

Cryptographically Generated Addresses (CGA)
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Abstract

This document describes a method for binding a public signature key to an IPv6 address in the Secure Neighbor Discovery (SEND) protocol. Cryptographically Generated Addresses (CGA) are IPv6 addresses where the interface identifier is generated by computing a cryptographic one-way hash function from a public key and auxiliary parameters. The binding between the public key and the address can be verified by re-computing the hash value and by comparing the hash with the interface identifier. Messages sent from an IPv6 address can be protected by attaching the public key and auxiliary parameters and by signing the message with the corresponding private key. The protection works without a certification authority or other security infrastructure.

Internet-Draft Cryptographically Generated Addresses (CGA) December 2003

Table of Contents

1.	Introduction	3
2.	CGA Format	4
3.	CGA Parameters and Hash Values	6
4.	CGA Generation	7
5.	CGA Verification	9
6.	CGA Signatures	11
7.	Security Considerations	13
7.1	Security Goals and Limitations	13
7.2	Hash extension	13
7.3	Privacy Considerations	15
7.4	Related protocols	16
8.	IANA Considerations	17
	Normative References	18
	Informative References	19
	Author's Address	20
A.	Example of CGA Generation	21
B.	Acknowledgments	23
	Intellectual Property and Copyright Statements	24

Internet-Draft Cryptographically Generated Addresses (CGA) December 2003

1. Introduction

This document specifies a method for securely associating a cryptographic public key with an IPv6 address in the Secure Neighbor Discovery (SEND) protocol [[I-D.ietf-send-ndopt](#)]. The basic idea is to generate the interface identifier (i.e., the rightmost 64 bits) of the IPv6 address by computing a cryptographic hash of the public key. The resulting IPv6 address is called a cryptographically generated address (CGA). The corresponding private key can then be used to sign messages sent from the address.

This document specifies:

- o how to generate a CGA from the cryptographic hash of a public key and auxiliary parameters,
- o how to verify the association between the public key and the CGA, and
- o how to sign a message that is sent from the CGA, and how to verify the signature.

In order to verify the association between the address and the public key, the verifier needs to know the address itself, the public key, and the values of the auxiliary parameters. No additional security infrastructure, such as a public key infrastructure (PKI), certification authorities, or other trusted servers, is needed.

The address format and the CGA parameter format are defined in Sections [2](#) and [3](#). Detailed algorithms for generating addresses and for verifying them are given in Sections [4](#) and [5](#), respectively. [Section 6](#) defines the procedures for generating and verifying CGA signatures. The security considerations in [Section 7](#) include limitations of CGA-based authentication, the reasoning behind the hash extension technique that enables effective hash lengths above

the 64-bit limit of the interface identifier, the implications of CGAs on privacy, and protection against related-protocol attacks.

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](#)].

[2](#). CGA Format

When talking about addresses, this document refers to IPv6 addresses where the leftmost 64 bits of a 128-bit address form the subnet prefix and the rightmost 64 bits of the address form the interface identifier [[RFC3513](#)]. We number the bits of the interface identifier starting from bit 0 on the left.

A cryptographically generated address (CGA) has a security parameter (Sec), which determines its strength against brute-force attacks. The security parameter is a 3-bit unsigned integer and it is encoded in the three leftmost bits (i.e., bits 0-2) of the interface identifier. This can be written as:

$$\text{Sec} = (\text{interface identifier} \ \& \ 0\text{xe}0000000000000000) \gg 61$$

The CGA is associated with a set of parameters, which consist of a public key and auxiliary parameters. Two hash values Hash1 (64 bits) and Hash2 (112 bits) are computed from the parameters. The formats of the public key and auxiliary parameters, and the way to compute the hash values are defined in [Section 3](#).

A cryptographically generated address is defined as an IPv6 address that satisfies the following two conditions:

- o The 16*Sec leftmost bits of the second hash value, Hash2, are zero.

- o The rightmost 64 bits of the first hash value, Hash1, equal the interface identifier of the address. Bits 0, 1, 2, 6 and 7 (i.e., the bits that encode the security parameter Sec and the "u" and "g" bits from the standard IPv6 address architecture format of interface identifiers [[RFC3513](#)]) are ignored in the comparison.

The above definition can be stated in terms of the following two bit masks:

```
Mask1 (112 bits) = 0x00000000000000000000000000000000 if Sec=0,
                  0xffff0000000000000000000000000000 if Sec=1,
                  0xffffffff000000000000000000000000 if Sec=2,
                  0xffffffffffffff000000000000000000 if Sec=3,
                  0xffffffffffffffff0000000000000000 if Sec=4,
                  0xffffffffffffffffffffff0000000000 if Sec=5,
                  0xffffffffffffffffffffffffffffff0000 if Sec=6, and
                  0xffffffffffffffffffffffffffffffff if Sec=7
```

```
Mask2 (64 bits)  = 0x1cffffffffffffffff
```

A cryptographically generated address is an IPv6 address for which the following two equations hold:

```
Hash1 & Mask2 == interface identifier & Mask2
Hash2 & Mask1 == 0x00000000000000000000000000000000
```

3. CGA Parameters and Hash Values

Each CGA is associated with a public key and auxiliary parameters. The public key **MUST** be formatted as a DER-encoded [\[ITU.X690.2002\]](#) ASN.1 structure of the type SubjectPublicKeyInfo defined in the Internet X.509 certificate profile [\[RFC3280\]](#). For SEND, the public key **SHOULD** be an RSA encryption key with the object identifier rsaEncryption (i.e., "1.2.840.113549.1.1.1") and the subject public key field **SHOULD** be formatted as an ASN.1 data structure of the type RSAEncryptionKey defined in [\[PKCS.1.2002\]](#). The RSA key length **SHOULD** be at least 384 bits. Other public key types or format **SHOULD NOT** be used for SEND to avoid incompatibilities [\[I-D.ietf-send-ndopt\]](#).

The auxiliary parameters are the following three unsigned integers:

- o a 128-bit modifier, which can be any value,
- o a 64-bit subnet prefix, which is equal to the subnet prefix of the CGA, and
- o an 8-bit collision count, which can have values 0, 1 and 2.

We use the name "CGA Parameters" for the data structure that is the concatenation (from left to right) of the 16-octet modifier, the 8-octet subnet prefix, the 1-octet collision count, and the variable-length encoded public key (i.e., the SubjectPublicKeyInfo structure).

The two hash values MUST be computed as follows. The SHA-1 hash algorithm [[FIPS.180-1.1995](#)] is applied to the public key and auxiliary parameters. When computing Hash1, the input to the SHA-1 algorithm is the CGA Parameters data structure. The 64-bit Hash1 is obtained by taking the leftmost 64 bits of the 160-bit SHA-1 hash value. When computing Hash2, the input is the same CGA Parameters data structure except that the subnet prefix and collision count are set to zero. The 112-bit Hash2 is obtained by taking the leftmost 112 bits of the 160-bit SHA-1 hash value.

[4.](#) CGA Generation

The process of generating a new CGA takes three input values: a 64-bit subnet prefix, the public key of the address owner as a DER-encoded ASN.1 structure of the type SubjectPublicKeyInfo, and the security parameter Sec, which is an unsigned 3-bit integer. The cost of generating a new CGA depends on the security parameter Sec, which

can have values from 0 to 7.

A CGA and associated parameters SHOULD be generated as follows:

1. Set the modifier to a random or pseudorandom 128-bit value.
2. Concatenate from left to right: the modifier, 9 zero octets, and the encoded public key. Execute the SHA-1 algorithm on the concatenation. Take the 112 leftmost bits of the SHA-1 hash value. The result is Hash2.
3. Compare the 16*Sec leftmost bits of Hash2 with zero. If they are all zero (or if Sec=0), continue with step (4). Otherwise, increment the modifier and go back to step (2).
4. Set the 8-bit collision count to zero.
5. Concatenate from left to right the final modifier value, the subnet prefix, the collision count and the encoded public key. Execute the SHA-1 algorithm on the concatenation. Take the 64 leftmost bits of the SHA-1 hash value. The result is Hash1.
6. Form an interface identifier from Hash1 by writing the value of Sec into the three leftmost bits and by setting bits 6 and 7 (i.e., the "u" and "g" bits) both to zero.
7. Concatenate the 64-bit subnet prefix and the 64-bit interface identifier to form a 128-bit IPv6 address with the subnet prefix to the left and interface identifier to the right as in a standard IPv6 address [[RFC3513](#)].
8. Perform address collision detection if required, as per [[I-D.ietf-send-ndopt](#)]. If an address collision is detected, increment the collision count and go back to step (5). However, after three collisions, stop and report the error.
9. Form the CGA Parameters data structure by concatenating from left to right the final modifier value, the subnet prefix, the final collision count value, and the encoded public key.

The output of the address generation algorithm is a new CGA and a CGA

Parameters data structure.

The initial value of the modifier in step (1) SHOULD be chosen randomly in order to make addresses generated from the same public key unlinkable, which enhances privacy (see [Section 7.3](#)). The quality of the random number generator does not affect the strength of the binding between the address and the public key.

For $\text{Sec}=0$, the above algorithm is deterministic and relatively fast. Nodes that implement CGA generation MAY always use the security parameter value $\text{Sec}=0$. If $\text{Sec}=0$, steps (2)-(3) of the generation algorithm can be skipped.

For Sec values greater than 0, the above algorithm is not guaranteed to terminate after a certain number of iterations. The brute-force search in steps (2)-(3) takes $O(2^{(16*\text{Sec})})$ iterations to complete. It is intentional that generating CGAs with high Sec values is infeasible with current technology.

Implementations MAY use optimized or otherwise modified versions of the above algorithm for CGA generation. However, the output of any such modified versions of the algorithm MUST fulfill the following two requirements. First, the resulting CGA and CGA Parameters data structure MUST be formatted as specified in Sections [2-3](#). Second, the CGA verification procedure defined in [Section 5](#) MUST succeed when invoked on the output of the CGA generation algorithm. It is important to note that some optimizations involve trade-offs between privacy and the cost of address generation.

One optimization is particularly important. If the subnet prefix of the address changes but the address owner's public key does not, the old modifier value MAY be reused. If it is reused, the algorithm SHOULD be started from step (4). This optimization avoids repeating the expensive search for an acceptable modifier value but may, in some situations, make it easier for an observer to link two addresses to each other.

Note that this document does not specify whether duplicate address detection should be performed and how the detection is done. Step (8) only defines what to do if some form of duplicate address detection is performed and an address collision is detected.

5. CGA Verification

CGA verification takes as input an IPv6 address and a CGA Parameters data structure. The CGA Parameters consist of the concatenated modifier, subnet prefix, collision count, and public key. The verification either succeeds or fails.

The CGA MUST be verified with the following steps:

1. Check that the collision count in the CGA Parameters data structure is 0, 1 or 2. The CGA verification fails if the collision count is out of the valid range.
2. Check that the subnet prefix in the CGA Parameters data structure is equal to the subnet prefix (i.e., the leftmost 64 bits) of the address. The CGA verification fails if the prefix values differ.
3. Execute the SHA-1 algorithm on the CGA Parameters data structure. Take the 64 leftmost bits of the SHA-1 hash value. The result is Hash1.
4. Compare Hash1 with the interface identifier (i.e., the rightmost 64 bits) of the address. Differences in the three leftmost bits and in bits 6 and 7 (i.e., the "u" and "g" bits) are ignored. If the 64-bit values differ (other than in the five ignored bits), the CGA verification fails.
5. Read the security parameter Sec from the three leftmost bits of the 64-bit interface identifier of the address. (Sec is an unsigned 3-bit integer.)
6. Concatenate from left to right the modifier, 9 zero octets, and the public key. Execute the SHA-1 algorithm on the concatenation. Take the 112 leftmost bits of the SHA-1 hash value. The result is Hash2.
7. Compare the 16*Sec leftmost bits of Hash2 with zero. If any one of them is non-zero, the CGA verification fails. Otherwise, the verification succeeds. (If Sec=0, the CGA verification never fails at this step.)

If the verification succeeds, the verifier knows that the public key in the CGA Parameters is the authentic public key of the address

owner. The verifier can extract the public key by removing 25 bytes from the beginning of the CGA Parameters and by decoding the following SubjectPublicKeyInfo data structure. Future versions of this specification may add new fields to the end of the CGA Parameters and the verifier SHOULD ignore any unrecognized data that

follows the encoded public key.

Note that the values of bits 6 and 7 (the "u" and "g" bits) of the interface identifier are ignored during CGA verification. After the verification succeeds, the verifier SHOULD process all CGAs in the same way regardless of the Sec, modifier and collision count values. In particular, the verifier SHOULD NOT have any security policy that differentiates between addresses based on the value of Sec. That way, the address generator is free choose any value of Sec.

All nodes that implement CGA verification MUST be able to process all security parameter values Sec = 0, 1, 2, 3, 4, 5, 6, 7. The verification procedure is relatively fast and always requires a constant amount of computation. If Sec=0, the verification never fails in steps (6)-(7) and these steps can be skipped.

Nodes that implement CGA verification for SEND SHOULD be able to process RSA public keys that have the OID rsaEncryption and key length between 384 and 2048 bits. Implementations MAY support longer keys. Future versions of this specification may recommend support for longer keys.

[6.](#) CGA Signatures

This section defines the procedures for generating and verifying CGA signatures. In order to sign a message, a node needs the CGA, the associated CGA Parameters data structure, the message, and the private cryptographic key that corresponds to the public key in the CGA Parameters. The node also needs to have a 128-bit type tag for the message from CGA Message Type name space.

To sign a message, a node SHOULD do the following:

- o Concatenate the 128-bit type tag and the message with the type tag to the left and the message to the right. The concatenation is the message to be signed in the next step.
- o Generate the RSA signature using the RSASSA-PKCS1-v1_5 [[PKCS.1.2002](#)] signature algorithm with the SHA-1 hash algorithm. The inputs to the generation operation are the private key and the concatenation created above.

The SEND protocol specification [[I-D.ietf-send-ndopt](#)] defines several messages that contain a signature in the Signature Option. The SEND protocol specification also defines a type tag from the CGA Message Type name space. The same type tag is used for all the SEND messages that have the Signature Option. This type tag is an IANA-allocated 128 bit integer that has been chosen at random to prevent accidental type collision with messages of other protocols that use the same public key but may or may not use IANA-allocated type tags.

The CGA, the CGA Parameters data structure, the message, and the signature are sent to the verifier. The SEND protocol specification defines how this data is sent in SEND protocol messages. Note that the 128-bit type tag is not included in the SEND protocol messages because the verifier knows its value implicitly from the ICMP message type field in the SEND message. See the SEND specification [[I-D.ietf-send-ndopt](#)] for precise information about how SEND handles the type tag.

In order to verify a signature, the verifier needs the CGA, the associated CGA Parameters data structure, the message, and the signature. The verifier also needs to have the 128-bit type tag for the message.

To verify the signature, a node SHOULD do the following:

- o Verify the CGA as defined in [Section 5](#). The inputs to the CGA verification are the CGA and the CGA Parameters data structure.

- o Concatenate the 128-bit type tag and the message with the type tag to the left and the message to the right. The concatenation is the message whose signature is to be verified in the next step.
- o Verify the RSA signature using the RSASSA-PKCS1-v1_5 [[PKCS.1.2002](#)] algorithm with the SHA-1 hash algorithm. The inputs to the verification operation are the public key (i.e., the RSAEncryptionKey structure from the SubjectPublicKeyInfo structure that is a part of the CGA Parameters data structure), the concatenation created above, and the signature.

The verifier MUST accept the signature as authentic only if both the CGA verification and the signature verification succeed.

[7. Security Considerations](#)

[7.1 Security Goals and Limitations](#)

The purpose of CGAs is to prevent stealing and spoofing of existing IPv6 addresses. The public key of the address owner is bound cryptographically to the address. The address owner can use the corresponding private key to assert its ownership of the address and to sign SEND messages sent from the address.

It is important to understand that an attacker can create a new address from an arbitrary subnet prefix and its own public key because CGAs are not certified. What the attacker cannot do is to impersonate somebody else's address. This is because the attacker would have to find a collision of the cryptographic hash value Hash1.

(The property of the hash function needed here is called second pre-image resistance [[MOV97](#)].)

For each valid CGA Parameters data structure, there are $4 \times (\text{Sec} + 1)$ different CGAs that match the value. This is because decrementing the Sec value in the three leftmost bits of the interface identifier does not invalidate the address, and the verifier ignores the values of the "u" and "g" bits. In SEND, this fact does not have any security or implementation implications.

Another limitation of CGAs is that there is no mechanism for proving that an address is not a CGA. Thus, an attacker could take someone else's CGA and present it as a non-cryptographically-generated address (e.g., as an [RFC-3041](#) address [[RFC3041](#)]). An attacker does not benefit from this because although SEND nodes accept both signed and unsigned messages from every address, they give priority to the information in the signed messages.

[7.2](#) Hash extension

As computers become faster, the 64 bits of the interface identifier will not be sufficient to prevent attackers from searching for hash collisions. It helps somewhat that we include the subnet prefix of the address in the hash input. This prevents the attacker from using a single pre-computed database to attack addresses with different subnet prefixes. The attacker needs to create a separate database for each subnet prefix. Link-local addresses are, however, left vulnerable because the same prefix is used by all IPv6 nodes.

In order to prevent the CGA technology from becoming outdated as computers become faster, the hash technique used to generate CGAs must be extended somehow. The chosen extension technique is to increase the cost of both address generation and brute-force attacks

by the same parameterized factor while keeping the cost of address use and verification constant. This provides protection also for link-local addresses. Introduction of the hash extension is the main difference between this document and earlier CGA proposals [[OR01](#)] [[Nik01](#)] [[MC02](#)].

To achieve the effective extension of the hash length, the input to the second hash function Hash2 is modified (by changing the modifier

value) until the leftmost $16 \times \text{Sec}$ bits of the hash value are zero. This increases the cost of address generation approximately by a factor of $2^{(16 \times \text{Sec})}$. It also increases the cost of brute-force attacks by the same factor. That is, the cost of creating a CGA Parameters data structure that binds the attacker's public key with somebody else's address is increased from $O(2^{59})$ to $O(2^{(59+16 \times \text{Sec})})$. The address generator may choose the security parameter Sec depending on its own computational capacity, perceived risk of attacks, and the expected lifetime of the address. Currently, Sec values between 0 and 2 are sufficient for most IPv6 nodes. As computers become faster, higher Sec values will slowly become useful.

Theoretically, if no hash extension is used (i.e., $\text{Sec}=0$) and a typical attacker is able to tap into N local networks at the same time, an attack against link-local addresses is N times as efficient as an attack against addresses of a specific network. The effect could be countered by using a slightly higher Sec value for link-local addresses. When higher Sec values (such that $2^{(16 \times \text{Sec})} > N$) are used for all addresses, the relative advantage of attacking link-local addresses becomes insignificant.

The effectiveness of the hash extension depends on the assumption that the computational capacities of the attacker and the address generator will grow at the same (potentially exponential) rate. This is not necessarily true if the addresses are generated on low-end mobile devices where the main design goals are lower cost and smaller size rather than increased computing power. But there is no reason for doing so. The expensive part of the address generation (steps (1)-(3) of the generation algorithm) may be delegated to a more powerful computer. Moreover, this work can be done in advance or offline, rather than in real time when a new address is needed.

In order to make it possible for mobile nodes whose subnet prefix changes frequently to use Sec values greater than 0, we have decided not to include the subnet prefix in the input of Hash2. The result is weaker than if the subnet prefix were included in the input of both hashes. On the other hand, our scheme is at least as strong as using the hash extension technique without including the subnet prefix in either hash. It is also at least as strong as not using the hash extension but including the subnet prefix. This trade-off was made

because mobile nodes frequently move to insecure networks where they

are at the risk of denial-of-service (DoS) attacks, for example, during the duplicate address detection procedure.

In most networks, the goal of Secure Neighbor Discovery and CGA-based authentication is to prevent denial-of-service attacks. Therefore, it is usually sensible to start by using a low Sec value and to replace addresses with stronger ones only when denial-of-service attacks based on brute-force search become a significant problem. (If CGAs were used as a part of a strong authentication or secrecy mechanisms, it would be necessary to start with higher Sec values.)

The collision count value is used to modify the input to Hash1 if there is an address collision. It is important not to allow collision count values higher than 2. First, it is extremely unlikely that three collisions would occur and the reason is certain to be either a configuration or implementation error or a denial-of-service attack. (When the SEND protocol is used, the deliberate collisions caused by a DoS attacker are detected and ignored.) Second, an attacker who is doing a brute-force search to match a given CGA can try all different values of collision count without repeating the brute-force search for the modifier value. Thus, if higher values are allowed for the collision count, the hash extension technique becomes less effective in preventing brute force attacks.

[7.3](#) Privacy Considerations

CGAs can give the same level pseudonymity as the IPv6 address privacy extensions defined in [RFC 3041](#) [[RFC3041](#)]. An IP host can generate multiple pseudorandom CGAs by executing the CGA generation algorithm of [Section 4](#) multiple times and by using a different random or pseudorandom initial value for the modifier every time. The host should change its address periodically as in [[RFC3041](#)]. When privacy protection is needed, the (pseudo)random number generator used in address generation SHOULD be strong enough to produce unpredictable and unlinkable values.

There are two apparent limitations to this privacy protection. However, as we will explain below, neither limitation is very serious.

First, the high cost of address generation may prevent hosts that use a high Sec value from changing their address frequently. This problem is mitigated by the fact that the expensive part of the address generation may be done in advance or offline, as explained in the previous section. It should also be noted that the nodes that benefit most from high Sec values (e.g., DNS servers, routers, and data servers) usually do not require pseudonymity, while the nodes that

have high privacy requirements (e.g., client PCs and mobile hosts) are unlikely targets for expensive brute-force attacks and can do with lower Sec values.

Second, the public key of the address owner is revealed in the authenticated SEND messages. This means that if the address owner wants to be pseudonymous towards the nodes in the local links that it accesses, it should not only generate a new address but also a new public key. With typical local-link technologies, however, a node's link-layer address is a unique identifier for the node. As long as the node keeps using the same link-layer address, it makes little sense to ever change the public key for privacy reasons.

[7.4](#) Related protocols

While this document defines CGAs only for the purposes of Secure Neighbor Discovery, other protocols could be defined elsewhere that use the same addresses and public keys. This raises the possibility of related-key attacks where a signed message from one protocol is replayed in another protocol. This means that other protocols (perhaps designed without an intimate knowledge of SEND) could endanger the security of SEND.

To prevent the related-protocol attacks, a type tag is prepended to every message before signing it. The type-tags are 128-bit randomly chosen values, which prevents accidental type collisions with even poorly designed protocols that do not use any type tags.

Finally, some cautionary notes should be made about using CGA-based authentication for other purposes than SEND. First, the other protocols should use type tags in all signed messages in the same way as SEND does. Because of the possibility of related-protocol attacks, it is advisable to use the public key only for signing and not for encryption. Second, CGA-based authentication is particularly suitable for securing neighbor discovery [[RFC2461](#)] and duplicate address detection [[RFC2462](#)] because these are network-layer signaling protocols where IPv6 addresses are natural endpoint identifiers. In any protocol that aims to protect higher-layer data, CGA-based authentication alone is not sufficient and there must also be a secure mechanism for mapping higher-layer identifiers, such as DNS names, to IP addresses.

8. IANA Considerations

This document defines a new CGA Message Type name space for use as type tags in messages may be signed using CGA signatures. The values in this name space are 128-bit integers. Values in this name space are allocated on a First Come First Served basis [[RFC2434](#)]. IANA assigns new 128-bit values directly without a review.

The new values SHOULD be generated by the requester with a strong random-number generator. Continuous ranges of at most 256 values can be allocated provided that the 120 most significant bits of the values have been generated with a strong random-number generator. It is not necessary for IANA to verify the randomness of the requested values. The name space is essentially unlimited and any number of individual values and ranges of at most 256 values can be allocated.

CGA Message Type values for private use MAY be generated with a strong random-number generator without IANA allocation.

This document does not define any new values in any name space.

Internet-Draft Cryptographically Generated Addresses (CGA) December 2003

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Aura

Expires June, 2004

[Page 18]

Internet-Draft Cryptographically Generated Addresses (CGA) December 2003

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[Appendix A](#). Example of CGA Generation

We generate a CGA with Sec=1 from the subnet prefix fe80:: and the following public key:

```
305c 300d 0609 2a86 4886 f70d 0101 0105 0003 4b00 3048 0241
00c2 c2f1 3730 5454 f10b d9ce a368 44b5 30e9 211a 4b26 2b16
467c b7df ba1f 595c 0194 f275 be5a 4d38 6f2c 3c23 8250 8773
c786 7f9b 3b9e 63a0 9c7b c48f 7a54 ebef af02 0301 0001
```

The modifier is initialized to a random value 89a8 a8b2 e858 d8b8

f263 3f44 d2d4 ce9a. The input to Hash2 is:

```
89a8 a8b2 e858 d8b8 f263 3f44 d2d4 ce9a 0000 0000 0000 0000 00
305c 300d 0609 2a86 4886 f70d 0101 0105 0003 4b00 3048 0241
00c2 c2f1 3730 5454 f10b d9ce a368 44b5 30e9 211a 4b26 2b16
467c b7df ba1f 595c 0194 f275 be5a 4d38 6f2c 3c23 8250 8773
c786 7f9b 3b9e 63a0 9c7b c48f 7a54 ebef af02 0301 0001
```

The 112 first bits of the SHA-1 hash value computed from the above input is Hash2=436b 9a70 dbfd dbf1 926e 6e66 29c0. This does not begin with 16*Sec=16 zero bits. Thus, we must increment the modifier and recompute the hash. The new input to Hash2 is:

```
89a8 a8b2 e858 d8b8 f263 3f44 d2d4 ce9b 0000 0000 0000 0000 00
305c 300d 0609 2a86 4886 f70d 0101 0105 0003 4b00 3048 0241
00c2 c2f1 3730 5454 f10b d9ce a368 44b5 30e9 211a 4b26 2b16
467c b7df ba1f 595c 0194 f275 be5a 4d38 6f2c 3c23 8250 8773
c786 7f9b 3b9e 63a0 9c7b c48f 7a54 ebef af02 0301 0001
```

The new hash value is Hash2=0000 01ca 680b 8388 8d09 12df fcce. The 16 leftmost bits of Hash2 are all zero. Thus, we found a suitable modifier. (We were very lucky to find it so soon.)

The input to Hash1 is:

```
89a8 a8b2 e858 d8b8 f263 3f44 d2d4 ce9b fe80 0000 0000 0000 00
305c 300d 0609 2a86 4886 f70d 0101 0105 0003 4b00 3048 0241
00c2 c2f1 3730 5454 f10b d9ce a368 44b5 30e9 211a 4b26 2b16
467c b7df ba1f 595c 0194 f275 be5a 4d38 6f2c 3c23 8250 8773
c786 7f9b 3b9e 63a0 9c7b c48f 7a54 ebef af02 0301 0001
```

The 64 first bits of the SHA-1 hash value of the above input are Hash1=fd4a 5bf6 ffb4 ca6c. We form an interface identifier from this by writing Sec=1 into the three leftmost bits and by setting bits 6 and 7 (the "u" and "g" bits) to zero. The new interface identifier is 3c4a:5bf6:ffb4:ca6c.

Finally, we form the IPv6 address fe80::3c4a:5bf6:ffb4:ca6c. This is the new CGA. No address collisions were detected this time. (Collisions are very rare.) The CGA Parameters data structure associated with the address is the same as the input to Hash1 above.

[Appendix B](#). Acknowledgments

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[Page 24]

Internet-Draft

Cryptographically Generated Addresses (CGA)

December 2003

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[Page 25]