating mappings for other devices. If there

are legacy devices that require inbound mappings, permanent mappings
can be created manually by the administrator, just as they are today.

If a mapping already exists for a given internal port on a given
local client (whether that mapping was created explicitly using
NAT-PMP, implicitly as a result of an outgoing TCP SYN packet, or
manually by a human administrator) and that client requests another
mapping for the same internal port (possibly requesting a different
external port) then the mapping request should succeed, returning the
already-assigned external port. This is necessary to handle the case
where a client requests a mapping with requested external port X,
and is granted a mapping with actual external port Y, but the
acknowledgement packet gets lost. When the client retransmits its
mapping request, it should get back the same positive acknowledgement
as was sent (and lost) the first time.

The NAT gateway MUST NOT accept mapping requests destined to the
NAT gateway's external IP address or received on its external network
interface. Only packets received on the internal interface(s) with
a destination address matching the internal address(es) of the NAT
gateway should be allowed.

The NAT gateway MUST fill in the "Seconds Since Start of Epoch" field
with the time elapsed since its port mapping table was initialized on
startup or reset for any other reason (see Section 3.6 "Seconds Since
Start of Epoch").

The Port Mapping Lifetime is an unsigned integer in seconds. The NAT
gateway MAY reduce the lifetime from what the client requested. The
NAT gateway SHOULD NOT offer a lease lifetime greater than that
requested by the client.

Upon receiving the response packet, the client MUST check the source
IP address, and silently discard the packet if the address is not the
address of the gateway to which the request was sent.

The client SHOULD begin trying to renew the mapping halfway to expiry
time, like DHCP. The renewal packet should look exactly the same as
a request packet, except that the client SHOULD set the requested
external port to what the NAT gateway previously mapped, not what the
client originally requested. As described above, this enables the
gateway to automatically recover its mapping state after a crash or
reboot.

3.4. Destroying a Mapping

A mapping may be destroyed in a variety of ways. If a client fails
to renew a mapping, then when its lifetime expires the mapping MUST
be automatically deleted. In the common case where the gateway
device is a combined DHCP server and NAT gateway, when a client's
DHCP address lease expires, the gateway device MAY automatically

delete any mappings belonging to that client. Otherwise a new client
being assigned the same IP address could receive unexpected inbound

UDP packets or inbound TCP connection requests that it did not ask
for and does not want.

A client MAY also send an explicit packet to request deletion of a
mapping that is no longer needed. A client requests explicit
deletion of a mapping by sending a message to the NAT gateway
requesting the mapping, with the Requested Lifetime in Seconds set
to 0. The requested external port MUST be set to zero by the client
on sending, and MUST be ignored by the gateway on reception.

When a mapping is destroyed successfully as a result of the client
explicitly requesting the deletion, the NAT gateway MUST send a
response packet which is formatted as defined in Section 3.3
"Creating a Mapping". The response MUST contain a result code of 0,
the internal port as indicated in the deletion request, an external
port of 0, and a lifetime of 0. The NAT gateway MUST respond to
a request to destroy a mapping that does not exist as if the
request were successful. This is because of the case where the
acknowledgement is lost, and the client retransmits its request to
delete the mapping. In this case the second request to delete the
mapping MUST return the same response packet as the first request.

If the deletion request was unsuccessful, the response MUST contain
a non-zero result code and the requested mapping; the lifetime is
undefined (MUST be set to zero on transmission, and MUST be ignored
on reception). If the client attempts to delete a port mapping which
was manually assigned by some kind of configuration tool, the NAT
gateway MUST respond with a 'Not Authorized' error, result code 2.

When a mapping is destroyed as a result of its lifetime expiring or
for any other reason, if the NAT gateway's internal state indicates
that there are still active TCP connections traversing that now-
defunct mapping, then the NAT gateway SHOULD send appropriately-
constructed TCP RST (reset) packets both to the local client and to
the remote peer on the Internet to terminate that TCP connection.

A client can request the explicit deletion of all its UDP or TCP
mappings by sending the same deletion request to the NAT gateway with
external port, internal port, and lifetime set to 0. A client MAY
choose to do this when it first acquires a new IP address in order to
protect itself from port mappings that were performed by a previous
owner of the IP address. After receiving such a deletion request, the
gateway MUST delete all its UDP or TCP port mappings (depending on
the opcode). The gateway responds to such a deletion request with a
response as described above, with the internal port set to zero. If
the gateway is unable to delete a port mapping, for example, because
the mapping was manually configured by the administrator, the gateway
MUST still delete as many port mappings as possible, but respond with

a non-zero result code. The exact result code to return depends on
the cause of the failure. If the gateway is able to successfully
delete all port mappings as requested, it MUST respond with a result
code of 0.

Result Codes

   Currently defined result codes:
   0 - Success
   1 - Unsupported Version
   2 - Not Authorized/Refused
       (e.g. box supports mapping, but user has turned feature off)
   3 - Network Failure
       (e.g. NAT box itself has not obtained a DHCP lease)
   4 - Out of resources
       (NAT box cannot create any more mappings at this time)
   5 - Unsupported opcode

   If the result code is non-zero, the format of the packet following
   the result code may be truncated. For example, if the client sends a
   request to the server with an opcode of 17 and the server does not
   recognize that opcode, the server SHOULD respond with a message where
   the opcode is 17 + 128 and the result code is 5 (opcode not
   supported). Since the server does not understand the format of
   opcode 17, it may not know what to place after the result code. In
   some cases, relevant data may follow the opcode to identify the
   operation that failed. For example, a client may request a mapping
   but that mapping may fail due to resource exhaustion. The server
   SHOULD respond with the result code to indicate resource exhaustion
   (4) followed by the requested port mapping so the client may identify
   which operation failed.

   Clients MUST be able to properly handle result codes not defined in
   this document. Undefined results codes MUST be treated as fatal
   errors of the request.

[3.6](#). **Seconds Since Start of Epoch**

   Every packet sent by the NAT gateway includes a "Seconds since start
   of epoch" field (SSSOE). If the NAT gateway resets or loses the
   state of its port mapping table, due to reboot, power failure, or any
   other reason, it MUST reset its epoch time and begin counting SSSOE
   from 0 again. Whenever a client receives any packet from the NAT
   gateway, either gratuitously or in response to a client request, the
   client computes its own conservative estimate of the expected SSSOE
   value by taking the SSSOE value in the last packet it received from
   the gateway and adding 7/8 (87.5%) of the time elapsed since that
   packet was received. If the SSSOE in the newly received packet is
   less than the client's conservative estimate by more than one second,
   then the client concludes that the NAT gateway has undergone a reboot
   or other loss of port mapping state, and the client MUST immediately
   renew all its active port mapping leases as described in [Section 3.7](#)

"Recreating Mappings On NAT Gateway Reboot".

3.7. Recreating Mappings On NAT Gateway Reboot

The NAT gateway MAY store mappings in persistent storage so when it
is powered off or rebooted, it remembers the port mapping state of
the network.

However, maintaining this state is not essential for correct
operation. When the NAT gateway powers on or clears its port mapping
state as the result of a configuration change, it MUST reset the
epoch time and re-announce its IP address as described in Section
3.2.1 "Announcing Address Changes". Reception of this packet where
time has apparently gone backwards serves as a hint to clients
on the network that they SHOULD immediately send renewal packets
(to immediately recreate their mappings) instead of waiting until
the originally scheduled time for those renewals. Clients who miss
receiving those gateway announcement packets for any reason will
still renew their mappings at the originally scheduled time and cause
their mappings to be recreated; it will just take a little longer for
these clients.

A mapping renewal packet is formatted identically to an original
mapping request; from the point of view of the client it is a
renewal of an existing mapping, but from the point of view of the
freshly-rebooted NAT gateway it appears as a new mapping request.

This self-healing property of the protocol is very important.

The remarkable reliability of the Internet as a whole derives
in large part from the fact that important state is held in the
endpoints, not in the network itself [ETEAISD]. Power-cycling an
Ethernet switch results only in a brief interruption in the flow
of packets; established TCP connections through that switch are not
broken, merely delayed for a few seconds. Indeed, an old Ethernet
switch can even be replaced with a new one, and as long as the cables
are transferred over reasonably quickly, after the upgrade all the
TCP connections that were previously going though the old switch will
be unbroken and now going through the new one. The same is true of
IP routers, wireless base stations, etc. The one exception is NAT
gateways. Because the port mapping state is required for the NAT
gateway to know where to forward inbound packets, loss of that state
breaks connectivity through the NAT gateway. By allowing clients to
detect when this loss of NAT gateway state has occurred, and recreate
it on demand, we turn hard state in the network into soft state, and
allow it to be recovered automatically when needed.

Without this automatic recreation of soft state in the NAT gateway,
reliable long-term networking would not be achieved. As mentioned
above, the reliability of the Internet does not come from trying

to build a perfect network in which errors never happen, but from
accepting that in any sufficiently large system there will always be
some component somewhere that's failing, and designing mechanisms

that can handle those failures and recover. To illustrate this point
with an example, consider the following scenario: Imagine a network
security camera that has a web interface and accepts incoming
connections from web browser clients. Imagine this network security
camera uses NAT-PMP or a similar protocol to set up an inbound
port mapping in the NAT gateway so that it can receive incoming
connections from clients the other side of the NAT gateway.
Now, this camera may well operate for weeks, months, or even years.
During that time it's possible that the NAT gateway could experience
a power failure or be rebooted. The user could upgrade the NAT
gateway's firmware, or even replace the entire NAT gateway device
with a newer model. The general point is that if the camera operates
for a long enough period of time, some kind of disruption to the NAT
gateway becomes inevitable. The question is not whether the NAT
gateway will lose its port mappings, but when, and how often.
If the network camera and devices like it on the network can detect
when the NAT gateway has lost its port mappings, and recreate them
automatically, then these disruptions are self-correcting and largely
invisible to the end user. If, on the other hand, the disruptions are
not self-correcting, and after a NAT gateway reboot the user has to
manually reset or reboot all the other devices on the network too,
then these disruptions are *very* visible to the end user. This
aspect of the design is what makes the difference between a protocol
that keeps on working indefinitely over a time scale of months or
years, and a protocol that works in brief testing, but in the real
world is continually failing and requiring manual intervention to get
it going again.

When a client renews its port mappings as the result of receiving
a packet where the "Seconds since start of epoch" field (SSSOE)
indicates that a reboot or similar loss of state has occurred,
the client MUST first delay by a random amount of time selected
with uniform random distribution in the range 0 to 5 seconds, and
then send its first port mapping request. After that request is
acknowledged by the gateway, the client may then send its second
request, and so on, as rapidly as the gateway allows. The requests
SHOULD be issued serially, one at a time; the client SHOULD NOT issue
multiple requests simultaneously in parallel.

The discussion in this section focusses on recreating inbound port
mappings after loss of NAT gateway state, because that is the more
serious problem. Losing port mappings for outgoing connections
destroys those currently active connections, but does not prevent
clients from establishing new outgoing connections. In contrast,
losing inbound port mappings not only destroys all existing inbound
connections, but also prevents the reception of any new inbound
connections until the port mapping is recreated. Accordingly,
we consider recovery of inbound port mappings the more important

priority. However, clients that want outgoing connections to survive
a NAT gateway reboot can also achieve that using NAT-PMP. After
initiating an outbound TCP connection (which will cause the NAT
gateway to establish an implicit port mapping) the client should send

the NAT gateway a port mapping request for the source port of its TCP
connection, which will cause the NAT gateway to send a response
giving the external port it allocated for that mapping. The client
can then store this information, and use later to recreate the
mapping if it determines that the NAT gateway has lost its mapping
state.

3.8. NAT Gateways with NAT Function Disabled

Note that *only* devices currently acting in the role of NAT gateway
should participate in NAT-PMP protocol exchanges with clients.
A network device that is capable of NAT (and NAT-PMP), but is
currently configured not to perform that function, (e.g. it is
acting as a traditional IP router, forwarding packets without
modifying them), MUST NOT respond to NAT-PMP requests from clients,
or send spontaneous NAT-PMP address-change announcements.

In particular, a network device not currently acting in the role of
NAT gateway should not even respond to NAT-PMP requests by returning
an error code such as "2 - Not Authorized/Refused", since to do so
is misleading to clients -- it suggests that NAT port mapping is
necessary on this network for the client to successfully receive
inbound connections, but is not available because the administrator
has chosen to disable that functionality.

Clients should also be careful to avoid making unfounded assumptions,
such as the assumption that if the client has an IPv4 address in
one of the RFC 1918 private IP address ranges then that means
NAT necessarily must be in use. Net 10/8 has enough addresses
to build a private network with millions of hosts and thousands
of interconnected subnets, all without any use of NAT. Many
organizations have built such private networks that benefit from
using standard TCP/IP technology, but by choice do not connect
to the public Internet. The purpose of NAT-PMP is to mitigate some
of the damage caused by NAT. It would be an ironic and unwanted
side-effect of this protocol if it were to lead well-meaning but
misguided developers to create products that refuse to work on a
private network *unless* they can find a NAT gateway to talk to.
Consequently, a client finding that NAT-PMP is not available on its
network should not give up, but should proceed on the assumption
that the network may be a traditional routed IP network, with no
address translation being used. This assumption may not always be
true, but it is better than the alternative of falsely assuming
the worst and not even trying to use normal (non-NAT) IP networking.

If a network device not currently acting in the role of NAT gateway
receives UDP packets addressed to port 5351, it SHOULD respond

immediately with an "ICMP Port Unreachable" message to tell the
client that it needn't continue with timeouts and retransmissions,
and it should assume that NAT-PMP is not available and not needed
on this network.

4. **UNSAF Considerations**

   The document "IAB Considerations for UNSAF Across NAT" [RFC 3424]
   covers a number of issues when working with NATs. RFC 3424 outlines
   some requirements for any document that attempts to work around
   problems associated with NATs. This section addresses those
   requirements.

4.1. **Scope**

   This protocol addresses the needs of TCP and UDP transport peers that
   are separated from the public Internet by exactly one NAT. Such
   peers must have access to some form of directory server for
   registering the public IP address and port at which they can be
   reached.

4.2. **Transition Plan**

   Any client making use of this protocol SHOULD implement IPv6 support.
   If a client supports IPv6 and is running on a device with a global
   IPv6 address, that IPv6 address SHOULD be preferred to the IPv4
   external address using this NAT mapping protocol. In case other
   clients do not have IPv6 connectivity, both the IPv4 and IPv6
   addresses SHOULD be registered with whatever form of directory server
   is used. Preference SHOULD be given to IPv6 addresses when
   available. By implementing support for IPv6 and using this protocol
   for IPv4, vendors can ship products today that will work under both
   scenarios. As IPv6 is more widely deployed, clients of this protocol
   following these recommendations will transparently make use of IPv6.

4.3. **Failure Cases**

   Aside from NATs that do not implement this protocol, there are a
   number of situations where this protocol may not work.

4.3.1. **NAT Behind NAT**

   Some people's primary IP address, assigned by their ISP, may itself
   be a NAT address. In addition, some people may have an external IP
   address, but may then double NAT themselves, perhaps by choice or
   perhaps by accident. Although it might be possible in principle for
   one NAT gateway to recursively request a mapping from the next one,
   this document does not advocate that and does not try to prescribe
   how it would be done.

It would be a lot of work to implement nested NAT port mapping
correctly, and there are a number of reasons why the end result might

not be as useful as we might hope. Consider the case of an ISP that
offers each of its customers only a single NAT address. This ISP
could instead have chosen to provide each customer with a single
public IP address, or, if the ISP insists on running NAT, it could
have chosen to allow each customer a reasonable number of addresses,
enough for each customer device to have its own NAT address directly
from the ISP. If instead this ISP chooses to allow each customer
just one and only one NAT address, forcing said customer to run
nested NAT in order to use more than one device, it seems unlikely
that such an ISP would be so obliging as to provide a NAT service
that supports NAT Port Mapping Protocol. Supposing that such an ISP
did wish to offer its customers NAT service with NAT-PMP so as to
give them the ability to receive inbound connections, this ISP could
easily choose to allow each client to request a reasonable number of
DHCP addresses from that gateway. Remember that Net 10/8 [RFC 1918]
allows for over 16 million addresses, so NAT addresses are not in any
way in short supply. A single NAT gateway with 16 million available
addresses is likely to run out of packet forwarding capacity before
it runs out of internal addresses to hand out. In this way the ISP
could offer single-level NAT with NAT-PMP, obviating the need to
support nested NAT-PMP. In addition, an ISP that is motivated to
provide their customers with unhindered access to the Internet by
allowing incoming as well as outgoing connections has better ways
to offer this service. Such an ISP could offer its customers real
public IP addresses instead of NAT addresses, or could choose to
offer its customers full IPv6 connectivity, where no mapping or
translation is required at all.

4.3.2. NATs with Multiple External IP Addresses

If a NAT maps internal addresses to multiple external addresses,
then it SHOULD pick one of those external addresses as the one it
will support for inbound connections, and for the purposes of this
protocol it SHOULD act as if that address were its only address.

4.3.3. NATs and Routed Private Networks

In some cases, a large network may be subnetted. Some sites
may install a NAT gateway and subnet the private network.
Such subnetting breaks this protocol because the router address
is not necessarily the address of the device performing NAT.

Addressing this problem is not a high priority. Any site with the
resources to set up such a configuration should have the resources to
add manual mappings or attain a range of globally unique addresses.

Not all NATs will support this protocol. In the case where a client

is run behind a NAT that does not support this protocol, the software
relying on the functionality of this protocol may be unusable.

4.3.4. Communication Between Hosts Behind the Same NAT

NAT gateways supporting NAT-PMP should also implement "hairpin translation". Hairpin translation means supporting communication between two local clients being served by the same NAT gateway.

Suppose device A is listening on internal address and port 10.0.0.2:80 for incoming connections. Using NAT-PMP, device A has obtained a mapping to external address and port x.x.x.x:80, and has recorded this external address and port in a public directory of some kind. For example, it could have created a DNS SRV record containing this information, and recorded it, using DNS Dynamic Update [RFC 3007], in a publicly accessible DNS server. Suppose then that device B, behind the same NAT gateway as device A, but unknowing or uncaring of this fact, retrieves device A's DNS SRV record and attempts to open a TCP connection to x.x.x.x:80. The outgoing packets addressed to this public Internet address will be sent to the NAT gateway for translation and forwarding. Having translated the source address and port number on the outgoing packet, the NAT gateway needs to be smart enough to recognize that the destination address is in fact itself, and then feed this packet back into its packet reception engine, to perform the destination port mapping lookup to translate and forward this packet to device A at address and port 10.0.0.2:80.

4.3.5. Non UDP/TCP Transport Traffic

Any communication over transport protocols other than TCP and UDP will not be served by this protocol. Examples are Generic Routing Encapsulation (GRE), Authentication Header (AH) and Encapsulating Security Payload (ESP).

4.4. Long Term Solution

As IPv6 is deployed, clients of this protocol supporting IPv6 will be able to bypass this protocol and the NAT when communicating with other IPv6 devices. In order to ensure this transition, any client implementing this protocol SHOULD also implement IPv6 and use this solution only when IPv6 is not available to both peers.

4.5. Existing Deployed NATs

Existing deployed NATs will not support this protocol. This protocol will only work with NATs that are upgraded to support it.

5. Security Considerations

As discussed in Section 3.2 "Determining the External Address", only
clients on the internal side of the NAT may create port mappings,
and only on behalf of themselves. By using IP address spoofing,
it's possible for one client to delete the port mappings of another
client. It's also possible for one client to create port mappings on
behalf of another client. In cases where this is a concern, it can be
dealt with using IPSec [RFC 4301]. One concern is that rogue software
running on a local host could create port mappings for unsuspecting
hosts, thereby rendering them vulnerable to external attack. However,
it's not clear how realistic this threat model is, since a rogue host
on the local network could attack such unsuspecting hosts directly
itself, without resorting to such a convoluted indirect technique.
This concern is also a little misguided because it is based on the
assumption that a NAT gateway and a firewall are the same thing,
which they are not.

Some people view the property that NATs block inbound connections as
a security benefit which is undermined by this protocol. The authors
of this document have a different point of view. In the days before
NAT, all hosts had unique public IP addresses, and had unhindered
ability to communicate with any other host on the Internet. When NAT
came along it broke this unhindered connectivity, relegating many
hosts to second-class status, unable to receive inbound connections.
This protocol goes some way to undo some of that damage. The purpose
of a NAT gateway should be to allow several hosts to share a single
address, not to simultaneously impede those host's ability to
communicate freely. Security is most properly provided by end-to-end
cryptographic security, and/or by explicit firewall functionality, as
appropriate. Blocking of certain connections should occur only as a
result of explicit and intentional firewall policy, not as an
accidental side-effect of some other technology.

However, since many users do have an expectation that their NAT
gateways can function as a kind of firewall, any NAT gateway
implementing this protocol SHOULD have an administrative mechanism
to disable it, thereby restoring the pre-NAT-PMP behaviour.

6. IANA Considerations

UDP ports 5350 and 5351 have been assigned for the use described
in this document.

No further IANA services are required by this document.

7. **Acknowledgments**

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   and implemented with help from Bob Bradley, Josh Graessley, Rory
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   Special credit goes to Mike Bell, the Apple Vice President who
   recognized the need for a clean, elegant, reliable Port Mapping
   Protocol, and made the decision early on that Apple's AirPort base
   stations would ship with NAT-PMP support.

8. **Deployment History**

   NAT-PMP client software first became available to the public
   through Apple's Darwin Open Source code in August 2004.
   NAT-PMP implementations began shipping to end users in large
   volumes (i.e. millions) with the launch of Mac OS X 10.4 Tiger
   and Bonjour for Windows 1.0 in April 2005.

   The NAT-PMP client in Mac OS X 10.4 Tiger and Bonjour for Windows
   exists as part of the mDNSResponder system service. When a client
   advertises a service using Wide Area Bonjour [DNS-SD], and the
   machine is behind a NAT-PMP-capable NAT gateway, then if the machine
   is so configured, the mDNSResponder system service automatically
   uses NAT-PMP to set up an inbound port mapping, and then records
   the external IP address and port in the global DNS. Existing client
   software using the existing Bonjour programming APIs [Bonjour]
   gets this functionality automatically. The logic is that if client
   software publishes its information into the global DNS via Wide
   Area Bonjour service advertising, then it's reasonable to infer an
   expectation that this information should be usable by the peers
   retrieving it. Generally speaking, recording a private IP address
   like 10.0.0.2 in the public DNS is likely to be pointless because
   that address is not reachable from clients on the other side of the
   NAT gateway. In the case of a home user with a single computer
   directly connected to their Cable or DSL modem, with a single global
   IPv4 address and no NAT gateway (a surprisingly common
   configuration), publishing that IP address into the global DNS is
   useful because that IP address is reachable. In contrast, a home user
   using a NAT gateway to share a single global IPv4 address between
   several computers loses this ability to receive inbound connections
   easily. This breaks many peer-to-peer collaborative applications,
   like the multi-user text editor SubEthaEdit [SEE]. Automatically
   creating the necessary inbound port mappings helps remedy this
   unintended side-effect of NAT.

The server side of the NAT-PMP protocol is implemented in Apple's "AirPort Extreme", "AirPort Express", and "Time Capsule" wireless base stations, and in the "Internet Sharing" feature of Mac OS X 10.4 and later.

9. Noteworthy Features of NAT Port Mapping Protocol

[Temporary Authors' Note (not to be included in published RFC):
The intent of this section is not to bash UPnP, but to be a fair and
accurate comparison of NAT-PMP and IGD. NAT-PMP is frequently compared
to IGD, because superficially it might appear that they perform much the
same task, so it would be an omission for this document to ignore that
and try to pretend the issue doesn't exist. The purpose of this section
is to point out the relevant differences so that implementors can make
an informed decision. If we have any errors or omissions in our
descriptions of how IGD works for creating port mappings, we invite and
welcome feedback from IGD experts who can help us correct those
mistakes.]

   Some readers have asked how NAT-PMP compares to other similar
   solutions, particularly the UPnP Forum's Internet Gateway Device
   (IGD) Device Control Protocol [IGD].

   The answer is that although UPnP IGD is often used as a way for
   client devices to create port mappings programmatically, that's not
   what it was created for. Whereas NAT-PMP was designed to be used
   primarily by software entities managing their own port mappings, UPnP
   IGD was designed to be used primarily by humans configuring all the
   settings of their gateway using some user interface tool. This
   different target audience leads to protocol differences. For example,
   while it is reasonable and sensible to require software entities to
   renew their mappings periodically to prove that they are still there,
   it's not reasonable to require the same thing of a human user. When
   a human user configures their gateway, they expect it to stay
   configured that way until they decide to change it. If they configure
   a port mapping, they expect it to stay configured until they decide
   to delete it.

   Because of this focus on being a general administation protocol for
   all aspects of home gateway configuration, UPnP IGD is a large and
   complicated collection of protocols (360 pages of specification
   spread over 13 separate documents, not counting supporting protocol
   specifications like SSDP and XML). While it may be a fine way for
   human users to configure their home gateways, it is not especially
   suited to the task of programmatically creating port mappings.

   The requirements for a good port mapping protocol, requirements which
   are met by NAT-PMP, are outlined below:

9.1. Simplicity

   Many home gateways, and many of the devices that connect to them,
   are small, low-cost devices, with limited RAM, flash memory, and CPU

resources. Protocols they use should be considerate of this,
supporting a small number of simple operations that can be

implemented easily with a small amount of code. A quick comparison,
based on page count of the respective documents alone, suggests that
NAT-PMP is at least ten times simpler than UPnP IGD.

9.2. Focussed Scope

The more things a protocol can do, the more chance there is that
something it does could be exploited for malicious purposes. NAT-PMP
is tightly focussed on the specific task of creating port mappings.
Were the protocol to be misused in some way, this limits the scope
of what mischief could be performed using the protocol.

Because UPnP IGD allows control over all home gateway configuration
settings, the potential for mischief is far greater. For example, a
UPnP IGD home gateway allows messages that tell it to change the DNS
server addresses that it sends to clients in its DHCP packets. Using
this mechanism, a single item of malicious web content (e.g. a rogue
Flash banner advert on a web page) can make a persistent change to
the home gateway's configuration without the user's knowledge, such
that all future DNS requests by all local clients will be sent to a
rogue DNS server. This allows criminals to perform a variety of
mischief, such as hijacking connections to bank web sites and
redirecting them to the criminals' web servers instead [VU347812].

9.3. Efficiency

Low-cost devices often have limited RAM resources. When implementing
a protocol on a constrained device, it's beneficial to have
well-defined bounds on RAM requirements. For example, when requesting
the gateway's external IP address, a NAT-PMP client knows that to
receive the reply it will require 20 bytes for the IP header, 12
bytes for the UDP header, and 12 bytes for the NAT-PMP payload.

In contrast, UPnP IGD uses an XML reply of unbounded size. It is not
uncommon for a UPnP IGD device to return an XML document 4kB to 8kB
in size to communicate it's four-byte external IP address, and the
protocol specification places no upper bound on how large the XML
response may be. This means that developers of UPnP client devices
can only guess at how much memory they may need to receive the XML
reply. Operational experience suggests that 8kB should be enough for
most UPnP IGD home gateways today, but that's no guarantee that some
future UPnP IGD home gateway might not return an XML reply larger
than that.

In addition, because the XML reply is too large to fit in a single
UDP packet, UPnP IGD has to use a TCP connection, thereby adding
the overhead of TCP connection setup and teardown.

The process of discovering a UPnP IGD home gateway's external IP
address consists of:

 o SSDP transaction to discover the TCP port number to use, and the
   "URL" of the XML document to fetch from the gateway. If following
   the SSDP specification, this is 3 multicast requests, eliciting 9
   unicast responses.

 o HTTP "GET" request to get the device description. Typically 16
   packets: 3 for TCP connection setup, 9 packets of data exchange,
   and a 4-packet FIN-ACK-FIN-ACK sequence to close the connection.

 o HTTP "POST" to request the external IP address. Typically 14
   packets: 3 for TCP connection setup, 7 packets of data exchange,
   and a 4-packet FIN-ACK-FIN-ACK sequence to close the connection.

To retrieve the external IP address NAT-PMP takes a two-packet UDP
exchange (34-byte request, 44-byte response); the same thing using
UPnP IGD takes 42 packets and thousands of bytes.

Similarly, UPnP IGD's HTTP "POST" request for a port mapping is
typically a 14-packet exchange, compared with NAT-PMP's two-packet
UDP exchange.

9.4. Atomic Allocation Operations

Some of the useful properties of NAT-PMP were inspired by DHCP, a
reliable and successful protocol. For example, DHCP allows a client
to request a desired IP address, but if that address is already in
use the DHCP server will instead assign some other available address.

Correspondingly, NAT-PMP allows a client to request a desired
external port, and if that external port is already in use by some
other client, the NAT-PMP server will instead assign some other
available external port.

UPnP IGD does not do this. If a UPnP IGD client requests an external
port that has already been allocated, then one of two things happens.

Some UPnP IGD home gateways just silently overwrite the old mapping
with the new one, causing the previous client to lose connectivity.
If the previous client renews its port mapping, then it in turn
overwrites the new mapping, and the two clients fight over the same
external port indefinitely, neither achieving reliable connectivity.

Other IGD home gateways return a "Conflict" error if the port is
already in use, which does at least tell the client what happened,
but doesn't tell the client what to do. Instead of the NAT gateway
(which does know which ports are available) assigning one to the
client, the NAT gateway makes the client (which doesn't know) keep
guessing until it gets lucky. This problem remains mild as long as

not many clients are using UPnP IGD, but gets progressively worse as
the number of clients on the network requesting port mappings goes
up.

9.5. Garbage Collection

In any system that operates for a long period of time (as a home
gateway should) it is important that garbage data does not accumulate
indefinitely until the system runs out of memory and fails.

Like DHCP address leases, NAT-PMP leases a port mapping to a client
for a finite length of time. The NAT-PMP client must renew the port
mapping before it expires or, like an unrenewed DHCP address, it will
be reclaimed. If a laptop computer is abruptly disconnected from the
network without the opportunity to delete its port mappings, the
NAT gateway will reclaim those mappings when they are not renewed.

In principle UPnP IGD should allow clients to specify a lifetime on
port mappings. However, a Google search for "UPnP NewLeaseDuration"
shows that in practice pretty much every client uses
"<NewLeaseDuration>0</NewLeaseDuration>" to request an infinite
lease, and the protocol has no way for the NAT gateway to decline
that infinite lease request and require the client to renew it at
reasonable intervals. Furthermore, anecdotal evidence is that if the
client requests a lease other than zero, there are IGD home gateways
that will ignore the request, fail in other ways, or even crash
completely. As a client implementer then, you would be well advised
not to attempt to request a lease other than zero, unless you want
to suffer the bad publicity and support costs of lots of people
complaining that your device brought down their entire network.

Because none of the early UPnP IGD clients requested port mapping
leases, many UPnP IGD home gateway vendors never tested that
functionality, and got away with shipping home gateways where that
functionality was buggy or nonexistent. Because there are so many
buggy UPnP IGD home gateways already deployed, client writers wisely
stick to the well-trodden path of only requesting infinite leases.
Because there are now few (if any) clients attempting to request
non-zero leases, home gateway vendors have little incentive to expend
resources implementing a feature no one uses.

This unfortunate consequence of the way UPnP IGD was developed and
deployed means that in practice it has no usable port mapping lease
facility today, and therefore when run for a long period of time UPnP
IGD home gateways have no good way to avoid accumulating an unbounded
number of stale port mappings.

9.6. State Change Announcements

When using DHCP on the external interface, as is the norm for home
gateways, there is no guarantee that a UPnP IGD home gateway's
external IP address will remain unchanged. Indeed, some ISPs change

their customer's IP address every 24 hours (possibly in an effort to
make it harder for their customers to "run a server" at home). What

this means is that if the home gateway's external IP address changes, it needs to inform its clients, so that they can make any necessary updates to global directory information (e.g. performing a Dynamic DNS update to update their address record).

When a NAT-PMP gateway's external IP address changes, it broadcasts announcement packets to inform clients of this. UPnP IGD does not.

9.7. Soft State Recovery

When run for a long enough period of time, any network will have devices that fail, get rebooted, suffer power outages, or lose state for other reasons. A home gateway that runs for long enough is likely to suffer some such incident eventually. After losing state, it has no record of the port mappings it created, and clients suffer a consequent loss of connectivity.

To handle this case, NAT-PMP has the "Seconds Since Start of Epoch" mechanism. After a reboot or other loss of state, a NAT-PMP gateway broadcasts announcement packets giving its external IP address, with the "Seconds Since Start of Epoch" field reset to begin counting from zero again. When a NAT-PMP client observes packets from its NAT-PMP gateway where the gateway's notion of time has apparently gone backwards compared to the client, the client knows the gateway has probably lost state, and immediately recreates its mappings to restore connectivity.

UPnP IGD has no equivalent mechanism.

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