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Sheng Jiang
Huawei Technologies Co., Ltd
Sean Shen
CNNIC
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Secure DHCPv6 Using CGAs
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Abstract

The Dynamic Host Configuration Protocol for IPv6 (DHCPv6) enables DHCPv6 servers to pass configuration parameters. It offers configuration flexibility. If not secured, DHCPv6 is vulnerable to various attacks, particularly spoofing attacks. This document analyzes the security issues of DHCPv6 and specifies a Secure DHCPv6 mechanism based on using CGAs.

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1. Introduction

The Dynamic Host Configuration Protocol for IPv6 (DHCPv6 [RFC3315]) enables DHCPv6 servers to pass configuration parameters. It offers configuration flexibility. If not secured, DHCPv6 is vulnerable to various attacks, particularly spoofing attacks.

This document analyzes the security issues of DHCPv6 in details. This document provides mechanisms for improving the security of DHCPv6:

- the address of a DHCPv6 message sender, which can be a DHCPv6 server, a relay agent or a client, can be verified by a receiver.

- The integrity of DHCPv6 messages can be checked by the receiver of the message.

The security mechanisms specified in this document is based on Cryptographically Generated Addresses (CGA [RFC3972]).

Secure DHCPv6 is applicable in environments where physical security on the link is not assured (such as over wireless) and attacks on DHCPv6 are a concern.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Security Overview of DHCPv6

DHCPv6 is a client/server protocol that provides managed configuration of devices. It enables DHCPv6 server to automatically configure relevant network parameters on clients. In the basic DHCPv6 specification [RFC3315], security of DHCPv6 message can be improved in a few aspects.

a) In the basic DHCPv6 specifications, the DHCPv6 server uses a "regular" IPv6 address for itself. It is possible for a malicious attacker to use a fake address to spoof or launch an attack. See Section 23, "Security Considerations" of [RFC3315] for more details.

CGA-based security mechanism can provide proof of ownership of source addresses, which prevents such attacks.

b) The basic DHCPv6 specifications can optionally authenticate the origin of messages and validate the integrity of messages using an authentication option with a symmetric key pair. [RFC3315] relies on pre-established secret keys. For any kind of meaningful security, each DHCPv6 client would need to be configured with its own secret key; [RFC3315] provides no mechanism for doing this.

For the key of the hash function, there are two key management mechanisms. Firstly, the key management is out of band, usually manual, i.e. operators set up key database for both server and client before running DHCPv6. Usually multiple keys are deployed one a time and key id is used to specify which key is used.

Manual key distribution runs counter to the goal of minimizing the configuration data needed at each host. [RFC3315] provides an additional mechanism for preventing off-network timing attacks using the Reconfigure message: the Reconfigure Key authentication method. However, this method provides no message integrity or source integrity check. This key is transmitted in plaintext.

Comparing to this, the CGA-based security mechanism only require a key pair on the sender. The key management mechanism is very simple.

c) Communication between a server and a relay agent, and communication between relay agents, can be secured through the use of IPsec, as described in section 21.1 in [RFC3315]. However, IPsec is quite complicated. A simpler security mechanism, which can be easier to deploy, is desirable.

4. Secure DHCPv6 Overview

To solve the abovementioned security issues, we introduce the use of CGAs into DHCPv6. CGAs are introduced in [RFC3972]. By combining CGAs with signatures based on the CGA-associated key pair, address ownership can be verified and messages protected, "without a certification authority or any security infrastructure." [RFC3972]

This document introduces a Secure DHCPv6 mechanism that uses CGAs to secure the DHCPv6 protocol. It assumes: the secured DHCPv6 message sender already has a CGA and its corresponding CGA parameters; and the receiver has already been have the CGAs of the sender, which may be pre-configured or recorded from previous communications; in the server-relay and relay-server scenarios, the receiver has also been pre-configured the associated CGA parameters of the sender.

In this document, we introduce a CGA option with a mechanism for proving address ownership and two signature options with a corresponding verification mechanism. A DHCPv6 message (from a server, a relay agent or a client), with a CGA as source address and

carry a digital signature, can be verified by the receiver for both the CGA and signature, then process the payload of the DHCPv6 message only if the validation is successful.

This improves communication security of DHCPv6 messages. The authentication options can also be used for replay protection.

Because the sender can be a DHCPv6 server, a relay agent or a client, the end-to-end security protection can be from DHCPv6 servers to relay agents or clients, or from clients to DHCPv6 servers. Relay agents MAY add its own Secure DHCPv6 options in Relay-Forward messages when transmitting client messages to the server.

4.1. New Components

The components of the solution specified in this document are as follows:

- CGAs are used to make sure that the sender of a DHCPv6 message is the "owner" of the claimed address. A public-private key pair has been generated by a node itself before it can claim an address. A new DHCPv6 option, the CGA Parameter Option, is used to carry the public key and associated parameters.

- Signatures signed by private key protect the integrity of the DHCPv6 messages and authenticate the identity of their sender.

- Server Address type of DUID is used to carry server's source address in the server-relay-client scenarios. The receiver gets the server's source CGA address for CGA verification.

4.2. Support for algorithm agility

Hash functions are the fundamental security mechanism, including CGAs in this document. "...they have two security properties: to be one way and collision free." "The recent attacks have demonstrated that one of those security properties is not true." [RFC4270] It is theoretically possible to perform collision attacks against the "collision-free" property.

Following the approach recommended by [RFC4270] and [NewHash], recent analysis shows none of these attacks are currently possible, according to [RFC6273]. "The broken security property will not affect the overall security of many specific Internet protocols, the conservative security approach is to change hash algorithms." [RFC4270]

However, these attacks indicate the possibility of future real-world attacks. Therefore, we have to take into account that attacks will improved in the future, and provide a support for multiple hash

algorithms. Our mechanism, in this document, supports not only hash algorithm agility but also signature algorithm agility.

Support for hash agility within CGAs has been defined in [RFC4982]. The usage of CGAs in this document SHOULD also obey [RFC4982], too.

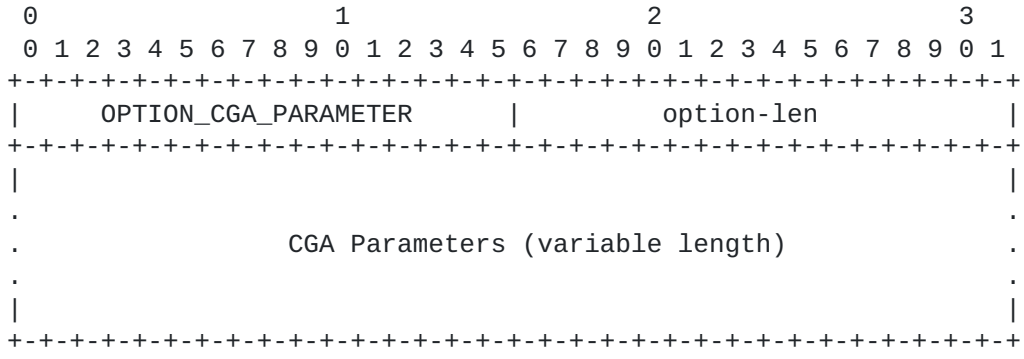
The support for algorithm agility in this document is mainly a unilateral notification model from a sender to a receiver. If the receiver cannot support the algorithm provided by the sender, it takes the risk itself. Senders in a same network do not have to upgrade to a new algorithm simultaneously.

5. Extensions for Secure DHCPv6

This section extends DHCPv6. Three new options and a new DUID type have been defined. The new options MUST be supported in the Secure DHCPv6 message exchange. The new DUID type MUST be supported in relay scenarios.

5.1. CGA Parameter Option

The CGA option allows the verification of the sender's CGAs. The format of the CGA option is described as follows:



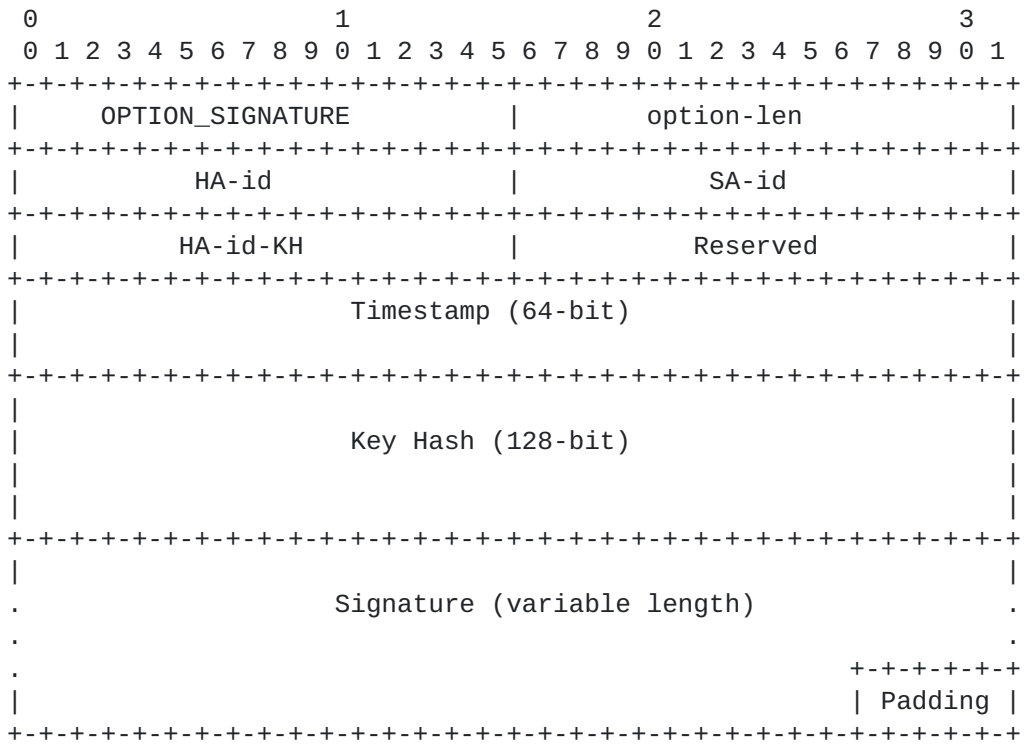
option-code OPTION_CGA_PARAMETER (TBA1).

option-len Length of CGA Parameters in octets.

CGA Parameters A variable-length field containing the CGA Parameters data structure described in Section 4 of [RFC3972]. This specification requires that the public key found from the CGA Parameters field in the CGA option MUST be that referred by the Key Hash field in the Signature option. Packets received with two different keys MUST be silently discarded.

5.2. Signature Option

The Signature option allows public key-based signatures to be attached to a DHCPv6 message. The Signature option could be any place within the DHCPv6 message. It protects the entire DHCPv6 header and options, particularly including the CGA option, except for the Signature option and the Authentication Option. The format of the Signature option is described as follows:



option-code OPTION_SIGNATURE (TBA2).

option-len 32 + Length of Signature field and Padding field in octets.

HA-id Hash Algorithm id. The hash algorithm is used for computing the signature result. This design is adopted in order to provide hash algorithm agility. The value is from the Hash Algorithm for Secure DHCPv6 registry in IANA. The initial values are assigned for SHA-1 is 0x0001.

SA-id Signature Algorithm id. The signature algorithm is used for computing the signature result. This design is adopted in order to provide signature algorithm agility. The value is from the Signature Algorithm for Secure DHCPv6 registry

in IANA. The initial values are assigned for RSASSA-PKCS1-v1_5 is 0x0001.

HA-id-KH — Hash Algorithm id for Key Hash. Hash algorithm used for producing the Key Hash field in the Signature option. This design is adopted in order to provide hash algorithm agility. The value is from the Hash Algorithm for Secure DHCPv6 registry in IANA. The initial values are assigned for SHA-1 is 0x0001.

Reserved — A 16-bit field reserved for future use. The value MUST be initialized to zero by the sender, and MUST be ignored by the receiver.

Timestamp — The current time of day (NTP-format timestamp [RFC5905], a 64-bit unsigned fixed-point number, in seconds relative to 0h on 1 January 1900.). It can reduce the danger of replay attacks.

Key Hash — A 128-bit field containing the most significant (leftmost) 128 bits of the hash value of the public key used for constructing the signature. The hash algorithm is indicated in the HA-id-KH field. The field is taken over the presentation used in the Public Key field of the CGA Parameters data structure carried in the CGA option. Its purpose is to associate the signature to a particular key known by the receiver. Such a key can either be stored in the certificate cache of the receiver or be received in the CGA option in the same message.

Signature — A variable-length field containing a digital signature. The signature value is computed with the hash algorithm and the signature algorithm, as described in HA-id and SA-id. The signature constructed by using the sender's private key protects the following sequence of octets:

1. The 128-bit CGA Message Type tag value for Secure DHCPv6, 0x81be a1eb 0021 ce7e caa9 4090 0665 d2e0 02c2.

2. The 128-bit Source IPv6 Address.

3. The 128-bit Destination IPv6 Address.

4. The DHCPv6 message header.

5. All DHCPv6 options except for the Signature option and the Authentication Option.

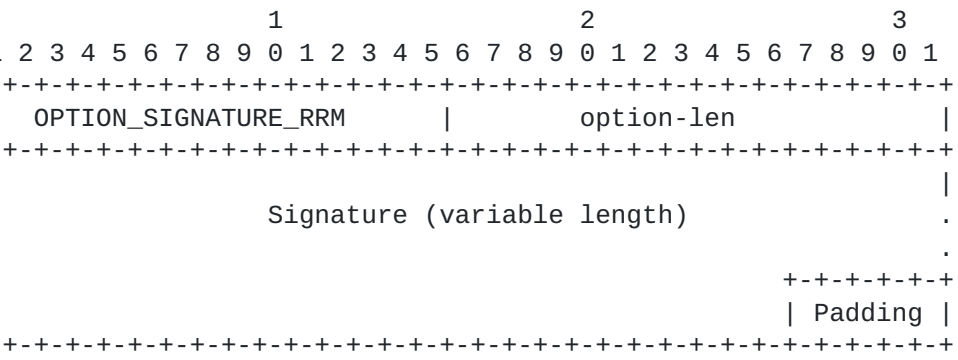
6. The content between the option-len field and the signature field in this Signature option, in the format described above.

Padding This variable-length field contains padding, as many bits long as remain after the end of the signature. This padding is only needed if the length of signature is not a multiple of 8 bits.

Note: a Relay-Reply message is constructed by a DHCPv6 server in segments. The server first constructs the server message for client, which includes a Signature Option that covers the server message. In the signed data, the destination address is the address of the client. It then constructs the Relay-Reply message by encapsulating the server message into a Relay Message Option. If there is additional option for relay, the server MUST include a Signature Option for Relay-Reply Message, defined below, which covers the entire Relay-Reply message. In the signed data, the destination address is the address of the target relay agent.

5.3. Signature Option for Relay-Reply Message

In the server-relay-client scenario, the Relay-Reply message may be carried two signatures: one covers the server message for client, one covers the entire relay-reply message. In order to save the double transmission of 32 byte duplicated data, which include HA-id, SA-id, SA-id-HK, Timestamp and Key Hash, another signature option is designed for Relay-Reply message only. On the receiver - the relay agent, these data can be obtained from the Signature Option within the Relay Message option. The format of the Signature Option for Relay-Reply message is described as follows:



option-code OPTION_SIGNATURE_RRM (TBA3).

option-len Length of Signature field and Padding field in octets.

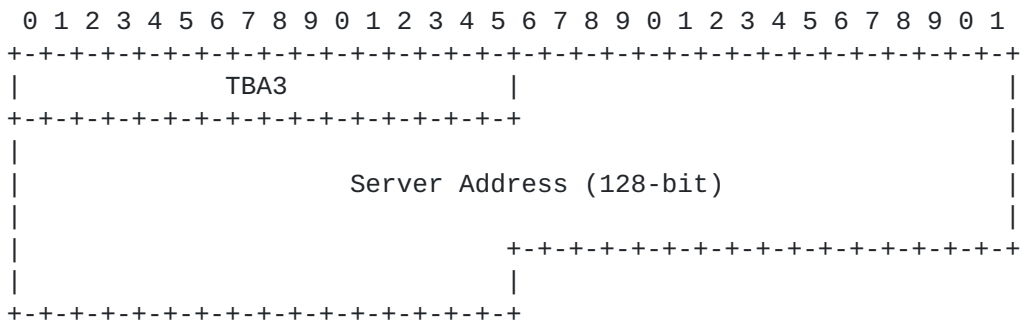
Signature The same with Section 5.3.

Padding The same with Section 5.3.

5.4. DUID-SA Type

Server Address Type DUID (DUID-SA) allows IPv6 address of DHCPv6 servers can be carried in DHCPv6 message payload.

The following diagram illustrates the format of a DUID-SA:



Type-code DUID-SA Type (TBA4)

Server Address The 128-bit IPv6 address of the DHCPv6 server.

The Server Address field of DUID-SA, which is the IPv6 address of the DHCPv6 server, MUST be a CGA in the Secure DHCPv6.

In the server-relay-client scenarios, a DHCPv6 server knows a client is behind relay(s) if it receives a Relay-forward DHCPv6 message. Then it will reply a Relay-reply message. Within the payload of Replay-reply message, the server's source CGA address is carried in the Server Address Type DUID that is encapsulated in a Relay Message option. In this way, the receiver, a DHCPv6 client can get the server's source CGA address for CGA verification.

All the payloads, including DUID-SA, are protected by signature option by the definition of section 5.1 and 5.2.

If there is DUID-SA in the server message and its address is different from the source address of IP packet, the client MUST use the address in DUID-SA for CGA verification.

6. Processing Rules and Behaviors

6.1. Processing Rules of Sender

The sender of a Secure DHCPv6 message could be a DHCPv6 server, a DHCPv6 relay agent or a DHCPv6 client.

The node MUST have the following information in order to create Secure DHCPv6 messages:

CGA parameters Any information required to construct CGAs, as described in [RFC3972].

Keypair A public-private key pair. The public key used for constructing the signature MUST be the same in CGA parameters.

CGA flag A flag that indicates whether CGA is used or not.

To support Secure DHCPv6, the Secure DHCPv6 enabled sender MUST construct the DHCPv6 message following the rules defined in [RFC3315]. The sender MUST use a CGA, which be constructed as specified in Section 4 of [RFC3972], as the source address, unless they are sent with the unspecified source address.

A Secure DHCPv6 message MUST contain both the CGA option and the Signature option, except for the Relay-forward and Relay-reply Messages. If a relay agent adds its own options in Relay-forward message, it MUST contain the Signature option. If it does not any add new options it MUST NOT add either the CGA option or the Signature option into Relay-forward message. If a server adds addition options for relay agents in Relay-reply message, it MUST contain the Signature Option for Relay-Reply Message. If it does not add any addition options, it MUST NOT add the CGA option, the Signature option, or the Signature Option for Relay-Reply Message into the Relay-reply message.

The CGA option is constructed according to the rules presented in Section 5.1 and in [RFC3972]. The public key in the field is the one associated with the CGA, which is also the source address in the message header.

The Signature option MUST be constructed as explained in Section 5.2. It protects the message header and the message payload and all DHCPv6 options (including the CGA option) except for the Signature option itself and the Authentication Option. The Signature Option for Relay-Reply Message MUST be constructed as explained in Section 5.3.

When constructing a Relay-reply message, a DHCPv6 server MUST include an OPTION_SERVERID [RFC3315] and put its CGA in the Server Address field of the DUID in the OPTION_SERVERID in the Relay Message Option. By applying this rule, the CGA of the DHCPv6 server will not be lost when the relay agents decapsulate the Relay-reply messages, so that the client can verify CGA address and signature.

6.2. Processing Rules of Receiver

When receiving a DHCPv6 message (except for Relay-Forward and Relay-Reply messages), a Secure DHCPv6 enabled receiver SHOULD discard the DHCPv6 message if either the CGA option or the Signature option is absent. If both options are absent, the receiver MAY fall back the unsecure DHCPv6 model.

The receiving node MUST verify the source CGA address of the DHCPv6 message by using the public key of the DHCPv6 message sender, CGA Parameters and the algorithm described in Section 5 of [RFC3972]. The inputs to the algorithm are the source address, as used in IPv6 header, and the CGA Parameters field. In the relay scenarios, a DHCPv6 server obtains the CGA of a client from the peer address field in the Relay-forward message. A DHCPv6 client obtains the CGA of a server from the Server Address field of the DUID in the OPTION_SERVERID.

If the CGA verification is successful, the recipient proceeds with a more time-consuming cryptographic check of the signature. Note that even if the CGA verification succeeds, no claims about the validity of the use can be made until the signature has been checked.

The receiving node MUST verify the Signature option as follows: the Key Hash field MUST indicate the use of a known public key, the one learned from a preceding CGA option in the same message. The signature field verification MUST show that the signature has been calculated as specified in Section 5.2.

Only the messages that get through both CGA and signature verifications are accepted as secured DHCPv6 messages and continue to be handled for their contained DHCPv6 options as defined in [RFC3315]. Messages that do not pass all the above tests MUST be discarded or treated as unsecure messages.

The receiver MAY record the verified CGA for future authentications.

Furthermore, the node that supports the verification of the Secure DHCPv6 messages MAY record the following information:

Minbits The minimum acceptable key length for public keys used in the generation of CGAs. An upper limit MAY also be set for the amount of

computation needed when verifying packets that use these security associations. The appropriate lengths SHOULD be set according to the signature algorithm and also following prudent cryptographic practice. For example, minimum length 1024 and upper limit 2048 may be used for RSA [RSA].

A Relay-forward message without any addition option to Relay Message option or a Relay-forward message with both addition options and the Signature option is accepted for a Secure DHCPv6 enabled server. Otherwise, the message SHOULD be discarded or treated as unsecure message. If Signature option is presented in the Relay-forward message, the CGA verification and signature verification are needed. The server obtains the CGA parameters of the relay agents from pre-configured data. The server MUST also verify the CGA and signature for the encapsulated client DHCPv6 message in the Relay Message Option. The client CGA address is obtained from the peer-address field in the Relay-forward message.

A Relay-reply message without any addition option to Relay Message option or a Relay-reply message with both addition options and the Signature Option for Relay-Reply message is accepted for a Secure DHCPv6 enabled server. Otherwise, the message SHOULD be discarded or treated as unsecure message. If the Signature Option for Relay-Reply message is presented in the Relay-reply message, the CGA verification and signature verification are needed. The relay agents obtain the CGA parameters of the server from pre-configured data. It obtains HA-id, SA-id, SA-id-HK, Timestamp and Key Hash from Signature option encapsulated in the Relay Message option.

6.3. Processing Rules of Relay Agent

To support Secure DHCPv6, relay agents MUST follow the same processing rules defined in [RFC3315].

In the client-relay-server scenario, the relay agent MAY verify the CGA and signature as a receiver before relaying the client message further, following verification procedure define in Section 6.2. In the case of failure, it MUST discard the DHCPv6 message. However, this does not save the load of the DHCPv6 server. The server still MUST verify the CGA and signature by itself in order to prevent the attack between the relay agent and server.

In the server-relay-client scenario, if the Signature Option for Relay-Reply message is presented, the relay agent MUST verify the CGA and signature before relaying the server message further, following verification procedure define in Section 6.2. In the case of failure, it MUST discard the DHCPv6 message.

In the relay scenarios, because relay agents restructure the DHCPv6 messages, a downstream receiver would not find the sender's source CGA address in the DHCPv6 message header.

In the client-relay-server scenarios, "The relay agent copies the source address from the IP datagram in which the message was received from the client into the peer-address field in the Relay-forward message" [RFC3315]. Therefore, the CGA of a client will not be lost during the relay processing from the client to the server. The receiver, a DHCPv6 server, can find the sender's source CGA address in the peer-address field for CGA verification.

During the relay processing from the server to the client, when the relay agent constructs the IPv6 header for the server message, the source IPv6 address is the relay's IPv6 address, rather than the server's IPv6 address. In order to make the CGA of the DHCPv6 server reach the client, DUID-SA, described in Section 5.4, MUST be used. Defined in [RFC6422], "the implicit requirement that relay agents not modify the content of encapsulation payloads as they are relayed back toward clients", A relay agent will not change the OPTION_SERVERID when processing Relay-reply message from a DHCPv6 server, so that the CGA of the DHCPv6 server will not be lost when the Relay-reply message is decapsulated in the relay agent. The relay agent MAY also verify the CGA and signature for the encapsulated DHCPv6 message in the Relay Message Option. This can be helpful if the DHCPv6 response traverses a separate administrative domain, or if the relay agent is in a separate administrative domain. However, this is not necessary because the DHCPv6 client validation will catch any modification to the response.

7. Security Considerations

This document provides new security features to the DHCPv6 protocol.

Using CGA as source addresses with its verification mechanism in DHCPv6 message exchanging provides the source address ownership verification and data integrity protection.

The Secure DHCPv6 mechanism is based on the pre-condition that the receiver knows the CGA of senders. For example, to prevent DHCPv6 server spoofing, the clients should be pre-configured with the DHCPv6 server CGA. The clients may decline the DHCPv6 messages from unknown servers, which may be fake servers; or may prefer DHCPv6 messages from known servers over unsigned messages or messages from unknown servers. The pre-configuration operation also needs to be protected, which is out of scope.

In the relay-server and server-relay authentication scenarios, the Secure DHCPv6 mechanism is based on the pre-condition that the receiver has been pre-configured with sender's CGAs and associated

CGA parameters. The pre-configuration operation also needs to be protected, which is out of scope.

CGA-based signatures cannot be used to authenticate a transaction if the CGA key isn't pre-configured in the DHCPv6 client that needs to authenticate the transaction. However, such a DHCPv6 client can make a leap of faith when it first encounters a new CGA. If the DHCPv6 server that used that CGA is in fact legitimate, then all future communication with that DHCPv6 server can be protected by caching the CGA and the associated public key. This does not provide complete security, but it limits the opportunity to mount an attack on a specific DHCPv6 client to the first time it communicates with a new DHCPv6 server.

DHCPv6 nodes without CGAs or the DHCPv6 messages that use unspecific addresses cannot be protected.

Downgrade attacks cannot be avoided if nodes are configured to accept both secured and unsecured messages. A future specification may provide a mechanism on how to treat unsecured DHCPv6 messages.

As stated in CGA definition [RFC3972], link-local CGAs are more vulnerable because the same prefix is used by all IPv6 nodes. Therefore, when link-local CGAs are used by the DHCPv6 clients, it is recommended to use a slightly higher Sec value, for example Sec=1 for now. When higher Sec values are used, the relative advantage of attacking link-local addresses becomes insignificant.

Impacts of collision attacks on current uses of CGAs are analyzed in [RFC4982]. The basic idea behind collision attacks, as described in Section 4 of [RFC4270], is on the non-repudiation feature of hash algorithms. However, CGAs do not provide non-repudiation features. Therefore, as [RFC4982] points out CGA-based protocols, including Secure DHCPv6 defined in this document, are not affected by collision attacks on hash functions.

[RFC6273] has analyzed possible threats to the hash algorithms used in SEND. Since the Secure DHCPv6 defined in this document uses the same hash algorithms in similar way to SEND (except that Secure DHCPv6 has not used PKIX Certificate), analysis results could be applied as well: current attacks on hash functions do not constitute any practical threat to the digital signatures used in the signature algorithm in the Secure DHCPv6. Attacks on CGAs, as described in [RFC4982], will compromise the security of Secure DHCPv6 and they need to be addressed by encoding the hash algorithm information into the CGA as specified in [RFC4982].

8. IANA Considerations

This document defines two new DHCPv6 [RFC3315] options, which MUST be assigned Option Type values within the option numbering space for DHCPv6 messages:

The CGA Parameter Option (TBA1), described in Section 5.1.

The Signature Option (TBA2), described in Section 5.2.

The Signature Option for Relay-Reply Message (TBA3), described in Section 5.3.

This document defines a new DHCPv6 DUID, which MUST be assigned DUID Type values within the DHCPv6 DUID Type numbering space:

The DUID-SA (TBA4), described in Section 5.4.

This document defines two new registries that have been created and are maintained by IANA. Initial values for these registries are given below. Future assignments are to be made through Standards Action [RFC5226]. Assignments for each registry consist of a name, a value and a RFC number where the registry is defined.

Hash Algorithm for Secure DHCPv6. The values in this name space are 16-bit unsigned integers. The following initial values are assigned for Hash Algorithm for Secure DHCPv6 in this document:

Name	Value	RFCs
Reserved	0x0000	this document
SHA-1	0x0001	this document
SHA-256	0x0002	this document

Signature Algorithm for Secure DHCPv6. The values in this name space are 16-bit unsigned integers. The following initial values are assigned for Signature Algorithm for Secure DHCPv6 in this document:

Name	Value	RFCs
Reserved	0x0000	this document
RSASSA-PKCS1-v1_5	0x0001	this document

This document defines a new 128-bit value under the CGA Message Type [RFC3972] namespace, 0x81be a1eb 0021 ce7e caa9 4090 0665 d2e0 02c2. (The tag value has been generated randomly by the editor of this specification. It may replaced by any IANA-allocated value when the specification is published.)

9. Acknowledgments

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Author's Addresses

Sheng Jiang
Huawei Technologies Co., Ltd
Q14, Huawei Campus
No.156 Beiqing Road
Hai-Dian District, Beijing 100095
P.R. China
EMail: jiangsheng@huawei.com

Sean Shen
CNNIC
4, South 4th Street, Zhongguancun
Beijing 100190
P.R. China
EMail: shenshuo@cnnic.cn