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Negotiation of NAT-Traversal in the IKE

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Abstract

This document describes how to detect one or more network address translation devices (NATs) between IPsec hosts, and how to negotiate the use of UDP encapsulation of IPsec packets through NAT boxes in Internet Key Exchange (IKE).

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1. Introduction

This document is split into two parts. The first describes what is needed in IKE Phase 1 for NAT-Traversal support. This includes detecting whether the other end supports NAT-Traversal, and detecting whether there is one or more NATs between the peers.

The second part describes how to negotiate the use of UDP encapsulated IPsec packets in IKE's Quick Mode. It also describes how to transmit the original source and destination addresses to the peer, if required. These addresses are used in transport mode to update the TCP/IP checksums incrementally so that they will match after the NAT transform. (The NAT cannot do this, because the TCP/IP checksum is inside the UDP encapsulated IPsec packet.)

The document [RFC3948] describes the details of UDP encapsulation, and [RFC3715] provides background information and motivation of NAT-Traversal in general. In combination with [RFC3948], this document represents an "unconditionally compliant" solution to the requirements as defined by [RFC3715].

In the basic scenario for this document, the initiator is behind NA(P)T, and the responder has a fixed static IP address.

This document defines a protocol that will work even if both ends are behind NAT, but the process of how to locate the other end is out of the scope of this document. In one scenario, the responder is behind a static host NAT (only one responder per IP, as there is no way to use any destination ports other than 500/4500). That is, it is known by the configuration.

2. Specification of Requirements

This document shall use the keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED, "MAY", and "OPTIONAL" to describe requirements. They are to be interpreted as described in [RFC2119].

3. Phase 1

The detection of support for NAT-Traversal and detection of NAT along the path between the two IKE peers occurs in IKE [RFC2409] Phase 1.

The NAT may change the IKE UDP source port, and recipients MUST be able to process IKE packets whose source port is different from 500. The NAT does not have to change the source port if:

- only one IPsec host is behind the NAT, or
- for the first IPsec host, the NAT can keep the port 500, and the NAT will only change the port number for later connections.

Recipients MUST reply back to the source address from the packet (see [RFC3715], section 2.1, case d). This means that when the original responder is doing rekeying or sending notifications to the original initiator, it MUST send the packets using the same set of port and IP numbers used when the IKE SA was last used.

For example, when the initiator sends a packet with source and destination port 500, the NAT may change it to a packet with source port 12312 and destination port 500. The responder must be able to process the packet whose source port is 12312. It must reply back with a packet whose source port is 500 and destination port is 12312. The NAT will then translate this packet to source port 500 and destination port 500.

3.1. Detecting Support of NAT-Traversal

The NAT-Traversal capability of the remote host is determined by an exchange of vendor ID payloads. In the first two messages of Phase 1, the vendor id payload for this specification MUST be sent if supported (and it MUST be received by both sides) for the NAT-Traversal probe to continue. The content of the payload is the MD5 hash of

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The exact content in hex for the payload is

4a131c81070358455c5728f20e95452f

3.2. Detecting the Presence of NAT

The NAT-D payload not only detects the presence of NAT between the two IKE peers, but also detects where the NAT is. The location of the NAT device is important, as the keepalives have to initiate from the peer "behind" the NAT.

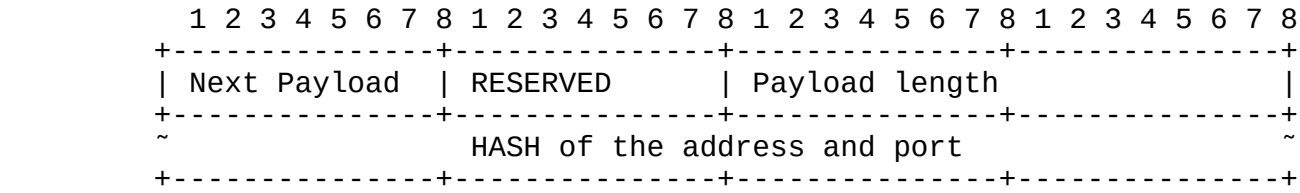
To detect NAT between the two hosts, we have to detect whether the IP address or the port changes along the path. This is done by sending the hashes of the IP addresses and ports of both IKE peers from each end to the other. If both ends calculate those hashes and get same result, they know there is no NAT between. If the hashes do not match, somebody has translated the address or port. This means that we have to do NAT-Traversal to get IPsec packets through.

If the sender of the packet does not know his own IP address (in case of multiple interfaces, and the implementation does not know which IP address is used to route the packet out), the sender can include multiple local hashes to the packet (as separate NAT-D payloads). In this case, NAT is detected if and only if none of the hashes match.

The hashes are sent as a series of NAT-D (NAT discovery) payloads. Each payload contains one hash, so in case of multiple hashes, multiple NAT-D payloads are sent. In the normal case there are only two NAT-D payloads.

The NAT-D payloads are included in the third and fourth packets of Main Mode, and in the second and third packets in the Aggressive Mode.

The format of the NAT-D packet is



The payload type for the NAT discovery payload is 20.

The HASH is calculated as follows:

HASH = HASH(CKY-I | CKY-R | IP | Port)

This uses the negotiated HASH algorithm. All data inside the HASH is in the network byte-order. The IP is 4 octets for an IPv4 address and 16 octets for an IPv6 address. The port number is encoded as a 2 octet number in network byte-order. The first NAT-D payload contains the remote end's IP address and port (i.e., the destination address of the UDP packet). The remaining NAT-D payloads contain possible local-end IP addresses and ports (i.e., all possible source addresses of the UDP packet).

If there is no NAT between the peers, the first NAT-D payload received should match one of the local NAT-D payloads (i.e., the local NAT-D payloads this host is sending out), and one of the other NAT-D payloads must match the remote end's IP address and port. If the first check fails (i.e., first NAT-D payload does not match any of the local IP addresses and ports), it means that there is dynamic NAT between the peers, and this end should start sending keepalives as defined in the [RFC3948] (this end is behind the NAT).

The CKY-I and CKY-R are the initiator and responder cookies. They are added to the hash to make precomputation attacks for the IP address and port impossible.

The following example is of a Phase 1 exchange using NAT-Traversal in Main Mode (authentication with signatures):

```
Initiator                               Responder
------------                            ------------
HDR, SA, VID -->
                                        <-- HDR, SA, VID
HDR, KE, Ni, NAT-D, NAT-D -->
                                        <-- HDR, KE, Nr, NAT-D, NAT-D
HDR*#, IDii, [CERT, ] SIG_I -->
                                        <-- HDR*#, IDir, [CERT, ], SIG_R
```

The following example is of Phase 1 exchange using NAT-Traversal in Aggressive Mode (authentication with signatures):

```
Initiator                               Responder
------------                            ------------
HDR, SA, KE, Ni, IDii, VID -->
                                        <-- HDR, SA, KE, Nr, IDir,
                                                [CERT, ], VID, NAT-D,
                                                NAT-D, SIG_R
HDR*#, [CERT, ], NAT-D, NAT-D,
    SIG_I -->
```

The # sign indicates that those packets are sent to the changed port if NAT is detected.

4. Changing to New Ports

IPsec-aware NATs can cause problems (See [RFC3715], section 2.3). Some NATs will not change IKE source port 500 even if there are multiple clients behind the NAT (See [RFC3715], section 2.3, case n). They can also use IKE cookies to demultiplex traffic instead of using the source port (See [RFC3715], section 2.3, case m). Both of these are problematic for generic NAT transparency, as it is difficult for IKE to discover the capabilities of the NAT. The best approach is simply to move the IKE traffic off port 500 as soon as possible to avoid any IPsec-aware NAT special casing.

Take the common case of the initiator behind the NAT. The initiator must quickly change to port 4500 once the NAT has been detected to minimize the window of IPsec-aware NAT problems.

In Main Mode, the initiator MUST change ports when sending the ID payload if there is NAT between the hosts. The initiator MUST set both UDP source and destination ports to 4500. All subsequent packets sent to this peer (including informational notifications) MUST be sent on port 4500. In addition, the IKE data MUST be prepended with a non-ESP marker allowing for demultiplexing of traffic, as defined in [RFC3948].

Thus, the IKE packet now looks like this:

```
      IP UDP(4500,4500) <non-ESP marker> HDR*, IDii, [CERT, ] SIG_I
```

This assumes authentication using signatures. The 4 bytes of non-ESP marker are defined in the [RFC3948].

When the responder gets this packet, the usual decryption and processing of the various payloads is performed. If these are successful, the responder MUST update local state so that all subsequent packets (including informational notifications) to the peer use the new port, and possibly the new IP address obtained from the incoming valid packet. The port will generally be different, as the NAT will map UDP(500,500) to UDP(X,500), and UDP(4500,4500) to UDP(Y,4500). The IP address will seldom be different from the pre-changed IP address. The responder MUST respond with all subsequent IKE packets to this peer by using UDP(4500,Y).

Similarly, if the responder has to rekey the Phase 1 SA, then the rekey negotiation MUST be started by using UDP(4500,Y). Any implementation that supports NAT traversal MUST support negotiations that begin on port 4500. If a negotiation starts on port 4500, then it doesn't need to change anywhere else in the exchange.

Once port change has occurred, if a packet is received on port 500, that packet is old. If the packet is an informational packet, it MAY be processed if local policy allows this. If the packet is a Main Mode or an Aggressive Mode packet (with the same cookies as previous packets), it SHOULD be discarded. If the packet is a new Main Mode or Aggressive exchange, then it is processed normally (the other end might have rebooted, and this is starting new exchange).

Here is an example of a Phase 1 exchange using NAT-Traversal in Main Mode (authentication with signatures) with changing port:

```
Initiator                               Responder
------------                            ------------
UDP(500,500) HDR, SA, VID -->
                                        <-- UDP(500,X) HDR, SA, VID
UDP(500,500) HDR, KE, Ni,
    NAT-D, NAT-D -->
                                        <-- UDP(500,X) HDR, KE, Nr,
                                                NAT-D, NAT-D
UDP(4500,4500) HDR*#, IDii,
    [CERT, ]SIG_I -->
                                        <-- UDP(4500,Y) HDR*#, IDir,
                                                [ CERT, ], SIG_R
```

The procedure for Aggressive Mode is very similar. After the NAT has been detected, the initiator sends IP UDP(4500,4500) <4 bytes of non-ESP marker> HDR*, [CERT,], NAT-D, NAT-D, and SIG_I. The responder does similar processing to the above, and if successful, MUST update it's internal IKE ports. The responder MUST respond with all subsequent IKE packets to this peer by using UDP(4500,Y).

```
Initiator                               Responder
------------                            ------------
UDP(500,500) HDR, SA, KE,
    Ni, IDii, VID -->
                                        <-- UDP(500,X) HDR, SA, KE,
                                                Nr, IDir, [CERT, ],
                                                VID, NAT-D, NAT-D,
                                                SIG_R
UDP(4500,4500) HDR*#, [CERT, ],
    NAT-D, NAT-D,
    SIG_I -->
                                        <-- UDP(4500, Y) HDR*#, ...
```

If the support of the NAT-Traversal is enabled, the port in the ID payload in Main Mode/Aggressive Mode MUST be set to 0.

The most common case for the responder behind the NAT is if the NAT is simply doing 1:1 address translation. In this case, the initiator still changes both ports to 4500. The responder uses an algorithm identical to that above, although in this case Y will equal 4500, as no port translation is happening.

A different port change case involves out-of-band discovery of the ports to use. Those discovery methods are out of the scope of this document. For instance, if the responder is behind a port translating NAT, and the initiator needs to contact it first, then the initiator will have to determine which ports to use, usually by contacting some other server. Once the initiator knows which ports to use to traverse the NAT, generally something like UDP(Z,4500), it initiates using these ports. This is similar to the responder rekey case above in that the ports to use are already known up front, and no additional change has to take place. Also, the first keepalive timer starts after the change to the new port, and no keepalives are sent to the port 500.

5. Quick Mode

After Phase 1, both ends know whether there is a NAT present between them. The final decision of using NAT-Traversal is left to Quick Mode. The use of NAT-Traversal is negotiated inside the SA payloads of Quick Mode. In Quick Mode, both ends can also send the original addresses of the IPsec packets (in case of the transport mode) to the other end so that each can fix the TCP/IP checksum field after the NAT transformation.

5.1. Negotiation of the NAT-Traversal Encapsulation

The negotiation of the NAT-Traversal happens by adding two new encapsulation modes. These encapsulation modes are

```
UDP-Encapsulated-Tunnel         3
UDP-Encapsulated-Transport      4
```

It is not normally useful to propose both normal tunnel or transport mode and UDP-Encapsulated modes. UDP encapsulation is required to fix the inability to handle non-UDP/TCP traffic by NATs (see [RFC3715], section 2.2, case i).

If there is a NAT box between hosts, normal tunnel or transport encapsulations may not work. In this case, UDP-Encapsulation SHOULD be used.

If there is no NAT box between, there is no point in wasting bandwidth by adding UDP encapsulation of packets. Thus, UDP-Encapsulation SHOULD NOT be used.

Also, the initiator SHOULD NOT include both normal tunnel or transport mode and UDP-Encapsulated-Tunnel or UDP-Encapsulated-Transport in its proposals.

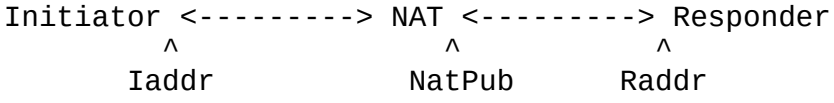
5.2. Sending the Original Source and Destination Addresses

To perform incremental TCP checksum updates, both peers may need to know the original IP addresses used by their peers when those peers constructed the packet (see [RFC3715], section 2.1, case b). For the initiator, the original Initiator address is defined to be the Initiator's IP address. The original Responder address is defined to be the perceived peer's IP address. For the responder, the original Initiator address is defined to be the perceived peer's address. The original Responder address is defined to be the Responder's IP address.

The original addresses are sent by using NAT-OA (NAT Original Address) payloads.

The Initiator NAT-OA payload is first. The Responder NAT-OA payload is second.

Example 1:



The initiator is behind a NAT talking to the publicly available responder. Initiator and Responder have the IP addresses Iaddr and Raddr. NAT has public IP address NatPub.

Initiator:

```
NAT-OAi = Iaddr
NAT-OAr = Raddr
```

Responder:

```
NAT-OAi = NATPub
NAT-OAr = Raddr
```

Example 2:

```
Initiator <------> NAT1 <---------> NAT2 <-------> Responder
          ^             ^           ^              ^
       Iaddr         Nat1Pub     Nat2Pub         Raddr
```

Here, NAT2 "publishes" Nat2Pub for Responder and forwards all traffic to that address to Responder.

Initiator:

```
NAT-OAi = Iaddr
NAT-OAr = Nat2Pub
```

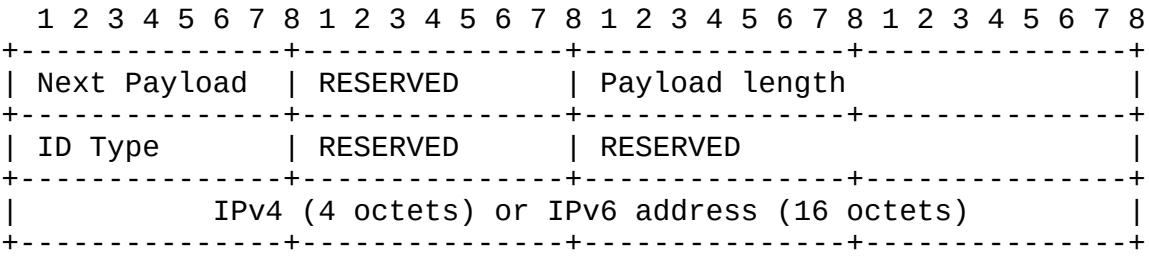
Responder:

```
NAT-OAi = Nat1Pub
NAT-OAr = Raddr
```

In the case of transport mode, both ends MUST send both original Initiator and Responder addresses to the other end. For tunnel mode, both ends SHOULD NOT send original addresses to the other end.

The NAT-OA payloads are sent inside the first and second packets of Quick Mode. The initiator MUST send the payloads if it proposes any UDP-Encapsulated-Transport mode, and the responder MUST send the payload only if it selected UDP-Encapsulated-Transport mode. It is possible that the initiator sends the NAT-OA payload but proposes both UDP-Encapsulated transport and tunnel mode. Then the responder selects the UDP-Encapsulated tunnel mode and does not send the NAT-OA payload back.

The format of the NAT-OA packet is



The payload type for the NAT original address payload is 21.

The ID type is defined in the [RFC2407]. Only ID_IPV4_ADDR and ID_IPV6_ADDR types are allowed. The two reserved fields after the ID Type must be zero.

The following example is of Quick Mode using NAT-OA payloads:

```
Initiator                           Responder
------------                        ------------
HDR*, HASH(1), SA, Ni, [, KE]
    [, IDci, IDcr ]
    [, NAT-OAi, NAT-OAr] -->
                                    <-- HDR*, HASH(2), SA, Nr, [, KE]
                                              [, IDci, IDcr ]
                                              [, NAT-OAi, NAT-OAr]
HDR*, HASH(3) -->
```

6. Initial Contact Notifications

The source IP and port address of the INITIAL-CONTACT notification for the host behind NAT are not meaningful (as NAT can change them), so the IP and port numbers MUST NOT be used to determine which IKE/IPsec SAs to remove (see [RFC3715], section 2.1, case c). The ID payload sent from the other end SHOULD be used instead; i.e., when an INITIAL-CONTACT notification is received from the other end, the receiving end SHOULD remove all the SAs associated with the same ID payload.

7. Recovering from the Expiring NAT Mappings

There are cases where NAT box decides to remove mappings that are still alive (for example, when the keepalive interval is too long, or when the NAT box is rebooted). To recover from this, ends that are NOT behind NAT SHOULD use the last valid UDP encapsulated IKE or IPsec packet from the other end to determine which IP and port addresses should be used. The host behind dynamic NAT MUST NOT do

this, as otherwise it opens a DoS attack possibility because the IP address or port of the other host will not change (it is not behind NAT).

Keepalives cannot be used for these purposes, as they are not authenticated, but any IKE authenticated IKE packet or ESP packet can be used to detect whether the IP address or the port has changed.

8. Security Considerations

Whenever changes to some fundamental parts of a security protocol are proposed, the examination of security implications cannot be skipped. Therefore, here are some observations about the effects, and about whether or not these effects matter.

- IKE probes reveal NAT-Traversal support to anyone watching the traffic. Disclosing that NAT-Traversal is supported does not introduce new vulnerabilities.

- The value of authentication mechanisms based on IP addresses disappears once NATs are in the picture. That is not necessarily a bad thing (for any real security, authentication measures other than IP addresses should be used). This means that authentication with pre-shared keys cannot be used in Main Mode without using group-shared keys for everybody behind the NAT box. Using group shared keys is a huge risk because it allows anyone in the group to authenticate to any other party and claim to be anybody in the group; e.g., a normal user could impersonate a vpn-gateway and act as a man in the middle, and read/modify all traffic to/from others in the group. Use of group-shared keys is NOT RECOMMENDED.

- As the internal address space is only 32 bits and is usually very sparse, it might be possible for the attacker to find out the internal address used behind the NAT box by trying all possible IP-addresses to find the matching hash. The port numbers are normally fixed to 500, and the cookies can be extracted from the packet. This limits the hash calculations to 2^32. If an educated guess of the private address space is made, then the number of hash calculations needed to find out the internal IP address goes down to 2^24 + 2 * (2^16).

- Neither NAT-D payloads nor Vendor ID payloads are authenticated in Main Mode nor in Aggressive Mode. This means that attacker can remove those payloads, modify them, or add them. By removing or adding them, the attacker can cause Denial of Service attacks. By modifying the NAT-D packets, the attacker can cause both ends to use UDP-Encapsulated modes instead of directly using tunnel or transport mode, thus wasting some bandwidth.

- Sending the original source address in the Quick Mode reveals the internal IP address behind the NAT to the other end. In this case we have already authenticated the other end, and sending the original source address is only needed in transport mode.

- Updating the IKE SA/ESP UDP encapsulation IP addresses and ports for each valid authenticated packet can cause DoS if an attacker can listen to all traffic in the network, change the order of the packets, and inject new packets before the packet he has already seen. In other words, the attacker can take an authenticated packet from the host behind NAT, change the packet UDP source or destination ports or IP addresses and send it out to the other end before the real packet reaches it. The host not behind the NAT will update its IP address and port mapping and send further traffic to the wrong host or port. This situation is fixed immediately when the attacker stops modifying the packets, as the first real packet will fix the situation. Implementations SHOULD AUDIT the event every time the mapping is changed, as it should not happen that often.

9. IANA Considerations

This document contains two new "magic numbers" allocated from the existing IANA registry for IPsec and renames existing registered port 4500. This document also defines 2 new payload types for IKE.

The following are new items that have been added in the "Internet Security Association and Key Management Protocol (ISAKMP) Identifiers" Encapsulation Mode registry:

Name	Value	Reference
UDP-Encapsulated-Tunnel	3	[RFC3947]
UDP-Encapsulated-Transport	4	[RFC3947]

Change in the registered port registry:

Keyword	Decimal	Description	Reference
ipsec-nat-t	4500/tcp	IPsec NAT-Traversal	[RFC3947]
ipsec-nat-t	4500/udp	IPsec NAT-Traversal	[RFC3947]

New IKE payload numbers need to be added to the Next Payload Types registry:

NAT-D	20	NAT Discovery Payload
NAT-OA	21	NAT Original Address Payload

10. IAB Considerations

The UNSAF [RFC3424] questions are addressed by the IPsec-NAT compatibility requirements document [RFC3715].

11. Acknowledgments

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12. References

12.1. Normative References

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[RFC2407] Piper, D., "The Internet IP Security Domain of Interpretation for ISAKMP", RFC 2407, November 1998.

[RFC3948] Huttunen, A., Swander, B., Volpe, V., DiBurro, L., and M. Stenberg, "UDP Encapsulation of IPsec Packets", RFC 3948, January 2005.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

12.2. Informative References

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[RFC3424] Daigle, L. and IAB, "IAB Considerations for UNilateral Self-Address Fixing (UNSAF) Across Network Address Translation", RFC 3424, November 2002.

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