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J. Rosenberg
Cisco Systems
C. Huitema
Microsoft
R. Mahy
Plantronics
D. Wing
Cisco Systems
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Simple Traversal Underneath Network Address Translators (NAT) (STUN) draft-ietf-behave-rfc3489bis-05

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Abstract

Simple Traversal Underneath NATs (STUN) is a lightweight protocol that serves as a tool for application protocols in dealing with NAT traversal. It allows a client to determine the IP address and port

allocated to them by a NAT and to keep NAT bindings open. It can also serve as a check for connectivity between a client and a server in the presence of NAT, and for the client to detect failure of the server. STUN works with many existing NATs, and does not require any special behavior from them. As a result, it allows a wide variety of applications to work through existing NAT infrastructure.

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1. Applicability Statement

This protocol is not a cure-all for the problems associated with NAT. It is a tool that is typically used in conjunction with other protocols, such as Interactive Connectivity Establishment (ICE) [13] for a more complete solution. The binding discovery usage, defined by this specification, can be used by itself with numerous application protocols as a solution for NAT traversal. However, when used in that way, STUN will not work with applications that require incoming TCP connections through NAT. It will allow incoming UDP packets through NAT, but only through a subset of existing NAT types. In particular, the STUN binding usage by itself does not enable incoming UDP packets through NATs whose mapping property is address dependent or address and port dependent [14]. Furthermore, the binding usage, when used by itself, does not work when a client is communicating with a peer which happens to be behind the same NAT. Nor will it work when the STUN server is not in a common shared address realm.

The STUN relay usage, defined in [16], allows a client to obtain an IP address and port that actually reside on the STUN server. The STUN relay usage, when used by itself, eliminates all of the limitations of using the binding usage by itself, as described above. However, it requires a server to act as a relay for application traffic, which can be expensive to provide, operate, and manage.

For multimedia protocols based on the offer/answer model [22], including the Session Initiation Protocol (SIP) [11], Interactive Connectivity Establishment (ICE) uses both the binding usage and relay usage, and furthermore defines a connectivity check usage to help determine which transport address to use.

Implementers should be aware of the specific deployment scenarios and the specific protocol (SIP, etc) being used to determine whether NAT traversal can be facilitated by STUN and which STUN usages are required.

2. Introduction

Network Address Translators (NATs), while providing many benefits, also come with many drawbacks. The most troublesome of those drawbacks is the fact that they break many existing IP applications and make it difficult to deploy new ones. Guidelines have been developed [20] that describe how to build "NAT friendly" protocols, but many protocols simply cannot be constructed according to those guidelines. Examples of such protocols include almost all peer-to-peer protocols such as multimedia communications, file sharing and

games.

To combat this problem, Application Layer Gateways (ALGs) have been embedded in NATs. ALGs perform the application layer functions required for a particular protocol to traverse a NAT. Typically, this involves rewriting application layer messages to contain translated addresses, rather than the ones inserted by the sender of the message. ALGs have serious limitations, including scalability, reliability, and speed of deploying new applications.

Many existing proprietary protocols, such as those for online games (such as the games described in RFC3027 [21]) and Voice over IP, have developed tricks that allow them to operate through NATs without changing those NATs and without relying on ALG behavior in the NATs. This document takes some of those ideas and codifies them into an interoperable protocol that can meet the needs of many applications.

The protocol described here, Simple Traversal Underneath NAT (STUN), provides a toolkit of functions. These functions allow entities behind a NAT to learn the address bindings allocated by the NAT and to keep those bindings open. STUN requires no changes to NATs and works with an arbitrary number of NATs in tandem between the application entity and the public Internet.

3. Terminology

In this document, the key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" are to be interpreted as described in BCP 14, RFC 2119 [1] and indicate requirement levels for compliant STUN implementations.

4. Definitions

STUN Client: A STUN client (also just referred to as a client) is an entity that generates STUN requests and receives STUN responses. Clients can also generate STUN indications.

STUN Server: A STUN Server (also just referred to as a server) is an entity that receives STUN requests and sends STUN responses. Servers also send STUN indications.

Transport Address: The combination of an IP address and (UDP or TCP) port.

Reflexive Transport Address: A transport address learned by a client that identifies that client as seen by another host on an IP network, typically a STUN server. When there is an intervening NAT between the client and the other host, the reflexive transport address represents the binding allocated to the client on the public side of the NAT. Reflexive transport addresses are learned from the mapped address attribute (MAPPED-ADDRESS or XOR-MAPPED-ADDRESS) in STUN responses.

Mapped Address: The source IP address and port of the STUN Binding Request packet received by the STUN server and inserted into the mapped address attribute (MAPPED-ADDRESS or XOR-MAPPED-ADDRESS) of the Binding Response message.

Long Term Credential: A username and associated password that represent a shared secret between client and server. Long term credentials are generally granted to the client when a subscriber enrolles in a service and persist until the subscriber leaves the service or explicitly changes the credential.

Long Term Password: The password from a long term credential.

Short Term Credential: A temporary username and associated password which represent a shared secret between client and server. A short term credential has an explicit temporal scope, which may be based on a specific amount of time (such as 5 minutes) or on an event (such as termination of a SIP dialog). The specific scope of a short term credential is defined by the application usage. A short term credential can be obtained from a Shared Secret request, though other mechanisms are possible.

Short Term Password: The password component of a short term credential.

5. Overview of Operation

This section is descriptive only. Normative behavior is described in Section 8 and Section 9

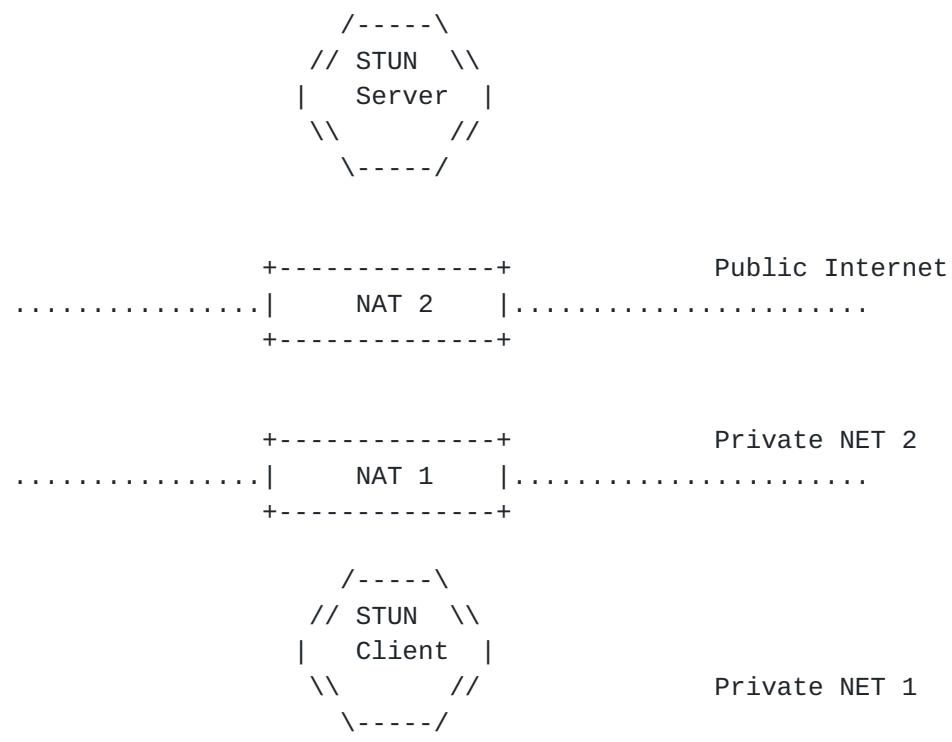


Figure 1: Typical STUN Server Configuration

The typical STUN configuration is shown in Figure 1. A STUN client is connected to private network 1. This network connects to private network 2 through NAT 1. Private network 2 connects to the public Internet through NAT 2. The STUN server resides on the public Internet.

STUN is a simple client-server protocol. It supports two types of transactions. One is a request/response transaction in which client sends a request to a server, and the server returns a response. The second are indications that are initiated by the server or the client and do not elicit a response. There are two types of requests defined in this specification - Binding Requests and Shared Secret Requests. There are no indications defined by this specification.

Binding Requests are sent from the client towards the server. When the Binding Request arrives at the STUN server, it may have passed through one or more NATs between the STUN client and the STUN server (in Figure 1, there were two such NATs). As a result, the source transport address of the request received by the server will be the mapped address created by the NAT closest to the server. The STUN server copies that source transport address into a STUN Binding Response and sends it back to the source transport address of the STUN request. Every type of NAT will route that response so that it

arrives at the STUN client. From this response, the client knows its transport address allocated by the outermost NAT towards the STUN server.

STUN provides several mechanisms for authentication and message integrity. The client and server can share a pre-provisioned shared secret, which is used for a digest challenge/response authentication operation. This is known as a long-term credential or long-term shared secret.

Alternatively, if the shared secret is obtained by some out-of-bands means and has a lifetime that is temporally scoped, a simple HMAC is provided, without a challenge operation. This is known as a short term credential or short term password. Short-term passwords are useful when there is no long-term relationship with a STUN server and thus no long-term password is shared between the STUN client and STUN server. Even if there is a long-term password, the issuance of a short-term password is useful to prevent dictionary attacks.

STUN itself provides a mechanism for obtaining such short term credentials, using the Shared Secret Request. Shared Secret requests are sent over TLS [5] over TCP. Shared Secret Requests ask the server to return a temporary username and password that can be used in subsequent STUN requests.

There are many ways in which these basic mechanisms can be used to accomplish a specific task. As a result, STUN has the notion of a usage. A usage is a specific use case for the STUN protocol. The usage will define what the client does with the mapped address it receives, defines when the client would send Binding requests and why, and would constrain the set of authentication mechanisms or attributes that get used in that usage. STUN usages can also define new attributes and message types, if needed. This specification defines three STUN usages - binding discovery, NAT keepalives, and short-term password.

The binding discovery usage is sometimes referred to as 'classic STUN,' since it is the usage originally envisioned in RFC 3489 [15], the predecessor to this specification. The purpose of the binding discovery usage is for the client to obtain a transport address at which it is reachable. The client can include these transport addresses in application layer signaling messages such as the Session Description Protocol (SDP) [19] (present in the body of SIP messages), where it indicates where the client wants to receive Real Time Transport Protocol (RTP [17]) traffic. In this usage, the STUN server is typically located on the public Internet and run by the service provider offering the application service (such as a SIP provider), though this need not be the case. The client would

utilize the STUN request just prior to sending a protocol message (such as a SIP INVITE request or 200 OK response) that requires the client to embed its transport address.

In the binding keepalive usage, a client sends an application protocol message (such as a SIP REGISTER message) to a server. The server notes the source transport address of the request, and remembers it. Later on, if it needs to reach the client, it sends a message to that transport address. However, this message will only be received by the client if the binding in the NAT is still alive. Since bindings allocated by NAT expire unless refreshed, the client must generate keepalive messages toward the server to refresh the binding. Rather than use expensive application layer messages, a STUN binding request is sent by the client to the server, and is sent to the exact same transport address used by the server for the application protocol. In the case of SIP, this would typically mean port 5060 or 5061. This has the effect of keeping the bindings in the NAT alive. The STUN binding responses also inform the client that the server is still responsive, and also inform the client if its transport address towards the server have changed (its reflexive transport address), in which case it may need application layer protocol messaging to update its transport address as seen by the server. The binding keepalive usage is used by the SIP outbound mechanism, for example [18].

These two usages all utilize the same Binding Request message, and all require the same basic processing on the server. They differ only in where the server is (a standalone server in the network, or embedded in an application layer server), when the Binding Request is used and what the client does with the mapped address that is returned.

The short-term password usage makes use of the Shared Secret request and response, and allows a client to obtain a temporary set of credentials to authenticate itself with the STUN server. The credentials obtained from this usage can be used in requests for any other usage.

Some usages (such as the binding keepalive) require STUN messages to be sent on the same transport address as some application protocol, such as RTP or SIP. To facilitate the demultiplexing of the two, STUN defines a special field in the message called the magic cookie, which is a fixed 32 bit value that identifies STUN traffic. STUN requests also contain a fingerprint, which is a cryptographic hash of the message, that allow for validation that the message was a STUN request and not a data packet that happened to have the same 32 bit value in the right place in the message.

STUN servers can be discovered through DNS, though this is not necessary in all usages. For those usages where it is needed, STUN makes use of SRV records [3] to facilitate discovery. This discovery allows for different transport addresses to be found for different usages.

6. STUN Message Structure

STUN messages are TLV (type-length-value) encoded using big endian (network ordered) binary. STUN messages are encoded using binary fields. All integer fields are carried in network byte order, that is, most significant byte (octet) first. This byte order is commonly known as big-endian. The transmission order is described in detail in Appendix B of RFC791 [2]. Unless otherwise noted, numeric constants are in decimal (base 10). All STUN messages start with a single STUN header followed by a STUN payload. The payload is a series of STUN attributes, the set of which depends on the message type. The STUN header contains a STUN message type, magic cookie, transaction ID, and length. The length indicates the total length of the STUN payload, not including the 20-byte header.

There are two types of transactions in STUN - request/response transactions, which utilize a request message and a response message, and indication transactions, which utilizes a single indication message. Furthermore, responses are broken into two types - success responses and error responses. Two bits in the message type field of the STUN header indicate the class of the message - whether the message is a request, a success response, an indication, or a failure response. An additional 12 bits in the message type indicate the method, which is the primary function of the message. This specification defines two methods, Binding and Shared Secret.

STUN Requests are sent reliably. STUN can run over UDP, TCP or TCP/TLS. When run over UDP, STUN requests are retransmitted in order to achieve reliability. The transaction ID is used to correlate requests and responses.

An indication message can be sent from the client to the server, or from the server to the client. Indication messages can be sent over TCP or UDP. STUN itself does not provide reliability for these messages, though they will be delivered reliably when sent over TCP. The transaction ID is used to distinguish indication messages.

All STUN messages consist of a 20 byte header:

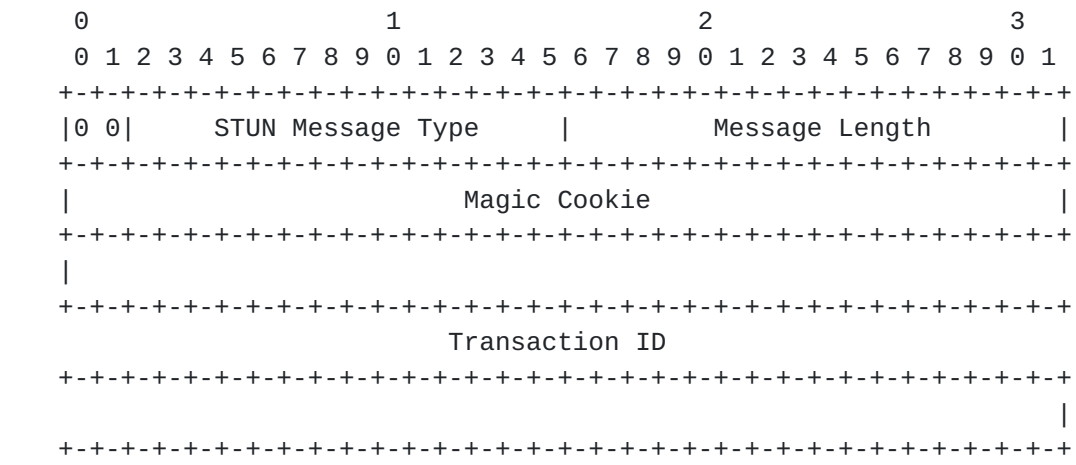


Figure 2: Format of STUN Message Header

The most significant two bits of every STUN message are both zeroes. This, combined with the magic cookie and the fingerprint attribute, aid in differentiating STUN packets from other protocols when STUN is multiplexed with other protocols on the same port.

The message type field is decomposed further into the following structure:

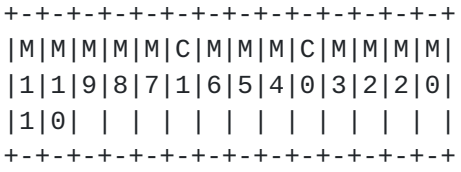


Figure 3: Format of STUN Message Type Field

M11 through M0 represent a 12-bit encoding of the method. C1 through C0 represent a 2 bit encoding of the class. A class of 0 is a Request, a class of 1 is an indication, a class of 2 is a success response, and a class of 3 is an error response. This specification defines two methods, Binding and Shared Secret. Their method values are enumerated in Section 15.

The message length is the size, in bytes, of the message not including the 20 byte STUN header.

The magic cookie is a fixed value, 0x2112A442. In the previous version of this specification [15] this field was part of the transaction ID. This fixed value is used as part of the identification of a STUN message when STUN is multiplexed with other

protocols on the same port, as is done for example in [13] and [18]. The magic cookie additionally indicates the STUN client is compliant with this specification. The magic cookie is present in all STUN messages -- requests, success responses, error responses and indications.

The transaction ID is a 96 bit identifier. STUN transactions are identified by their unique 96-bit transaction ID. For request/ response transactions, the transaction ID is chosen by the STUN client and MUST be unique for each new STUN transaction generated by that STUN client. The transaction ID MUST be uniformly and randomly distributed between 0 and 2**96 - 1. The large range is needed because the transaction ID serves as a form of randomization, helping to prevent replays of previously signed responses from the server. A reponse to the STUN request, whether it be a success or error response, carries the same transaction ID as the request. Indications are also identified by their transaction ID. The transaction ID there MUST also be uniformly and randomly distributed between 0 and 2**96 - 1.As with requests, the value is chosen by the server and MUST be unique for each unique indication generated by the server. Unless a request or indication is bit-wise identical to a previous request, and was sent to the same server from the same transport address, a client MUST choose a new transaction ID for it.

After the STUN header are zero or more attributes. Each attribute is TLV encoded, with a 16 bit type, 16 bit length, and variable value. Each STUN attribute ends on a 32 bit boundary:

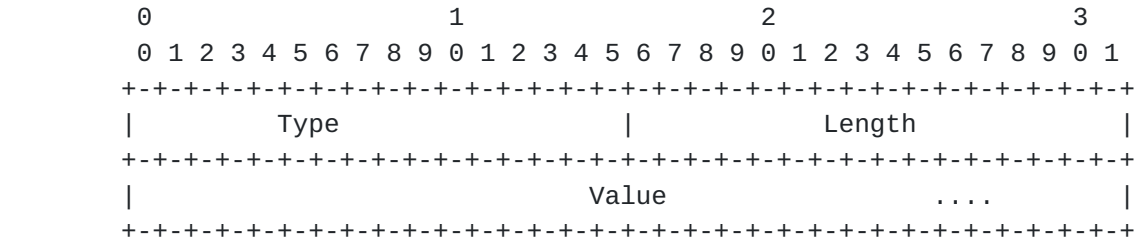


Figure 4: Format of STUN Attributes

The Length refers to the length of the actual useful content of the Value portion of the attribute, measured in bytes. Since STUN aligns attributes on 32 bit boundaries, attributes whose content is not a multiple of 4 bytes are padded with 1, 2 or 3 bytes of padding so that they are a multiple of 4 bytes. Such padding is only needed with attributes that take freeform strings, such as USERNAME and PASSWORD. For attributes that contain more structured data, the attributes are constructed to align on 32 bit boundaries. The value in the Length field refers to the length of the Value part of the attribute prior to padding - i.e., the useful content. Consequently,

when parsing messages, implementations will need to round up the Length field to the nearest multiple of four in order to find the start of the next attribute.

The attribute types defined in this specification are in Section 11 .

7. STUN Transactions

STUN defines two types of transactions - request/response transactions and indication transactions.

7.1. Request/Response Transactions

STUN clients are allowed to pipeline STUN requests. That is, a STUN client MAY have multiple outstanding STUN requests with different transaction IDs and not wait for completion of a STUN request/ response exchange before sending another STUN request.

When running STUN over UDP it is possible that the STUN request or its response might be dropped by the network. Reliability of STUN request message types is accomplished through client retransmissions. Clients SHOULD retransmit the request starting with an interval of RTO, doubling after each retransmission. RTO is an estimate of the round-trip-time, and is computed as described in RFC 2988 [8], with two exceptions. First, the initial value for RTO SHOULD be configurable (rather than the 3s recommended in RFC 2988). In fixed-line access links, a value of 100ms is RECOMMENDED. Secondly, the value of RTO MUST NOT be rounded up to the nearest second. Rather, a 1ms accuracy MUST be maintained. As with TCP, the usage of Karn's algorithm is RECOMMENDED. When applied to STUN, it means that RTT estimates SHOULD NOT be computed from STUN transactions which result in the retransmission of a request.

The value for RTO SHOULD be cached by an agent after the completion of the transaction, and used as the starting value for RTO for the next transaction to the same host (based on equality of IP address). The value SHOULD be considered stale and discarded after 10 minutes.

Retransmissions continue until a response is received, or a total of 7 requests have been sent. If no response is received by 1.6 seconds after the last request has been sent, the client SHOULD consider the transaction to have failed. A STUN transaction over UDP is also considered failed if there has been a transport failure of some sort, such as a fatal ICMP error. For example, assuming an RTO of 100ms, requests would be sent at times 0ms, 100ms, 300ms, 700ms, 1500ms, 3100ms, and 6300ms. At 7900ms, the agent would consider the transaction to have timed out if no response has been received.

When running STUN over TCP, TCP is responsible for ensuring delivery. The STUN application SHOULD NOT retransmit STUN requests when running over TCP. If the client has not received a response after 7900ms, it considers the transaction to have timed out.

Regardless of whether TCP or UDP was used for the transaction, if a failure occurs and the client has other servers it can reach (as a consequence of an SRV query which provides a multiplicity of STUN servers Section 8.1, for example), the client SHOULD create a new request, which is identical to the previous, but has a different transaction ID (and consequently a different MESSAGE INTEGRITY and/or FINGERPRINT attribute).

7.2. Indications

Indications are sent from the client to the server, or from the server to the client. Though no indications are used by this specification, they are used by the STUN relay usage [16]. When sent over UDP, there are no retransmissions, and reliability is not provided. When sent over TCP, reliability is provided by TCP.

Regardless of whether TCP or UDP was used for the indication, if a failure occurs (due to a fatal ICMP error or TCP error), and the client has other servers it can reach (as a consequence of an SRV query which provides a multiplicity of STUN servers Section 8.1, for example), the client SHOULD create a new indication, which is identical to the previous, but has a different transaction ID (and consequently a different MESSAGE INTEGRITY and/or FINGERPRINT attribute).

8. Client Behavior

Client behavior can be broken down into several steps. The first is discovery of the STUN server. The next is obtaining a shared secret. For request/response transactions, the next steps are formulating the request and processing the response. For indication transactions, the next step is formulating the indication.

8.1. Discovery

Unless stated otherwise by a STUN usage, DNS is used to discover the STUN server following these procedures.

The client will be configured with a domain name of the provider of the STUN servers. This domain name is resolved to a transport address using the SRV procedures specified in RFC2782 [3]. The mechanism for configuring the STUN client with the domain name to

look up is not in scope of this document.

The DNS SRV service name depends on the application usage. For the binding usage, the service name is "stun". The protocol can be "udp" for UDP, "tcp" for TCP and "tls" for TLS over TCP. For the short term password application usage, the service name is "stun-pass". The protocol is always "tls" for TLS over TCP. The binding keepalive usage always starts with a transport address, so no DNS SRV service names are defined for it. New STUN usages MAY define additional DNS SRV service names. These SHOULD start with "stun".

The procedures of RFC 2782 are followed to determine the server to contact. RFC 2782 spells out the details of how a set of SRV records are sorted and then tried. However, RFC2782 only states that the client should "try to connect to the (protocol, address, service)" without giving any details on what happens in the event of failure; those details for STUN are described in Section 8.3.3.

A STUN server supporting multiple usages (such as the short term password and binding discovery usage) MAY use the same ports for different usages, as long as ports are not needed to differentiate the usages. Different ports are not needed to differentiate the usages defined in this specification. Different ports SHOULD be used for TCP and TCP/TLS, so that the server can determine whether the first message it will receive after the TCP connection is set up is a STUN message or a TLS message.

The default port for STUN requests is 3478, for both TCP and UDP. There is no default port for STUN over TLS. Administrators SHOULD use this port in their SRV records for UDP and TCP, but MAY use others. If no SRV records were found, the client performs an A or AAAA record lookup of the domain name. The result will be a list of IP addresses, each of which can be contacted at the default port using UDP or TCP, independent of the STUN usage. For usages that require TLS, such as the short term password usage, lack of SRV records is equivalent to a failure of the transaction, since the request or indication MUST NOT be sent unless SRV records provided a transport address specifically for TLS.

8.2. Obtaining a Shared Secret

As discussed in Section 13, there are several attacks possible on STUN systems. Many of these attacks are prevented through integrity protection of requests and responses. To provide that integrity, STUN makes use of a shared secret between client and server which is used as the keying material for the MESSAGE-INTEGRITY attribute in STUN messages. STUN allows for the shared secret to be obtained in any way. The application usage defines the mechanism and required

implementation strength for shared secrets.

Some usages assume that out of band protocols are used to obtain the necessary credentials. Other usages, such as binding keepalives, don't use authentication, as it is not required. Others, such as the binding discovery, allows for authentication using either a long term shared secret or a short term shared secret. The latter can be obtained by using the short term password usage to obtain a short term shared secret.

Consequently, the STUN usages define rules for obtaining shared secrets prior to sending a request.

8.3. Request/Response Transactions

8.3.1. Formulating the Request Message

The client follows the syntax rules defined in Section 6 and the transmission rules of Section 7. The message class MUST be a request.

The client creates a STUN message following the STUN message structure described in Section 6. The client SHOULD add a MESSAGE-INTEGRITY and USERNAME attribute to the Request message if the usage employs authentication. The specific credentials to use are described by the STUN usage, which can specify no credentials, a short term credential, or a long term credential. The procedures for each are:

1. If the STUN usage specifies that no credentials are used, the message is sent without MESSAGE-INTEGRITY

2. If a short term credential is to be used, the STUN Request or STUN Indication would contain the USERNAME and MESSAGE-INTEGRITY attributes. The message MUST NOT contain the REALM attribute. The key for MESSAGE-INTEGRITY is the password.

3. If a long term credential is to be used, the STUN request contains the USERNAME, REALM, and MESSAGE-INTEGRITY attributes. The 16-byte key for MESSAGE-INTEGRITY HMAC is formed by taking the MD5 hash of the result of concatenating the following five fields: (1) The username, with any quotes and trailing nulls removed, (2) A single colon, (3) The realm, with any quotes and trailing nulls removed, (4) A single colon, and (5) The password, with any trailing nulls removed. For example, if the USERNAME field were 'user', the REALM field were '"realm"', and the PASSWORD field were 'pass', then the 16-byte HMAC key would be the result of performing an MD5 hash on the string 'user:realm:

pass', or 0x8493fbc53ba582fb4c044c456bdc40eb.

This format for the key was chosen so as to enable a common authentication database for SIP, which uses digest authentication as defined in RFC 2617 [7] and STUN, as it is expected that credentials are usually stored in their hashed forms.

The NONCE is included in the request only if a short or long term credential is being used, and only if the STUN request is a retry as a consequence of a previous error response which provided the client with a NONCE.

For TCP and TLS-over-TCP, the client opens a TCP connection to the server. The TLS_RSA_WITH_AES_128_CBC_SHA ciphersuite MUST be supported at a minimum by implementers when TLS is used with STUN. Implementers MAY also support any other ciphersuite. When it receives the TLS Certificate message, the client SHOULD verify the certificate and inspect the site identified by the certificate. If the certificate is invalid, revoked, or if it does not identify the appropriate party, the client MUST NOT send the STUN message or otherwise proceed with the STUN transaction. The client MUST verify the identity of the server. To do that, it follows the identification procedures defined in Section 3.1 of RFC 2818 [4]. Those procedures assume the client is dereferencing a URI. For purposes of usage with this specification, the client treats the domain name or IP address used in Section 8.1 as the host portion of the URI that has been dereferenced. If DNS was not used, the client MUST be configured with a set of authorized domains whose certificates will be accepted.

When STUN is being multiplexed on the same transport address as application data, and there are valid application layer data packets which could be confused with STUN packets (because, for example, bits 32 through 63 can contain an arbitrary binary value which might be equal to 0x2112A442), the FINGERPRINT attribute MUST be present. Otherwise, its inclusion is RECOMMENDED.

Next, the client sends the request. For UDP-based requests, reliability is accomplished through client retransmissions, following the procedure in Section 7.1. For TCP (including TLS over TCP), there are no retransmissions.

For TCP and TLS over TCP, the client MAY send multiple requests on the connection. When using TCP or TLS over TCP, the client SHOULD close the connection as soon as it has received the STUN Response, if it has no plans to send further requests.

Regardless of the transport protocol, a client MAY pipeline requests

(that is, it can have multiple requests outstanding at the same time).

8.3.2. Processing Responses

Once the client has received a response to its request that it did not discard, it MUST discard any further responses for the same request.

All responses that were not discarded, whether success responses or error responses, MUST first be authenticated by the client. Authentication is performed by first comparing the Transaction ID of the response to an oustanding request. If there is no match, the client MUST discard the response. Then the client SHOULD check the response for a MESSAGE-INTEGRITY attribute. If not present, and the client placed a MESSAGE-INTEGRITY attribute into the associated request, it MUST discard the response. If MESSAGE-INTEGRITY is present, the client computes the HMAC over the response as described in Section 11.4. The key that is used MUST be same as used to compute the MESSAGE-INTEGRITY attribute in the request. If the client did not place a MESSAGE-INTEGRITY attribute into the request, it MUST ignore the MESSAGE-INTEGRITY attribute in the response and continue processing the response.

If the computed HMAC matches the one from the response, processing continues.

If the response is an Error Response, the client checks the response code from the ERROR-CODE attribute of the response. For a 400 (Bad Request) response code, the client SHOULD display the reason phrase to the user. For a 420 (Unknown Attribute) response code, the client SHOULD retry the request, this time omitting any attributes listed in the UNKNOWN-ATTRIBUTES attribute of the response.

If the client receives a 401 (Unauthorized) response and had not included a MESSAGE-INTEGRITY attribute in the request, it is an indication from the server that credentials are required. If the REALM attribute was present in the response, it is a signal to the client to use a long term shared secret and retry the request. The client SHOULD retry the request, using the username and password associated with the REALM (this username and password are assumed to be pre-provisioned into the client through some other means). If the REALM attribute was absent in the response, it is a signal to the client to use a short term shared secret and retry the request. If the client doesn't have a short term shared secret, it SHOULD use the Shared Secret request to obtain one, and then retry the request with the username and password obtained as a result.

If the client receives a 401 (Unauthorized) response but had included a MESSAGE-INTEGRITY attribute in the request, there has been an unrecoverable error. This shouldn't ever happen, but if it does, the client SHOULD NOT retry the request.

If the client receives a 432 (Missing Username) response, and the client had omitted the USERNAME from the request but included a MESSAGE-INTEGRITY, the client SHOULD retry the request and include both MESSAGE-INTEGRITY and USERNAME. If the client receives a 432 (Missing Username) but had included both MESSAGE-INTEGRITY and USERNAME in the request, there has been an unrecoverable error. This shouldn't ever happen, but if it does, the client SHOULD NOT retry the request.

If the client receives a 435 (Missing Nonce) response, but had included a NONCE in the request, an unrecoverable error has occurred and the client SHOULD NOT retry. However, if it had omitted the NONCE in the request and received a 435, or it had included the NONCE but received a 438, it is a request from the server to retry using the same credential, but with a different nonce. The client SHOULD retry the request.

If the client receives a 430 (Stale Credentials) response, it means that the client used a short term credential that has expired. If the client had submitted the request using a short term credential obtained from a Shared Secret request, the client SHOULD generate a new Shared Secret request to obtain a new short term credential and then retry the request with that credential. Note that the Shared Secret request may or may not go to the same server which generated the 430 (Stale Credentials) response; the server that receives the Shared Secret request is determined by the DNS procedures defined above. If a 430 (Stale Credentials) response was received and the client had used a short term credential provided through some other means, the client SHOULD obtain a new short term credential using that mechanism. If the client had not used a short term credential in the request, the 430 (Stale Credentials) error is unrecoverable and the request SHOULD NOT be retried.

For a 431 (Integrity Check Failure) response code, the client SHOULD alert the user, and if a short term credential obtained from a Shared Secret request had been used previously, the client MAY try the request again after obtaining a new short term username and password.

If the client receives a 433 (Use TLS) response, and the request was a Shared Secret request which was not sent over TLS, the client SHOULD retry the request, and MUST send it using TLS. If this response is received to any other request except for a Shared Secret request, or if the client had sent the Shared Secret request over

TLS, it is an unrecoverable error and the client SHOULD NOT retry.

If the client receives a 434 (Missing Realm) response, and had omitted the REALM in the request, but had included MESSAGE-INTEGRITY, it is an indication that, though a short-term credential was used for the request, the server desires the client to use a long term credential. The client SHOULD retry the request using the username and password associated with the REALM. If the 434 (Missing Realm) was received but the request had contained a REALM, and the REALM in the response differs from the REALM in the request, the client SHOULD retry using the username and password associated with the REALM in the response. If the REALMS were equal, this is an unrecoverable error and the client SHOULD NOT retry.

It the client receives a 436 (Unknown Username) response, it means that the username it provided in the request is unknown. For usages where the username was collected from the user, the client SHOULD alert the user. The client SHOULD NOT retry with the same username. If the username was obtained using the Shared Secret request, the client SHOULD obtain a new credential and retry. However, if the retries are repeatedly rejected with a 436 (Unknown Username), it SHOULD cease retrying.

For error responses which can contain a NONCE, if the error response results in a retry, the client MUST include the NONCE in a subsequent retry. Furthermore, the client SHOULD cache the nonce, and continue using it in subsequent requests sent to the same server, identified by transport address.

For a 300 (Try Alternate) response code, the client SHOULD attempt a new transaction to the server indicated in the ALTERNATE-SERVER attribute. The client SHOULD reuse its credentials (username and password) when retrying. This is useful for load balancing requests across a STUN server cluster, when those requests require some amount of resources to process. Though this specification allows the 300 (Try Alternate) response to be applied to Binding Requests, it is generally not useful to do so, since the work of redirecting a Binding Request is equal to, if not more than, the work of just processing the Binding Request. Consequently, the 300 (Try Alternate) response code is targeted for other usages of STUN, such as the relay usage [16].

For a 500 (Server Error) response code, the client MAY wait several seconds and then retry the request on the same server. Or, if the server was learned through DNS SRV records, the client MAY try the request on the next server in the list. The same username and password MAY be used. For a 600 (Global Failure) response code, client MUST NOT retry the request on this server, or if the server

was learned through DNS, any other server found through the DNS resolution procedures.

Unknown response codes between 300 and 399 are treated like a 300. Unknown response codes between 400 and 499 are treated like a 400, unknown response codes between 500 and 599 are treated like a 500, and unknown response codes between 600 and 699 are treated like a 600. Any response between 100 and 299 MUST result in the cessation of request retransmissions, but otherwise is discarded.

Unknown optional attributes in a response (greater than 0x7FFF) MUST be ignored by the STUN client. Responses containing unknown mandatory attributions (less than or equal to 0x7FFF) MUST be discarded and considered immediately as a failed transaction.

For a success response, the client SHOULD cache any nonce present in the response, and continue using it in subsequent requests sent to the same server, identified by transport address.

8.3.3. Timeouts

If the STUN transaction times out without receipt of a response, the client SHOULD consider it a failure and retry the request to the next server in the list of servers from the DNS SRV response, as specified in RFC 2782.

8.4. Indication Transactions

This section applies to client and server behavior for sending an Indication message.

The client or server follows the syntax rules defined in Section 6 and the transmission rules of Section 7. The message class MUST be an indication.

Indication messages cannot be challenged or rejected. Consequently, they cannot be authenticated using long term credentials. If a STUN usage specifies that authentication is needed for an indication message, it can only be done using a short term credential. In that case, the client or server MUST add a MESSAGE-INTEGRITY and USERNAME attribute to the Request message. The key for MESSAGE-INTEGRITY is the password.

When STUN is being multiplexed on the same transport address as application data, and there are valid application layer data packets which could be confused with STUN packets (because, for example, bits 32 through 63 can contain an arbitrary binary value which might be equal to 0x2112A442), the FINGERPRINT attribute MUST be present.

Otherwise, its inclusion is RECOMMENDED.

Typically, indication messages are sent to the same transport address, or over the same TCP connections as a previous request message. However, a usage can specify that indication messages are sent based on a DNS query, in which case the discovery procedures in Section 8.1 are followed, along with the TCP/TLS connection establishment procedures defined in Section 8.3.1.

Indication message types are not sent reliably, do not elicit a response from the server, and are not retransmitted.

For TCP and TLS over TCP, the client or server MAY send multiple indications on the connection. When using TCP or TLS over TCP, the client SHOULD close the connection as soon as it determines it has no further messages to send to the server.

By definition, since indications do not generate a response, they can be pipelined, regardless of the transport protocol.

9. Server Behavior

As with clients, server behavior depends on whether it is a request/response transaction or indication.

9.1. Request/Response Transactions

9.1.1. Receive Request Message

A STUN server MUST be prepared to receive request messages on the transport address that will be discovered by the STUN client when the STUN client follows its discovery procedures described in Section 8.1. Depending on the usage, the STUN server will listen for incoming UDP STUN messages, incoming TCP STUN messages, or incoming TLS exchanges followed by TCP STUN messages.

If the request is a retransmission of a request for which the server has already generated a response within the last 10 seconds, the server MUST retransmit the response. A server can do this either by remembering the response it transmitted, or by re-processing the request and computing the response. The latter technique can only be applied to requests which are idempotent and would result in the same response for the same request. This is the case for the Binding Request, but not for the Shared Secret Request. Extensions to STUN SHOULD state whether their request types have this property or not.

When a STUN request is received, the server determines the usage.

The usages describe how the STUN server makes this determination.

Based on the usage, the server determines whether the request requires any authentication and message integrity checks. It can require none, short-term credential based authentication, or long-term credential authentication.

If authentication is required, the server checks for the presence of the MESSAGE-INTEGRITY attribute. If not present, the server generates an error response with an ERROR-CODE attribute and a response code of 401 (Unauthorized). If the server wishes the client to use a short term credential, the REALM is omitted from the response. If the server wishes the client to use a long term credential, the REALM is included in the response containing a realm from which the username and password are scoped [7].

If the MESSAGE-INTEGRITY attribute was present, the server checks for the existence of the USERNAME attribute. If it was not present, the server MUST generate an error response. The error response MUST include an ERROR-CODE attribute with a response code of 432 (Missing Username). If the server is using a long term credential for authentication, the response MUST include a REALM. If the server is using a short-term credential, it MUST NOT include a REALM in the response.

If the server is using long term credentials for authentication, and the request contained the MESSAGE-INTEGRITY and USERNAME attributes, the server checks for the existence of the REALM attribute. If the attribute is not present, the server MUST generate an error response. That error response MUST include an ERROR-CODE attribute with response code of 434 (Missing Realm). That error response MUST also include a REALM attribute.

If the REALM attribute was present and the server is using a long term credential for authentication, the server checks for the existence of the NONCE attribute. If the NONCE attribute is not present, the server MUST generate an error response. That error response MUST include an ERROR-CODE attribute with a response code of 435 (Missing Nonce). That error response MUST include a REALM attribute. If the NONCE was absent and the server is authenticating with short term credentials, the server MAY generate an error response with an ERROR-CODE attribute with a response code of 435 (Missing Nonce). This response MUST include a NONCE. If the NONCE was present in the request, but the server has determined it is stale, the server MUST generate an error response with an ERROR-CODE attribute with a response code of 438 (Stale Nonce).

If the server is authenticating the request with a short term

credential, it checks the value of the USERNAME field. If the USERNAME was previously valid but has expired, the server generates an error response with an ERROR-CODE attribute with a response code of 430 (Stale Credentials). If the server is authenticating with either short or long term credentials, it determines whether the USERNAME contains a known entity, and in the case of a long-term credential, known within the realm of the REALM attribute of the request. If the USERNAME is unknown, the server generates an error response with an ERROR-CODE attribute with a response code of 436 (Unknown Username). For authentication using long-term credentials, that error response MUST include a REALM attribute. For authentication using short-term credentials, it MUST NOT include a REALM.

At this point, if the server is doing authentication, the request contains everything needed for that purpose. The server computes the HMAC over the request as described in Section 11.4. The key depends on the credential. For short-term credentials, it equals the password associated with the username. For long term credentials, it is computed as described in Section 8.3.1.

If the computed HMAC differs from the one from the MESSAGE-INTEGRITY attribute in the request, the server MUST generate an error response with an ERROR-CODE attribute with a response code of 431 (Integrity Check Failure). If long term credentials are being used for authentication, this response MUST include a REALM attribute. If short term credentials are being used, it MUST NOT include a REALM.

When an error response is to be generated by the server as a consequence of authentication problems (error codes 401, 432, 434, 435, 430 and 436, and the REALM is present in the response (signifying the usage of a long term credential), the server MUST include a NONCE attribute in the response. The nonce includes a random value that the server wishes the client to reflect back in a subsequent request (and therefore include in the message integrity computation). When the REALM is absent in the response, the server MAY include a NONCE in the response if it wishes to use nonces along with short-term shared secrets (with the exception of 435, where NONCE is mandatory even for short term credentials). However, there is little reason to do so, since the short-term password is, by definition, short-term, and thus additional temporal scoping through the nonce is not needed.

At this point, the request has been authentication checked and integrity verified.

If the method of the request is unknown to the server, it MUST generate an error response which includes an ERROR-CORE attribute

with a 400 response code.

Next, the server MUST check for any mandatory attributes in the request (values less than or equal to 0x7fff) which it does not understand. If it encounters any, the server MUST generate an error response, and it MUST include an ERROR-CODE attribute with a 420 response code. Any attributes that are known, but are not supposed to be present in a message (MAPPED-ADDRESS in a request, for example) MUST be ignored.

9.1.2. Constructing the Response

To construct the STUN Response the STUN server follows the message structure described in Section 6. The message type MUST indicate either a success response or error response class and MUST indicate the same method as the request. The server MUST copy the transaction ID from the request to the response.

The attributes that get added to the response depend on the type of response. See Figure 5 for a summary.

If the response is a type which can carry either MAPPED-ADDRESS or XOR-MAPPED-ADDRESS (the Binding Response as defined in this specification meets that criteria), the server examines the magic cookie in the STUN header. If it has the value 0x2112A442, it indicates that the client supports this version of the specification. The server MUST insert a XOR-MAPPED-ADDRESS into the response, carrying the exclusive-or of the source transport address and magic cookie. If the magic cookie did not have this value, it indicates that the client supports the previous version of this specification. The server MUST insert a MAPPED-ADDRESS attribute into the response, carrying the souce transport address from the request. Insertion of either XOR-MAPPED-ADDRESS or MAPPED-ADDRESS happens regardless of the transport protocol used for the request.

XOR-MAPPED-ADDRESS and MAPPED-ADDRESS differ only in their encoding of the transport address. The former, as implied by the name, encodes the transport address by exclusive-or'ing them with the magic cookie. The latter encodes them directly in binary. RFC 3489 originally specified only MAPPED-ADDRESS. However, deployment experience found that some NATs rewrite the 32-bit binary payloads containing the NAT's public IP address, such as STUN's MAPPED-ADDRESS attribute, in the well-meaning but misguided attempt at providing a generic ALG function. Such behavior interferes with the operation of STUN and also causes failure of STUN's message integrity checking.

If the request contained the MESSAGE-INTEGRITY attribute, the server MUST include a MESSAGE-INTEGRITY attribute in a successful response.

The MESSAGE-INTEGRITY attribute MUST use the same username and password used to authenticate the request. If long term credentials were used, the response MUST include a NONCE. For short term credentials, a NONCE MAY be included.

The server SHOULD include a SERVER attribute in all responses, indicating the identity of the server generating the response. This is useful for diagnostic purposes.

When STUN is being multiplexed on the same transport address as application data, and there are valid application layer data packets which could be confused with STUN packets (because, for example, bits 32 through 63 can contain an arbitrary binary value which might be equal to 0x2112A442), the FINGERPRINT attribute MUST be present in the response. Otherwise, its inclusion is RECOMMENDED.

In cases where the server cannot handle the request, due to exhaustion of resources, the server MAY generate a 300 response with an ALTERNATE-SERVER attribute. This attribute identifies an alternate server which can service the requests. It is not expected that 300 responses or this attribute would be used by the methods defined in this specification.

9.1.3. Sending the Response

All UDP response messages are sent to the transport address the associated Binding Request came from, and sent from the transport address the Binding Request was sent to. All TCP or TLS over TCP responses messages are sent on the TCP connections that the request arrived on.

9.2. Indication Transactions

Indication messages cause the server to change its state. Indication message types do not cause the server to send a response message.

A STUN server MUST be prepared to receive indication messages on the transport address that will be discovered by the STUN client when the STUN client follows its discovery procedures described in Section 8.1. Depending on the usage, the STUN server will listen for incoming UDP STUN messages, incoming TCP STUN messages, or incoming TLS exchanges followed by TCP STUN messages.

When a STUN indication is received, the server determines the usage. The usages describe how the STUN server makes this determination.

Based on the usage, the server determines whether the indication requires any authentication and message integrity checks. It can

require none or short-term credential based authentication. If short-term credentials are utilized, the server follows the same procedures as defined in Section 9.1.1, but if those procedures require transmission of an error response, the server MUST instead silently discard the indication.

Once authenticated (if authentication was in use), the processing of the indication message depends on the method. This specification doesn't define any indication messages.

10. Demultiplexing of STUN and Application Traffic

In the binding refresh usage, STUN traffic is multiplexed on the same transport address as application traffic, such as RTP. In order to apply the processing described in this specification, STUN messages must first be separated from the application packets. This disambiguation is done identically for all message types.

First, all STUN messages start with two bits equal to zero. If STUN is being multiplexed with application traffic where it is known that the topmost two bits are never zeroes, the presence of these two zeroes signals STUN traffic.

If this mechanism doesn't suffice, the magic cookie can be used. All STUN messages have the value 0x2112A442 as the second 32 bit word. If the application traffic can not have this value as the second 32 bit word, then any packets with this value are STUN packets. Even if the application packet can have this value (for example, in cases where the application packets contain random binary data), there is only a one in 2^32 chance that an application packet will have a value of 0x2112A442 in its second 32 bit word. If this probability is deemed sufficiently small for the application at hand (for example, it is considered adequate for Voice over IP applications), then any packet with this value in its second 32 bit word is processed as a STUN packet.

However, a mis-classification of 1 in 2^32 may still be too high for some usages of STUN. Consequently, STUN messages can contain a FINGERPRINT attribute. This is a cryptographic hash over the message, covering everything prior to the attribute. This attribute is different from MESSAGE-INTEGRITY. The latter uses a keyed HMAC, and thus requires a shared secret. FINGERPRINT does not use a password, and can be computed just by examining the STUN message. Thus, if a packet appears to be a STUN message because it has a value of 0x2112A442 in its second 32 bit word, a client or server then assumes the message is a STUN message, and computes the value for the fingerprint. It then looks for the FINGERPRINT attribute in the

message, and if the value equals the computed value, the message is considered to be a STUN message. If not, it is considered to be an application packet.

11. STUN Attributes

To allow future revisions of this specification to add new attributes if needed, the attribute space is divided into optional and mandatory ones. Attributes with values greater than 0x7fff are optional, which means that the message can be processed by the client or server even though the attribute is not understood. Attributes with values less than or equal to 0x7fff are mandatory to understand, which means that the client or server cannot successfully process the message unless it understands the attribute.

The values of the message attributes are enumerated in Section 15.

The following figure indicates which attributes are present in which messages. An M indicates that inclusion of the attribute in the message is mandatory, O means its optional, C means it's conditional based on some other aspect of the message, and - means that the attribute is not applicable to that message type.

Attribute	Request	Response	Error Response	Indication
MAPPED-ADDRESS	-	C	-	-
USERNAME	C	-	-	O
PASSWORD	-	C	-	-
MESSAGE-INTEGRITY	O	C	C	O
ERROR-CODE	-	-	M	-
ALTERNATE-SERVER	-	-	C	-
REALM	C	-	C	-
NONCE	C	-	C	-
UNKNOWN-ATTRIBUTES	-	-	C	-
XOR-MAPPED-ADDRESS	-	C	-	-
SERVER	-	O	O	O
REFRESH-INTERVAL	-	O	-	-
FINGERPRINT	O	O	O	O

Figure 5: Mandatory Attributes and Message Types

11.1. MAPPED-ADDRESS

The MAPPED-ADDRESS attribute indicates the mapped transport address. It consists of an eight bit address family, and a sixteen bit port, followed by a fixed length value representing the IP address. If the

address family is IPv4, the address is 32 bits, in network byte order. If the address family is IPv6, the address is 128 bits in network byte order.

The format of the MAPPED-ADDRESS attribute is:

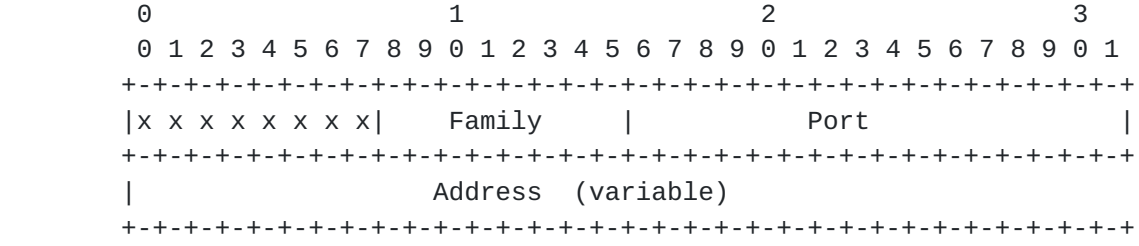


Figure 6: Format of MAPPED-ADDRESS attribute

The address family can take on the following values:

0x01:IPv4
0x02:IPv6

The port is a network byte ordered representation of the port the request arrived from.

The first 8 bits of the MAPPED-ADDRESS are ignored for the purposes of aligning parameters on natural 32 bit boundaries.

It is possible for an IPv4 host to receive a MAPPED-ADDRESS containing an IPv6 address, or for an IPv6 host to receive a MAPPED-ADDRESS containing an IPv4 address. Clients MUST be prepared for this case.

11.2. USERNAME

The USERNAME attribute is used for message integrity. It identifies the shared secret used in the message integrity check. Consequently, the USERNAME MUST be included in any request that contains the MESSAGE-INTEGRITY attribute.

The USERNAME is also always present in a Shared Secret Response, along with the PASSWORD, which informs a client of a short term password.

The value of USERNAME is a variable length opaque value. Note that, as described above, if the USERNAME is not a multiple of four bytes it is padded for encoding into the STUN message, in which case the attribute length represents the length of the USERNAME prior to padding.

11.3. PASSWORD

If the message type is Shared Secret Response it MUST include the PASSWORD attribute.

The value of PASSWORD is a variable length opaque value. The password returned in the Shared Secret Response is used as the HMAC key in the MESSAGE-INTEGRITY attribute of a subsequent STUN transaction. Note that, as described above, if the USERNAME is not a multiple of four bytes it is padded for encoding into the STUN message, in which case the attribute length represents the length of the USERNAME prior to padding.

11.4. MESSAGE-INTEGRITY

The MESSAGE-INTEGRITY attribute contains an HMAC-SHA1 [10] of the STUN message. The MESSAGE-INTEGRITY attribute can be present in any STUN message type. Since it uses the SHA1 hash, the HMAC will be 20 bytes. The text used as input to HMAC is the STUN message, including the header, up to and including the attribute preceding the MESSAGE-INTEGRITY attribute. That text is then padded with zeroes so as to be a multiple of 64 bytes. As a result, the MESSAGE-INTEGRITY attribute is either the last attribute, or the next to last attribute in any STUN message (depending on whether FINGERPRINT is present). With the exception of the FINGERPRINT attribute, which appears after MESSAGE-INTEGRITY, elements MUST ignore all other attributes that follow MESSAGE-INTEGRITY.

The key used as input to HMAC depends on the STUN usage and the shared secret mechanism.

11.5. FINGERPRINT

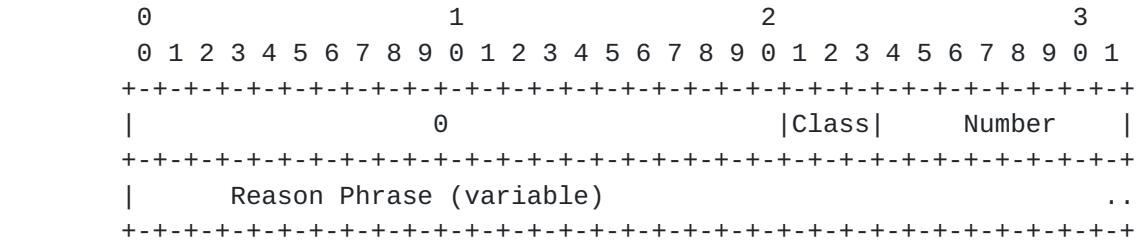
The FINGERPRINT attribute can be present in all STUN messages. It is computed as the CRC-32 of the STUN message up to (but excluding) the FINGERPRINT attribute itself, xor-d with the 32 bit value 0x5354554e (the XOR helps in cases where an application packet is also using CRC-32 in it). The 32 bit CRC is the one defined in ITU V.42 [9], which has a generator polynomial of x32+x26+x23+x22+x16+x12+x11+x10+ x8+x7+x5+x4+x2+x+1. When present, the FINGERPRINT attribute MUST be the last attribute in the message.

11.6. ERROR-CODE

The ERROR-CODE attribute is present in the Binding Error Response and Shared Secret Error Response. It is a numeric value in the range of 100 to 699 plus a textual reason phrase encoded in UTF-8, and is consistent in its code assignments and semantics with SIP [11] and

HTTP [12]. The reason phrase is meant for user consumption, and can be anything appropriate for the response code. Recommended reason phrases for the defined response codes are presented below.

To facilitate processing, the class of the error code (the hundreds digit) is encoded separately from the rest of the code.



The class represents the hundreds digit of the response code. The value MUST be between 1 and 6. The number represents the response code modulo 100, and its value MUST be between 0 and 99.

If the reason phrase has a length that is not a multiple of four bytes, it is padded for encoding into the STUN message, in which case the attribute length represents the length of the entire ERROR-CODE attribute (including the reason phrase) prior to padding.

The following response codes, along with their recommended reason phrases (in brackets) are defined at this time:

300 (Try Alternate): The client should contact an alternate server for this request.

400 (Bad Request): The request was malformed. The client should not retry the request without modification from the previous attempt.

401 (Unauthorized): The request did not contain a MESSAGE-INTEGRITY attribute.

420 (Unknown Attribute): The server did not understand a mandatory attribute in the request.

430 (Stale Credentials): The request did contain a MESSAGE-INTEGRITY attribute, but it used a shared secret that has expired. The client should obtain a new shared secret and try again.

431 (Integrity Check Failure): The request contained a MESSAGE-INTEGRITY attribute, but the HMAC failed verification. This could be a sign of a potential attack, or client implementation error.

432 (Missing Username): The request contained a MESSAGE-INTEGRITY attribute, but not a USERNAME attribute. Both USERNAME and MESSAGE-INTEGRITY must be present for integrity checks.

433 (Use TLS): The Shared Secret request has to be sent over TLS, but was not received over TLS.

434 (Missing Realm): The REALM attribute was not present in the request.

435 (Missing Nonce): The NONCE attribute was not present in the request.

436 (Unknown Username): The USERNAME supplied in the request is not known or is not known to the server.

438 (Stale Nonce): The NONCE attribute was present in the request but wasn't valid.

500 (Server Error): The server has suffered a temporary error. The client should try again.

600 (Global Failure): The server is refusing to fulfill the request. The client should not retry.

11.7. REALM

The REALM attribute is present in requests and responses. It contains text which meets the grammar for "realm" as described in RFC 3261 [11], and will thus contain a quoted string (including the quotes).

Presence of the REALM attribute in a request indicates that long-term credentials are being used for authentication. Presence in certain error responses indicates that the server wishes the client to use a long-term credential for authentication.

11.8. NONCE

The NONCE attribute is present in requests and in error responses. It contains a sequence of qdtext or quoted-pair, which are defined in RFC 3261 [11]. See RFC 2617 [7] for guidance on selection of nonce values in a server.

11.9. UNKNOWN-ATTRIBUTES

The UNKNOWN-ATTRIBUTES attribute is present only in an error response when the response code in the ERROR-CODE attribute is 420.

The attribute contains a list of 16 bit values, each of which represents an attribute type that was not understood by the server. If the number of unknown attributes is an odd number, one of the attributes MUST be repeated in the list, so that the total length of the list is a multiple of 4 bytes.

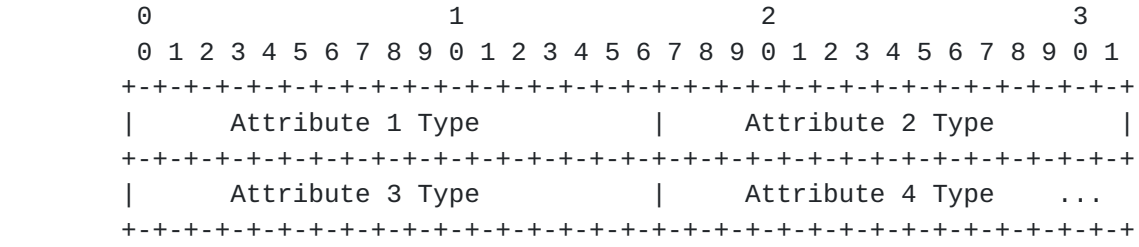


Figure 9: Format of UNKNOWN-ATTRIBUTES attribute

11.10. XOR-MAPPED-ADDRESS

The XOR-MAPPED-ADDRESS attribute is present in responses. It provides the same information that would present in the MAPPED-ADDRESS attribute but because the NAT's public IP address is obfuscated through the XOR function, STUN messages are able to pass through NATs which would otherwise interfere with STUN.

This attribute MUST always be present in a Binding Response and may be used in other responses as well. Usages defining new requests and responses should specify if XOR-MAPPED-ADDRESS is applicable to their responses.

The format of the XOR-MAPPED-ADDRESS is:

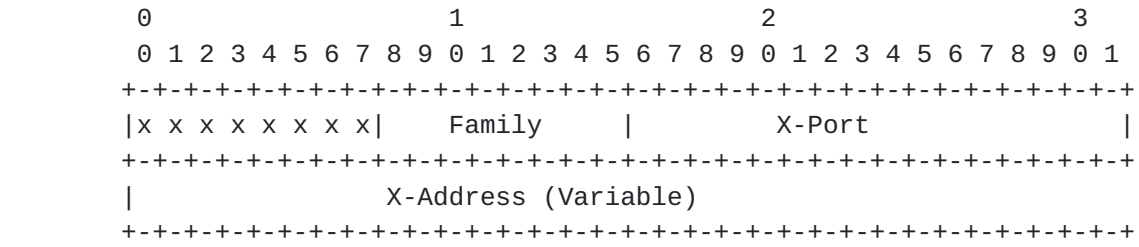


Figure 10: Format of XOR-MAPPED-ADDRESS Attribute

The Family represents the IP address family, and is encoded identically to the Family in MAPPED-ADDRESS.

X-Port is the mapped port, exclusive or'd with most significant 16 bits of the magic cookie. If the IP address family is IPv4, X-Address is the mapped IP address exclusive or'd with the magic

cookie. If the IP address family is IPv6, the X-Address is the mapped IP address exclusively or'ed with the magic cookie and the 96-bit transaction ID.

For example, using the "^" character to indicate exclusive or, if the IP address is 192.168.1.1 (0xc0a80101) and the port is 5555 (0x15B3), the X-Port would be 0x15B3 ^ 0x2112 = 0x34A1, and the X-Address would be 0xc0a80101 ^ 0x2112A442 = 0xe1baa543.

It is possible for an IPv4 host to receive a XOR-MAPPED-ADDRESS containing an IPv6 address, or for an IPv6 host to receive a XOR-MAPPED-ADDRESS containing an IPv4 address. Clients MUST be prepared for this case.

11.11. SERVER

The server attribute contains a textual description of the software being used by the server, including manufacturer and version number. The attribute has no impact on operation of the protocol, and serves only as a tool for diagnostic and debugging purposes. The value of SERVER is variable length. If the value of SERVER is not a multiple of four bytes, it is padded for encoding into the STUN message, in which case the attribute length represents the length of the USERNAME prior to padding.

11.12. ALTERNATE-SERVER

The alternate server represents an alternate transport address for a different STUN server to try. It is encoded in the same way as MAPPED-ADDRESS.

This attribute MUST only appear in an error response.

11.13. REFRESH-INTERVAL

The REFRESH-INTERVAL indicates the number of milliseconds that the server suggests the client should use between refreshes of the NAT bindings between the client and server. Even though the server may not know the binding lifetimes in intervening NATs, this attribute serves as a useful configuration mechanism for suggesting a value for use by the client. Furthermore, when the NAT Keepalive usage is being used, the server may become overloaded with Binding Requests that are being used for keepalives. The REFRESH-INTERVAL provies a mechanism for the server to gradually reduce the load on itself by pushing back on the client.

REFRESH-INTERVAL is specified as an unsigned 32 bit integer, and represents an interval measured in millseconds. It can be present in

Binding Responses.

12. STUN Usages

STUN is a simple request/response protocol that provides a useful capability in several situations. In this section, different usages of STUN are described. Each usage may differ in how STUN servers are discovered, when the STUN requests are sent, what message types are used, what message attributes are used, and how authentication is performed.

This specification defines the STUN usages for binding discovery (Section 12.1), NAT keepalives (Section 12.2) and short-term password (Section 12.3).

New STUN usages may be defined by other standards-track documents. New STUN usages MUST describe their applicability, client discovery of the STUN server, how the server determines the usage, new message types (requests or indications), new message attributes, new error response codes, and new client and server procedures.

12.1. Binding Discovery

The previous version of this specification, RFC3489 [15], described only this binding discovery usage.

12.1.1. Applicability

Binding discovery is used to learn reflexive addresses from servers on the network, generally the public Internet. That is, it is used by a client to determine its dynamically-bound 'public' UDP transport address that is assigned by a NAT between a STUN client and a STUN server. This transport address will be present in the mapped address of the STUN Binding Response.

The mapped address present in the binding response can be used by clients to facilitate traversal of NATs for many applications. NAT traversal is problematic for applications that require a client to insert a transport address into a message, to which subsequent messages will be delivered by other entities in a network. Normally, the client would insert the transport address from a local interface into the message. However, if the client is behind a NAT, this local interface will be a private address. Clients within other address realms will not be able to send messages to that address.

An example of a such an application is SIP, which requires a client to include transport address information in several places, including

the Session Description Protocol (SDP [19]) body carried by SIP. The transport address present in the SDP is used for receipt of media.

To use STUN as a technique for traversal of SIP and other protocols, when the client wishes to send a protocol message, it figures out the places in the protocol data unit where it is supposed to insert its own transport address. Instead of directly using a port allocated from a local interface, the client allocates a port from the local interface, and from that port, generates a STUN Binding Request. The mapped address in the Binding Response (XOR-MAPPED-ADDRESS or MAPPED-ADDRESS) provides the client with an alternative transport address that it can then include in the protocol payload. This transport address may be within a different address family than the local interfaces used by the client. This is not an error condition. In such a case, the client would use the learned IP address and port as if the client was a host with an interface within that address family.

In the case of SIP, to populate the SDP appropriately, a client would generate two STUN Binding Request messages at the time a call is initiated or answered. One is used to obtain the transport address for RTP, and the other, for the Real Time Control Protocol (RTCP)[17]. The client might also need to use STUN to obtain transport addresses for usage in other parts of the SIP message. The detailed usage of STUN to facilitate SIP NAT traversal is outside the scope of this specification.

As discussed above, the transport addresses learned by STUN may not be usable with all entities with whom a client might wish to communicate. The way in which this problem is handled depends on the application protocol. The ideal solution is for a protocol to allow a client to include a multiplicity of transport addresses in the PDU. One of those can be the transport address determined from STUN, and the others can include transport addresses learned from other techniques. The application protocol would then provide a means for dynamically detecting which one works. An example of such an an approach is Interactive Connectivity Establishment (ICE [13]).

12.1.2. Client Discovery of Server

Clients SHOULD be configured with a domain name for a STUN server to use. In cases where the client has no explicit configuration mechanism for STUN, but knows the domain of its service provider, the client SHOULD use that domain (in the case of SIP, this would be the domain from their Address-of-Record). The discovery mechanisms defined in Section 8.1 are then applied to that domain name.

12.1.3. Server Determination of Usage

It is anticipated that servers would advertise a specific port in the DNS for the Binding Discovery usage. Thus, when a request arrives at that particular port, the server knows that the binding usage is in use. This fact is only needed for purposes of determining the authentication and message integrity mechanism to apply.

12.1.4. New Requests or Indications

This usage does not define any new message types.

12.1.5. New Attributes

This usage does not define any new message attributes.

12.1.6. New Error Response Codes

This usage does not define any new error response codes.

12.1.7. Client Procedures

The binding discovery is utilized by a client just prior to generating an application PDU that requires the client to include its transport address. The client MAY first obtain a short term credential using the short term password STUN usage. The credential that is obtained is then using in Binding Request messages. A Binding Request message is generated for each distinct transport address that the client requires to formulate the application PDU.

A successful response message will carry either an XOR-MAPPED-ADDRESS or MAPPED-ADDRESS attribute, depending on the version of the server. A client SHOULD use the XOR-MAPPED-ADDRESS if present. If not, it uses the MAPPED-ADDRESS.

12.1.8. Server Procedures

It is RECOMMENDED that servers utilize short term credentials, obtained by the client from a Shared Secret request, for authentication and message integrity. Consequently, if a Binding Request is generated without a short term credential, the server SHOULD challenge for one.

12.1.9. Security Considerations for Binding Discovery

There are no security considerations for this usage beyond those described in Section 13.

12.2. NAT Keepalives

12.2.1. Applicability

In this STUN usage, a client is connected to a server for a particular application protocol (for example, a SIP proxy server). The connection is long-lived, allowing for asynchronous messaging from the server to the client. The client is connected to the server either using TCP, in which case there is a long-lived TCP connection from the client to the server, or using UDP, in which case the server stores the source transport address of a message from a client (such as SIP REGISTER), and sends messages to the client using that transport address.

Since the connection between the client and server is very-long lived, the bindings established by that connection need to be maintained in any intervening NATs. Rather than implement expensive application-layer keepalives, the keepalives can be accomplished using STUN Binding Requests. The client will periodically send a Binding Request to the server, using the same transport addresses used for the application protocol. These Binding Requests are demultiplexed at the server using the magic cookie and possibly FINGERPRINT. The response from the server informs the client that the server is still alive. The STUN message also keeps the binding active in intervening NATs. The client can also examine the mapped address in the Binding Response. If it has changed, the client can re-initiate application layer procedures to inform the server of its new transport address.

12.2.2. Client Discovery of Server

In this usage, the STUN server and the application protocol are using the same fixed port.

12.2.3. Server Determination of Usage

The server multiplexes both STUN and its application protocol on the same port. The server knows it is has this usage because the URI that gets resolved to this port indicates the server supports this multiplexing.

12.2.4. New Requests or Indications

This usage does not define any new message types.

12.2.5. New Attributes

This usage does not define any new message attributes.

12.2.6. New Error Response Codes

This usage does not define any new error response codes.

12.2.7. Client Procedures

If the STUN Response indicates the client's mapped address has changed from the client's expected mapped address, the client SHOULD inform other applications of its new mapped address. For example, a SIP client could use the binding discovery usage to obtain a new mapped address, and then register it using SIP registration procedures.

The client SHOULD NOT include a MESSAGE-INTEGRITY attribute unless prompted for one by the server, since authentication is not generally used with this STUN usage.

12.2.8. Server Procedures

The server SHOULD NOT authenticate the client or look for a MESSAGE-INTEGRITY attribute. Since the keepalives come with some regularity, and will come for each client that is connected to the server, the processing cost associated with authenticating each request is very high. Consequently, authentication should only be used by small servers, for whom the processing cost is not an issue, or when used with application protocols where the consequences of a fake response are very significant.

12.2.9. Security Considerations for NAT Keepalives

This STUN usage does not recommend the usage of message integrity or authentication. This is because the client never actually uses the mapped address from the STUN response. It merely treats a change in that address as a hint that the client should re-apply application layer procedures for connection establishment and registration.

An attacker could attempt to inject faked responses, or modify responses in transit. Such an attack would require the attacker to be on-path in order to determine the transaction ID. In the worst case, the attack would cause the client to see a change in IP address or port, and then perform an application layer re-registration. Such a re-registration would not use the transport address obtained from the Binding Response. Thus, the worst that the attacker can do is cause the client to re-register every half minute or so, when it otherwise wouldn't need to. Given the difficulty in launching this attack (it requires the attacker to be on-path and to disrupt the actual response from the server) compared to the benefit, there is little motivation for authentication or integrity mechanisms.

When used with application protocols where the cost of "re-registration" is in fact high, the keepalive usage can still be used without authentication. However, the usage would serve ONLY to keep NAT bindings alive; it would not be useful for detecting failures of the server or of intervening NAT. In such a case, the client would not perform any application layer processing based on the STUN response, even if it indicated a change in transport address.

12.3. Short-Term Password

In order to ensure interoperability, this usage describes a TLS-based mechanism to obtain a short-term credential. The usage makes use of the Shared Secret Request and Response messages. It is defined as a separate usage in order to allow it to run on a separate port, and to allow it to be more easily separated from the different STUN usages, only some of which require this mechanism.

12.3.1. Applicability

To thwart some on-path attacks described in Section 13, it is necessary for the STUN client and STUN server to integrity protect the information they exchange over UDP. In the absence of a long-term secret (password) that is shared between them, a short-term password can be obtained using the usage described in this section.

The username and password returned in the STUN Shared Secret Response are valid for use in subsequent STUN transactions for nine (9) minutes with any applicable hosts as described in Section 12.3.2. The username and password obtained with this usage are used as the USERNAME and in the HMAC for the MESSAGE-INTEGRITY in a subsequent STUN message, respectively.

12.3.2. Client Discovery of Server

The client follows the procedures in Section 8.1. The SRV protocol is "tls" and the service name "stun-pass".

For example a client would look up "_stun-pass._tls.example.com" in DNS.

12.3.3. Server Determination of Usage

The server advertises this port in the DNS as capable of receiving TLS over TCP connections, along with the Shared Secret messages that run over it. The server MAY also advertise this same port in DNS for other TLS over TCP usages if the server is capable of multiplexing those different usages. For example, the server could advertise the short-term password and binding discovery usages on the same TLS/TCP

port.

12.3.4. New Requests or Indications

The message type Shared Secret Request and its associated Shared Secret Response and Shared Secret Error Response are defined in this section. Their values are enumerated in Section 15.

The following figure indicates which attributes are present in the Shared Secret Request, Response, and Error Response. An M indicates that inclusion of the attribute in the message is mandatory, O means its optional, C means it's conditional based on some other aspect of the message, and - means that the attribute is not applicable to that message type. Attributes not listed are not applicable to Shared Secret Request, Response, or Error Response.

Attribute	Shared Secret Request	Shared Secret Response	Shared Secret Error Response
USERNAME	O	M	-
PASSWORD	-	M	-
MESSAGE-INTEGRITY	O	O	O
ERROR-CODE	-	-	M
ALTERNATE-SERVER	-	-	C
UNKNOWN-ATTRIBUTES	-	-	C
SERVER	-	O	O
REALM	C	-	C
NONCE	C	-	C

The Shared Secret requests, like other STUN requests, can be authenticated. However, since its purpose is to obtain a short-term credential, the Shared Secret request itself cannot be authenticated with a short-term credential. However, it can be authenticated with a long-term credential.

12.3.5. New Attributes

No new attributes are defined by this usage.

12.3.6. New Error Response Codes

This usage defines the 433 error response. Only the MESSAGE-INTEGRITY, ERROR-CODE and SERVER attributes are applicable to this response.

12.3.7. Client Procedures

Shared Secret requests are formed like other STUN requests, with the following additions. Clients MUST NOT use a short-term credential with a Shared Secret request. They SHOULD send the request with no credentials (omitting MESSAGE-INTEGRITY and USERNAME).

Processing of the Shared Secret response follows that of any other STUN response. Note that clients MUST be prepared to be challenged for a long-term credential.

If the response was a Shared Secret Response, it will contain a short lived username and password, encoded in the USERNAME and PASSWORD attributes, respectively. A client SHOULD use these credentials whenever short term credentials are needed for any server discovered using the same domain name as was used to discover the one which returned those credentials. For example, if a client used a domain name of example.com, it would have looked up _stun-pass._tls.example.com in DNS, found a server, and sent a Shared Secret request that provided a credential to the client. The client would use this credential with a server discovered by looking up _stun._udp.example.com in the DNS.

If the response was a Shared Secret Error Response, and ERROR-CODE attribute was present with a response code of 433, and the client had not sent the request over TLS, the client SHOULD establish a TLS connection to the server and retry the request over that connection. If the client had used TLS, this error response is unrecoverable and the client SHOULD NOT retry.

12.3.8. Server Procedures

The procedures for general processing of STUN requests apply to Shared Secret requests. Servers MAY challenge the client for a long-term credential if one was not provided in a request. However, they MUST NOT challenge the request for a short-term credential.

If the Shared Secret Request did not arrive over a TLS connection, the server MUST generate a Shared Secret Error response with an ERROR-CODE attribute that has a response code of 433.

If the request is valid and authenticated (assuming the server is performing authentication), the server MUST create a short term credential for the user. This credential consists of a username and password. The credentials MUST be valid for a duration of at least nine minutes, and SHOULD NOT be valid for a duration of longer than thirty minutes. The username MUST be distinct, with extremely high probabilities, from all usernames that have been handed out across

all servers that are returned from DNS SRV queries for the same domain name. Extremely high probability means that the likelihood of collision SHOULD be better than 1 in 2**64. The password for each username MUST be cryptographically random with at least 128 bits of entropy.

12.3.9. Security Considerations for Short-Term Password

The security considerations in Section 13 do not apply to the Shared Secret request and response, since these messages do not make use of mapped addresses, which is the primary source of security consideration discussed there. Rather, shared secret requests are used to obtain short term credentials that are used in the authentication of other messages.

Because the Shared Secret response itself carries a credential, in the form of a username and password, it must be sent encrypted. For this reason, STUN servers MUST reject any Shared Secret request that has not arrived over a TLS connection.

Malicious clients could generate a multiplicity of Shared Secret requests, each of which causes the server to allocate shared secrets, each of which might consume memory and processing resources. If shared secret requests are not being authenticated, this leads to a possible denial-of-service attack. Indeed, even if the requestor is authenticated, attacks are still possible.

To prevent being swamped with traffic, a STUN server SHOULD limit the number of simultaneous TLS connections it will hold open by dropping an existing connection when a new connection request arrives (based on an Least Recently Used (LRU) policy, for example).

Similarly, servers SHOULD allocate only a small number of shared secrets to a host with a particular source transport address. Requests from the same transport address which exceed this limit SHOULD be rejected with a 600 response. Servers SHOULD also limit the total number of shared secrets they will provide at a time across all clients, based on the number of users and expected loads during normal peak usage. If a Shared Secret request arrives and the server has exceeded its limit, it SHOULD reject the request with a 500 response.

Furthermore, for servers that are not authenticating shared secret requests, it is RECOMMENDED that short-term credentials be constructed in a way such that they do not require memory or disk to store.

This can be done by intelligently computing the username and

password. One approach is to construct the USERNAME as:

USERNAME = <prefix,rounded-time,hmac>

Where prefix is some random text string (different for each shared secret request), rounded-time is the current time modulo 20 minutes, and hmac is an HMAC [13] over the prefix and rounded-time, using a server private key.

The password is then computed as:

password = <hmac(USERNAME,anotherprivatekey)>

With this structure the server can verify that the username was not tampered with using the hmac present in the username.

13. Security Considerations

Attacks on STUN systems vary depending on the usage. The short term password usage is quite different from the other usages defined here, and its security considerations are unique to it and discussed as part of the usage definition. However, all of the other usages are very similar and share a similar set of security considerations as a consequence of their usage of the mapped address from STUN Binding Responses. Consequently, these security considerations apply to usage of the mapped address.

13.1. Attacks on STUN

Generally speaking, attacks on STUN can be classified into denial of service attacks and eavesdropping attacks. Denial of service attacks can be launched against a STUN server itself or against other elements using the STUN protocol. The attacks of greater interest are those in which the STUN server and client are used to launch denial of service (DoS) attacks against other entities, including the client itself. Many of the attacks require the attacker to generate a response to a legitimate STUN request, in order to provide the client with a faked mapped address. The attacks that can be launched using such a technique include:

13.1.1. Attack I: DDoS Against a Target

In this case, the attacker provides a large number of clients with the same faked mapped address that points to the intended target. This will trick all the STUN clients into thinking that their addresses are equal to that of the target. The clients then hand out that address in order to receive traffic on it (for example, in SIP

or H.323 messages). However, all of that traffic becomes focused at the intended target. The attack can provide substantial amplification, especially when used with clients that are using STUN to enable multimedia applications.

13.1.2. Attack II: Silencing a Client

In this attack, the attacker seeks to deny a client access to services enabled by STUN (for example, a client using STUN to enable SIP-based multimedia traffic). To do that, the attacker provides that client with a faked mapped address. The mapped address it provides is a transport address that routes to nowhere. As a result, the client won't receive any of the packets it expects to receive when it hands out the mapped address. This exploitation is not very interesting for the attacker. It impacts a single client, which is frequently not the desired target. Moreover, any attacker that can mount the attack could also deny service to the client by other means, such as preventing the client from receiving any response from the STUN server, or even a DHCP server.

13.1.3. Attack III: Assuming the Identity of a Client

This attack is similar to attack II. However, the faked mapped address points to the attacker themself. This allows the attacker to receive traffic which was destined for the client.

13.1.4. Attack IV: Eavesdropping

In this attack, the attacker forces the client to use a mapped address that routes to itself. It then forwards any packets it receives to the client. This attack would allow the attacker to observe all packets sent to the client. However, in order to launch the attack, the attacker must have already been able to observe packets from the client to the STUN server. In most cases (such as when the attack is launched from an access network), this means that the attacker could already observe packets sent to the client. This attack is, as a result, only useful for observing traffic by attackers on the path from the client to the STUN server, but not generally on the path of packets being routed towards the client.

13.2. Launching the Attacks

It is important to note that attacks of this nature (injecting responses with fake mapped addresses) require that the attacker be capable of eavesdropping requests sent from the client to the server (or to act as a man in the middle for such attacks). This is because STUN requests contain a transaction identifier, selected by the client, which is random with 96 bits of entropy. The server echoes

this value in the response, and the client ignores any responses that don't have a matching transaction ID. Therefore, in order for an attacker to provide a faked response that is accepted by the client, the attacker needs to know the transaction ID of the request. The large amount of randomness, combined with the need to know when the client sends a request and the transport addresses used for that request, precludes attacks that involve guessing the transaction ID.

Since all of the above attacks rely on this one primitive - injecting a response with a faked mapped address - preventing the attacks is accomplished by preventing this one operation. To prevent it, we need to consider the various ways in which it can be accomplished. There are several:

13.2.1. Approach I: Compromise a Legitimate STUN Server

In this attack, the attacker compromises a legitimate STUN server through a virus or Trojan horse. Presumably, this would allow the attacker to take over the STUN server, and control the types of responses it generates. Compromise of a STUN server can also lead to discovery of open ports. Knowledge of an open port creates an opportunity for DoS attacks on those ports (or DDoS attacks if the traversed NAT is a full cone NAT). Discovering open ports is already fairly trivial using port probing, so this does not represent a major threat.

13.2.2. Approach II: DNS Attacks

STUN servers are discovered using DNS SRV records. If an attacker can compromise the DNS, it can inject fake records which map a domain name to the IP address of a STUN server run by the attacker. This will allow it to inject fake responses to launch any of the attacks above. Clearly, this attack is only applicable for usages which discover servers through DNS.

13.2.3. Approach III: Rogue Router or NAT

Rather than compromise the STUN server, an attacker can cause a STUN server to generate responses with the wrong mapped address by compromising a router or NAT on the path from the client to the STUN server. When the STUN request passes through the rogue router or NAT, it rewrites the source transport address of the packet to be that of the desired mapped address. This address cannot be arbitrary. If the attacker is on the public Internet (that is, there are no NATs between it and the STUN server), and the attacker doesn't modify the STUN request, the address has to have the property that packets sent from the STUN server to that address would route through the compromised router. This is because the STUN server will send

the responses back to the source transport address of the request. With a modified source transport address, the only way they can reach the client is if the compromised router directs them there.

If the attacker is on a private network (that is, there are NATs between it and the STUN server), the attacker will not be able to force the server to generate arbitrary mapped addresses in responses. They will only be able force the STUN server to generate mapped addresses which route to the private network. This is because the NAT between the attacker and the STUN server will rewrite the source transport address of the STUN request, mapping it to a public address that routes to the private network. Because of this, the attacker can only force the server to generate faked mapped addresses that route to the private network. Unfortunately, it is possible that a low quality NAT would be willing to map an allocated public address to another public address (as opposed to an internal private address), in which case the attacker could forge the source address in a STUN request to be an arbitrary public address. This kind of behavior from NATs does appear to be rare.

13.2.4. Approach IV: Man in the Middle

As an alternative to approach III (Section 13.2.3), if the attacker can place an element on the path from the client to the server, the element can act as a man-in-the-middle. In that case, it can intercept a STUN request, and generate a STUN response directly with any desired value of the mapped address field. Alternatively, it can forward the STUN request to the server (after potential modification), receive the response, and forward it to the client. When forwarding the request and response, this attack is subject to the same limitations on the mapped address described in Approach III (Section 13.2.3).

13.2.5. Approach V: Response Injection Plus DoS

In this approach, the attacker does not need to be a MitM (as in approaches III and IV). Rather, it only needs to be able to eavesdrop onto a network segment that carries STUN requests. This is easily done in multiple access networks such as ethernet or unprotected 802.11. To inject the fake response, the attacker listens on the network for a STUN request. When it sees one, it simultaneously launches a DoS attack on the STUN server, and generates its own STUN response with the desired mapped address value. The STUN response generated by the attacker will reach the client, and the DoS attack against the server is aimed at preventing the legitimate response from the server from reaching the client. Arguably, the attacker can do without the DoS attack on the server, so long as the faked response beats the real response back to the

client, and the client uses the first response, and ignores the second (even though it's different).

13.2.6. Approach VI: Duplication

This approach is similar to approach V (Section 13.2.5). The attacker listens on the network for a STUN request. When it sees one, it generates its own STUN request towards the server. This STUN request is identical to the one it saw, but with a spoofed source IP address. The spoofed address is equal to the one that the attacker desires to have placed in the mapped address of the STUN response. In fact, the attacker generates a flood of such packets. The STUN server will receive the one original request, plus a flood of duplicate fake ones. It generates responses to all of them. If the flood is sufficiently large for the responses to congest routers or some other equipment, there is a reasonable probability that the one real response is lost (along with many of the faked ones), but the net result is that only the faked responses are received by the STUN client. These responses are all identical and all contain the mapped address that the attacker wanted the client to use.

The flood of duplicate packets is not needed (that is, only one faked request is sent), so long as the faked response beats the real response back to the client, and the client uses the first response, and ignores the second (even though it's different).

Note that, in this approach, launching a DoS attack against the STUN server or the IP network, to prevent the valid response from being sent or received, is problematic. The attacker needs the STUN server to be available to handle its own request. Due to the periodic retransmissions of the request from the client, this leaves a very tiny window of opportunity. The attacker must start the DoS attack immediately after the actual request from the client, causing the correct response to be discarded, and then cease the DoS attack in order to send its own request, all before the next retransmission from the client. Due to the close spacing of the retransmits (100ms to a few seconds), this is very difficult to do.

Besides DoS attacks, there may be other ways to prevent the actual request from the client from reaching the server. Layer 2 manipulations, for example, might be able to accomplish it.

Fortunately, this approach is subject to the same limitations documented in Approach III (Section 13.2.3), which limit the range of mapped addresses the attacker can cause the STUN server to generate.

13.3. Countermeasures

STUN provides mechanisms to counter the approaches described above, and additional, non-STUN techniques can be used as well.

First off, it is RECOMMENDED that networks with STUN clients implement ingress source filtering [6]. This is particularly important for the NATs themselves. As Section 13.2.3 explains, NATs which do not perform this check can be used as "reflectors" in DDoS attacks. Most NATs do perform this check as a default mode of operation. We strongly advise people who purchase NATs to ensure that this capability is present and enabled.

Secondly, for usages where the STUN server is not co-located with some kind of application (such as the binding discovery usage), it is RECOMMENDED that STUN servers be run on hosts dedicated to STUN, with all UDP and TCP ports disabled except for the STUN ports. This is to prevent viruses and Trojan horses from infecting STUN servers, in order to prevent their compromise. This helps mitigate Approach I (Section 13.2.1).

Thirdly, to prevent the DNS attack of Section 13.2.2, Section 8.2 recommends that the client verify the credentials provided by the server with the name used in the DNS lookup.

Finally, all of the attacks above rely on the client taking the mapped address it learned from STUN, and using it in application layer protocols. If encryption and message integrity are provided within those protocols, the eavesdropping and identity assumption attacks can be prevented. As such, applications that make use of STUN addresses in application protocols SHOULD use integrity and encryption, even if a SHOULD level strength is not specified for that protocol. For example, multimedia applications using STUN addresses to receive RTP traffic would use secure RTP [23].

The above three techniques are non-STUN mechanisms. STUN itself provides several countermeasures.

Approaches IV (Section 13.2.4), when generating the response locally, and V (Section 13.2.5) require an attacker to generate a faked response. A faked response must match the 96-bit transaction ID of the request. The attack is further prevented by using the message integrity mechanism provided in STUN, described in Section 11.4.

Approaches III (Section 13.2.3), IV (Section 13.2.4), when using the relaying technique, and VI (Section 13.2.6), however, are not preventable through server signatures. These three approaches are functional when the attacker modifies nothing but the source address

of the STUN request. Sadly, this is the one thing that cannot be protected through cryptographic means, as this is the change that STUN itself is seeking to detect and report. It is therefore an inherent weakness in NAT, and not fixable in STUN.

13.4. Residual Threats

None of the countermeasures listed above can prevent the attacks described in Section 13.2.3 if the attacker is in the appropriate network paths. Specifically, consider the case in which the attacker wishes to convince client C that it has address V. The attacker needs to have a network element on the path between A and the server (in order to modify the request) and on the path between the server and V so that it can forward the response to C. Furthermore, if there is a NAT between the attacker and the server, V must also be behind the same NAT. In such a situation, the attacker can either gain access to all the application-layer traffic or mount the DDOS attack described in Section 13.1.1. Note that any host which exists in the correct topological relationship can be DDOSed. It need not be using STUN.

14. IAB Considerations

The IAB has studied the problem of "Unilateral Self Address Fixing" (UNSAF), which is the general process by which a client attempts to determine its address in another realm on the other side of a NAT through a collaborative protocol reflection mechanism (RFC3424 [24]). STUN is an example of a protocol that performs this type of function for the binding discovery usage. The IAB has mandated that any protocols developed for this purpose document a specific set of considerations. This section meets those requirements for the binding discovery usage.

14.1. Problem Definition

From RFC3424 [24], any UNSAF proposal must provide:

> Precise definition of a specific, limited-scope problem that is to be solved with the UNSAF proposal. A short term fix should not be generalized to solve other problems; this is why "short term fixes usually aren't".

The specific problem being solved by STUN is to provide the functionality necessary to describe how to connect two endpoints regardless of the location of type of NATs in the topology.

14.2. Exit Strategy

From RFC3424 [24], any UNSAF proposal must provide:

> Description of an exit strategy/transition plan. The better short term fixes are the ones that will naturally see less and less use as the appropriate technology is deployed.

STUN by itself does not provide an exit strategy. This is provided by techniques, such as Interactive Connectivity Establishment (ICE [13]), that allow a client to determine whether addresses learned from STUN are needed, or whether other addresses, such as the one on the local interface, will work when communicating with another host. With such a detection technique, as a client finds that the addresses provided by STUN are never used, STUN queries can cease to be made, thus allowing them to phase out.

14.3. Brittleness Introduced by STUN

From RFC3424 [24], any UNSAF proposal must provide:

> Discussion of specific issues that may render systems more "brittle". For example, approaches that involve using data at multiple network layers create more dependencies, increase debugging challenges, and make it harder to transition.

STUN introduces brittleness into the system in several ways:

- Transport addresses discovered by STUN in the Binding Discovery usage will only be useful for receiving packets from a peer if the NAT does not have address or address and port dependent mapping properties. When this usage is used in isolation, this makes STUN brittle, since its effectiveness depends on the type of NAT. This brittleness is eliminated when the Binding Discovery usage is used in concert with mechanisms which can verify the transport address and use others if it doesn't work. ICE is an example of such a mechanism.

- Transport addresses discovered by STUN in the Binding Discovery usage will only be useful for receiving packets from a peer if the STUN server subtends the address realm of the peer. For example, consider client A and B, both of which have residential NAT devices. Both devices connect them to their cable operators, but both clients have different providers. Each provider has a NAT in front of their entire network, connecting it to the public Internet. If the STUN server used by A is in A's cable operator's network, an address obtained by it will not be usable by B. The STUN server must be in the network which is a common ancestor to

both - in this case, the public Internet. When this usage is used in isolation, this makes STUN brittle, since its effectiveness depends on the topological placement of the STUN server. This brittleness is eliminated when the Binding Discovery usage is used in concert with mechanisms which can verify the transport address and use others if it doesn't work. ICE is an example of such a mechanism.

- The bindings allocated from the NAT need to be continuously refreshed. Since the timeouts for these bindings is very implementation specific, the refresh interval cannot easily be determined. When the binding is not being actively used to receive traffic, but to wait for an incoming message, the binding refresh will needlessly consume network bandwidth.

- The use of the STUN server in the Binding Discovery usage as an additional network element introduces another point of potential security attack. These attacks are largely prevented by the security measures provided by STUN, but not entirely.

- The use of the STUN server as an additional network element introduces another point of failure. If the client cannot locate a STUN server, or if the server should be unavailable due to failure, the application cannot function.

- The use of STUN to discover address bindings may result in an increase in latency for applications.

- Transport addresses discovered by STUN in the Binding Discovery usage will only be useful for receiving packets from a peer behind the same NAT if the STUN server supports hairpinning [14]. When this usage is used in isolation, this makes STUN brittle, since its effectiveness depends on the topological placement of the STUN server. This brittleness is eliminated when the Binding Discovery usage is used in concert with mechanisms which can verify the transport address and use others if it doesn't work. ICE is an example of such a mechanism.

- Most significantly, STUN introduces potential security threats which cannot be eliminated through cryptographic means. These security problems are described fully in Section 13.

14.4. Requirements for a Long Term Solution

From RFC3424 [24], any UNSAF proposal must provide:

> Identify requirements for longer term, sound technical solutions -- contribute to the process of finding the right longer term

solution.

Our experience with STUN has led to the following requirements for a long term solution to the NAT problem:

- Requests for bindings and control of other resources in a NAT need to be explicit. Much of the brittleness in STUN derives from its guessing at the parameters of the NAT, rather than telling the NAT what parameters to use, or knowing what parameters the NAT will use.

- Control needs to be in-band. There are far too many scenarios in which the client will not know about the location of middleboxes ahead of time. Instead, control of such boxes needs to occur in-band, traveling along the same path as the data will itself travel. This guarantees that the right set of middleboxes are controlled.

- Control needs to be limited. Users will need to communicate through NATs which are outside of their administrative control. In order for providers to be willing to deploy NATs which can be controlled by users in different domains, the scope of such controls needs to be extremely limited - typically, allocating a binding to reach the address where the control packets are coming from.

- Simplicity is Paramount. The control protocol will need to be implemented in very simple clients. The servers will need to support extremely high loads. The protocol will need to be extremely robust, being the precursor to a host of application protocols. As such, simplicity is key.

14.5. Issues with Existing NAPT Boxes

From RFC3424 [24], any UNSAF proposal must provide:

> Discussion of the impact of the noted practical issues with existing, deployed NA[P]Ts and experience reports.

Originally, RFC 3489 was developed as a standalone solution for NAT traversal for several types of applications, including VoIP. However, practical experience found that the limitations of its usage in isolation made it impractical as a complete solution. There were too many NATs which didn't support hairpinning or which had address and port dependent mapping properties.

Consequently, STUN was revised to produce this specification, which turns STUN into a tool that is used as part of a broader solution.

For multimedia communications protocols, this broader solution is ICE. ICE uses the binding discovery usage and defines its own connectivity check usage, and then utilizes them together. When done this way, ICE eliminates almost all of the brittleness and issues found with RFC 3489 alone.

15. IANA Considerations

IANA is hereby requested to create two new registries - STUN methods and STUN Attributes. IANA must assign the following values to both registries before publication of this document as an RFC. New values for both STUN methods and STUN attributes are assigned through the IETF consensus process via RFCs approved by the IESG [25].

15.1. STUN Methods Registry

The initial STUN methods are:

0x001:Binding
0x002:Shared Secret

15.2. STUN Attribute Registry

STUN attributes values above 0x7FFF are considered optional attributes; attributes equal to 0x7FFF or below are considered mandatory attributes. The STUN client and STUN server process optional and mandatory attributes differently. IANA should assign values based on the RFC consensus process.

The initial STUN Attributes are:

0x0001: MAPPED-ADDRESS
0x0006: USERNAME
0x0007: PASSWORD
0x0008: MESSAGE-INTEGRITY
0x0009: ERROR-CODE
0x000A: UNKNOWN-ATTRIBUTES
0x0014: REALM
0x0015: NONCE
0x0020: XOR-MAPPED-ADDRESS
0x8023: FINGERPRINT
0x8022: SERVER
0x8023: ALTERNATE-SERVER
0x8024: REFRESH-INTERVAL

16. Changes Since RFC 3489

This specification updates RFC3489 [15]. This specification differs from RFC3489 in the following ways:

- Removed the usage of STUN for NAT type detection and binding lifetime discovery. These techniques have proven overly brittle due to wider variations in the types of NAT devices than described in this document. Removed the RESPONSE-ADDRESS, CHANGED-ADDRESS, CHANGE-REQUEST, SOURCE-ADDRESS, and REFLECTED-FROM attributes.

- Added a fixed 32-bit magic cookie and reduced length of transaction ID by 32 bits. The magic cookie begins at the same offset as the original transaction ID.

- Added the XOR-MAPPED-ADDRESS attribute, which is included in Binding Responses if the magic cookie is present in the request. Otherwise the RFC3489 behavior is retained (that is, Binding Response includes MAPPED-ADDRESS). See discussion in XOR-MAPPED-ADDRESS regarding this change.

- Introduced formal structure into the Message Type header field, with an explicit pair of bits for indication of request, response, error response or indication. Consequently, the message type field is split into the class (one of the previous four) and method.

- Explicitly point out that the most significant two bits of STUN are 0b00, allowing easy differentiation with RTP packets when used with ICE.

- Added support for IPv6. Made it clear that an IPv4 client could get a v6 mapped address, and vice-a-versa.

- Added long-term credential-based authentication.

- Added the SERVER, REALM, NONCE, and ALTERNATE-SERVER attributes.

- Removed recommendation to continue listening for STUN Responses for 10 seconds in an attempt to recognize an attack.

- Introduced the concept of STUN usages and defined three usages - Binding Discovery, NAT Keepalive, and Short term password.

- Changed transaction timers to be more TCP friendly.

- Removed the STUN example that centered around the separation of the control and media planes. Instead, provided more information

on using STUN with protocols.

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Authors' Addresses

Jonathan Rosenberg
Cisco Systems
600 Lanidex Plaza
Parsippany, NJ 07054
US

Phone: +1 973 952-5000
Email: jdrosen@cisco.com
URI: http://www.jdrosen.net

Christian Huitema
Microsoft
One Microsoft Way
Redmond, WA 98052
US

Email: huitema@microsoft.com

Rohan Mahy
Plantronics
345 Encinal Street
Santa Cruz, CA 95060
US

Email: rohan@ekabal.com

Dan Wing
Cisco Systems
771 Alder Drive
San Jose, CA 95035
US

Email: dwing@cisco.com

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