CFRG
Internet-Draft
Intended status: Informational
Expires: July 22, 2017

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January 18, 2017

AES-GCM-SIV: Nonce Misuse-Resistant Authenticated Encryption
draft-irtf-cfrg-gcmsiv-03

Abstract

This memo specifies two authenticated encryption algorithms that are nonce misuse-resistant - that is that they do not fail catastrophically if a nonce is repeated.

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1. Introduction

The concept of "Authenticated encryption with additional data" (AEAD [RFC5116]) couples confidentiality and integrity in a single operation that is easier for practitioners to use correctly. The most popular AEAD, AES-GCM [GCM], is seeing widespread use due to its attractive performance.

However, most AEADs suffer catastrophic failures of confidentiality and/or integrity when two distinct messages are encrypted with the same nonce. While the requirements for AEADs specify that the pair of (key, nonce) shall only ever be used once, and thus prohibit this, in practice this is a worry.

Nonce misuse-resistant AEADs do not suffer from this problem. For this class of AEADs, encrypting two messages with the same nonce only discloses whether the messages were equal or not. This is the minimum amount of information that a deterministic algorithm can leak in this situation.

This memo specifies two nonce misuse-resistant AEADs: "AEAD_AES_128_GCM_SIV" and "AEAD_AES_256_GCM_SIV". These AEADs are designed to be able to take advantage of existing hardware support for AES-GCM and can decrypt within 5% of the speed of AES-GCM.

Encryption is, perforce, slower than AES-GCM because two passes are required. However, measurements suggest that it can still run at 2/3rds of the speed of AES-GCM.

We suggest that these AEADs be considered in any situation where there is the slightest doubt about nonce uniqueness.

2. Requirements Language

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 RFC 2119 [RFC2119].

3. POLYVAL

The GCM-SIV construction is similar to GCM: the block cipher is used in counter mode to encrypt the plaintext and a polynomial authenticator is used to provide integrity. The authenticator in GCM-SIV is called POLYVAL.

POLYVAL, like GHASH, operates in a binary field of size 2^128. The field is defined by the irreducible polynomial x^128 + x^127 + x^126 + x^121 + 1. The sum of any two elements in the field is the result of XORing them. The product of any two elements is calculated using standard (binary) polynomial multiplication followed by reduction modulo the irreducible polynomial.

We define another binary operation on elements of the field: dot(a, b), where dot(a, b) = a * b * x^-128. The value of the field element x^-128 is equal to x^127 + x^124 + x^121 + x^114 + 1. The result, dot(a, b), of this multiplication is another field element.

Polynomials in this field are converted to and from 128-bit strings by taking the least-significant bit of the first byte to be the coefficient of x^0, the most-significant bit of the first byte to the the coefficient of x^7 and so on, until the most-significant bit of the last byte is the coefficient of x^127.

POLYVAL takes a field element, H, and a series of field elements X_1, ..., X_s. Its result is S_s, where S is defined by the iteration S_0 = 0; S_j = dot(S_{j-1} + X_j, H), for j = 0..s

We note that POLYVAL(H, X_1, X_2, ...) is equal to ByteReverse(GHASH(ByteReverse(H)*x, ByteReverse(X_1), ByteReverse(X_2), ...)), where ByteReverse is a function that reverses the order of 16 bytes. See Appendix A for a more detailed explanation.

4. Encryption

AES-GCM-SIV encryption takes a 16- or 32-byte key-generating key, a 96-bit nonce, and arbitrary-length plaintext & additional data byte-strings. It outputs an authenticated ciphertext that will be 16 bytes longer than the plaintext.

If the key-generating key is 16 bytes long then AES-128 is used throughout. Otherwise AES-256 is used throughout.

The first step of encryption is to generate per-nonce, record-authentication and record-encryption keys. The record-authentication key is 128-bit and the record-authentication key is either 128- (for AES-128) or 256-bit (for AES-256).

These keys are generated by encrypting a series of plaintext blocks that contain a 32-bit, little-endian counter followed by the nonce, and then discarding the second half of the resulting ciphertext. In the AES-128 case, 128 + 128 = 256 bits of key material need to be generated and, since encrypting each block yeilds 64 bits after discarding half, four blocks need to be encrypted. The counter values for these blocks are 0, 1, 2 and 3. For AES-256, six blocks are needed in total, with counter values 0 through 5 (inclusive).

In pseudocode form:

```
U32LE(x) =
  [x & 0xff, (x >> 8) & 0xff, (x >> 16) & 0xff, (x >> 24) & 0xff]

record-authentication-key = AES128(key = key-generating-key,
                                   input = U32LE(0) ++ nonce)[:8] ++
                            AES128(key = key-generating-key,
                                   input = U32LE(1) ++ nonce)[:8]

if bytelen(key-generating-key) == 16 {
  record-encryption-key = AES128(key = key-generating-key,
                                 input = U32LE(2) ++ nonce)[:8] ++
                          AES128(key = key-generating-key,
                                 input = U32LE(3) ++ nonce)[:8]
} else if bytelen(key-generating-key) == 32 {
  record-encryption-key = AES128(key = key-generating-key,
                                 input = U32LE(2) ++ nonce)[:8] ++
                          AES128(key = key-generating-key,
                                 input = U32LE(3) ++ nonce)[:8] ++
                          AES128(key = key-generating-key,
                                 input = U32LE(4) ++ nonce)[:8] ++
                          AES128(key = key-generating-key,
                                 input = U32LE(5) ++ nonce)[:8]
}
```

Define the _length block_ as a 16-byte value that is the concatenation of the 64-bit, little-endian encodings of bytelen(additional_length)*8 and bytelen(plaintext)*8. Pad the plaintext and additional data with zeros until they are each a multiple of 16 bytes, the AES block size. Then X_1, X_2, ... (the series of field elements that are inputs to POLYVAL) are the concatenation of the padded additional data, the padded plaintext and the length block.

Calculate S_s = POLYVAL(record-authentication-key, X_1, X_2, ...). XOR the first twelve bytes of S_s with the nonce and clear the most-significant bit of the last byte. Encrypt the result with AES using the record-encryption key to produce the tag.

The ciphertext is produced by using AES, with the record-encryption key, in counter mode on the unpadded plaintext. The initial counter block is the tag with the most-significant bit of the last byte set to one. The counter advances by incrementing the first 32 bits interpreted as an unsigned, little-endian integer. The result of the encryption is the resulting ciphertext (truncated to the length of the plaintext) followed by the tag.

5. Decryption

Decryption takes a 16- or 32-byte key-generating key, a 96-bit nonce, and arbitrary-length ciphertext & additional data byte-strings. It either fails, or outputs a plaintext that is 16 bytes shorter than the ciphertext.

Firstly, the record-encryption and record-authentication keys are derived in the same manner as when encrypting.

If the ciphertext is less than 16 bytes or more than 2^36 + 16 bytes, then fail. Otherwise split the input into the encrypted plaintext and a 16-byte tag. Decrypt the encrypted plaintext with the record-encryption key in counter mode, where the initial counter block is the tag with the most-significant bit of the last byte set to one. The counter advances in the same way as for encryption.

Pad the additional data and plaintext with zeros until they are each a multiple of 16 bytes, the AES block size. Calculate the length block and X_1, X_2, ... as above and compute S_s = POLYVAL(record-authentication-key, X_1, X_2, ...). Compute the expected tag by XORing S_s and the nonce, clearing the most-significant bit of the last byte and encrypting with the record-encryption key. Compare the provided and expected tag values in constant time. If they do not match, fail. Otherwise return the plaintext.

6. AEADs

We define two AEADs, in the format of RFC 5116, that use AES-GCM-SIV: AEAD_AES_128_GCM_SIV and AEAD_AES_256_GCM_SIV. They differ only in the size of the AES key used.

The key input to these AEADs becomes the key-generating key. Thus AEAD_AES_128_GCM_SIV takes a 16-byte key and AEAD_AES_256_GCM_SIV takes a 32-byte key.

The parameters for AEAD_AES_128_GCM_SIV are then: K_LEN is 16, P_MAX is 2^36, A_MAX is 2^61 - 1, N_MIN and N_MAX are 12 and C_MAX is 2^36 + 16.

The parameters for AEAD_AES_256_GCM_SIV differ only in the key size: K_LEN is 32, P_MAX is 2^36, A_MAX is 2^61 - 1, N_MIN and N_MAX are 12 and C_MAX is 2^36 + 16.

7. Field operation examples

Polynomials in this document will be written as 16-byte values. For example, the sixteen bytes 01000000000000000000000000000492 would represent the polynomial x^127 + x^124 + x^121 + x^114 + 1, which is also the value of x^-128 in this field.

If a = 66e94bd4ef8a2c3b884cfa59ca342b2e and b = ff000000000000000000000000000000 then a+b = 99e94bd4ef8a2c3b884cfa59ca342b2e, a*b = 37856175e9dc9df26ebc6d6171aa0ae9 and dot(a, b) = ebe563401e7e91ea3ad6426b8140c394.

8. Worked example

Consider the encryption of the plaintext "Hello world" with the additional data "example" under key ee8e1ed9ff2540ae8f2ba9f50bc2f27c using AEAD_AES_128_GCM_SIV. The random nonce that we'll use for this example is 752abad3e0afb5f434dc4310.

In order to generate the record-authentication and record-encryption keys, a counter is combined with the nonce to form four blocks. These blocks are encrypted with key given above:

```
Counter |       Nonce                          Ciphertext
00000000752abad3e0afb5f434dc4310 -> 310728d9911f1f38c40e952ca83d093e
01000000752abad3e0afb5f434dc4310 -> 37b24316c3fab9a046ae90952daa0450
02000000752abad3e0afb5f434dc4310 -> a4c5ae624996327947920b2d2412474b
03000000752abad3e0afb5f434dc4310 -> c100be4d7e2c6edd1efef004305ab1e7
```

The latter halves of the ciphertext blocks are discarded and the remainding bytes are concatenated to form the per-record keys. Thus the record-authentication key is 310728d9911f1f3837b24316c3fab9a0 and the record-encryption key is a4c5ae6249963279c100be4d7e2c6edd.

The length block contains the encoding of the bit-lengths of the additional data and plaintext, respectively, which are and 56 and 88. Thus the length block is 38000000000000005800000000000000.

The input to POLYVAL is the padded additional data, padded plaintext and then the length block. This is 6578616d706c650000000000000000048656c6c6f20776f726c6400000000003800000000000000580000000000000000.

Calling POLYVAL with the record-authentication key and the input above results in S_s = ad7fcf0b5169851662672f3c5f95138f.

Before encrypting, the nonce is XORed in and the most-significant bit of the last byte is cleared. This gives

d85575d8b1c630e256bb6c2c5f95130f because that bit happened to be one previously. Encrypting with the record-encryption key gives the tag, which is 4fbcdeb7e4793f4a1d7e4faa70100af1.

In order to form the initial counter block, the most-significant bit of the last byte of the tag is set to one. That doesn't result in a change in this example. Encrypting this with the record key gives the first block of the keystream: 1551f2c1787e81deac9a99f139540ab5.

The final ciphertext is the result of XORing the plaintext with the keystream and appending the tag. That gives 5d349ead175ef6b1def6fd4fbcdeb7e4793f4a1d7e4faa70100af1.

9. Security Considerations

We recommend a limit of 2^50 plaintexts encrypted with a given key. Past this point, AES-GCM-SIV may be distinguishable from an ideal AEAD. (This is based on standard assumptions about AES.)

The AEADs defined in this document calculate fresh AES keys for each nonce. This allows a larger number of plaintexts to be encrypted under a given key. Without this step, each SIV encryption would be like a standard GCM encryption with a random nonce. Since the nonce size for GCM is only 12 bytes, NIST set a limit [GCM] of 2^32 encryptions before the probability of duplicate nonces becomes too high.

The authors felt that, while large, 2^32 wasn't so large that this limit could be safely ignored. For example, consider encrypting the contents of a hard disk where the AEAD record size is 512 bytes, to match the traditional size of a disk sector. This process would have encrypted 2^32 records after processing 2TB, yet hard drives of multiple terabytes are now common.

Deriving fresh AES keys for each nonce alleviates this problem.

If the nonce is fixed then AES-GCM-SIV acts like AES-GCM with a random nonce, with the caveat that identical plaintexts will produce identical ciphertexts. However, we feel that the 2^32 limit for AES-GCM is too risky in a multi-key setting. Thus with AES-GCM-SIV we recommend that, for a specific key, a nonce not be repeated more than 2^8 times. (And, ideally, not be repeated at all.)

Suzuki et al [multibirthday] show that even if nonces are selected uniformly at random, the probability that one or more values would be repeated 256 or more times is negligible until the number of nonces reaches 2^102. (Specifically the probability is 1/((2^96)^(255)) * Binomial(q, 256), where q is the number of nonces.) Since 2^102 is

vastly greater than the limit on the number of plaintexts per key given above, we don't feel that this limit on the number of repeated nonces will be a problem. This also means that selecting nonces at random is a safe practice with AES-GCM-SIV.

In addition to calculating fresh AES keys for each nonce, these AEADs also calculate fresh POLYVAL keys. Previous versions of GCM-SIV did not do this and, instead, used part of the AEAD's key as the POLYVAL key. Bleichenbacher pointed out that this allowed an attacker who controlled the AEAD key to force the POLYVAL key to be zero. If a user of this AEAD authenticated messages with a secret additional-data value then this would be insecure as the attacker could calculate a valid authenticator without knowing the input. This does not violate the standard properties of an AEAD as the additional data is not assumed to be confidential. However, we want these AEADs to be robust to plausible misuse and also to be drop-in replacements for AES-GCM and so derive nonce-specific POLYVAL keys to avoid this issue.

A security analysis of a similar scheme appears in [GCM-SIV].

10. IANA Considerations

This document has no actions for IANA.

11. Acknowledgements

The authors would like to thank Uri Blumenthal, Ondrej Mosnaček, Daniel Bleichenbacher, Kenny Paterson, Bart Preneel and Deb Cooley's team at IAD for their helpful suggestions.

12. References

12.1. Normative References

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12.2. Informative References

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Appendix A. The relationship between POLYVAL and GHASH

GHASH and POLYVAL both operate in GF(2^128), although with different irreducible polynomials: POLYVAL works modulo x^128 + x^127 + x^126 + x^121 + 1 and GHASH works modulo x^128 + x^7 + x^2 + x + 1. Note that these irreducible polynomials are the "reverse" of each other.

GHASH also has a different mapping between 128-bit strings and field elements. Where as POLYVAL takes the least-significant to most-significant bits of the first byte to be the coefficients of x^0 to x^7, GHASH takes them to be the coefficients of x^7 to x^0. This continues until, for the last byte, POLYVAL takes the least-significant to most-significant bits to be the coefficients of x^120 to x^127 while GHASH takes them to be the coefficients of x^127 to x^120.

The combination of these facts means that it's possible to "convert" values between the two by reversing the order of the bytes in a 16-byte string. The differing interpretations of bit order takes care of reversing the bits within each byte and then reversing the bytes does the rest. This may have a practical benefit for implementations that wish to implement both GHASH and POLYVAL.

In order to be clear which field a given operation is performed in, let mulX_GHASH be a function that takes a 16-byte string, converts it to an element of GHASH's field using GHASH's convention, multiplies it by x and converts back to a string. Likewise, let mulX_POLYVAL be a function that converts a 16-byte string to an element of POLYVAL's field using POLYVAL's convention, multiplies it by x and converts back.

Given the 16-byte string 01000000000000000000000000000000, mulX_GHASH of that string is 00800000000000000000000000000000 and mulX_POLYVAL of that string is 02000000000000000000000000000000. As a more general example, given 9c98c04df9387ded828175a92ba652d8, mulX_GHASH of that string is 4e4c6026fc9c3ef6c140bad495d3296c and mulX_POLYVAL of it is 3931819bf271fada0503eb52574ca5f2.

Lastly, let ByteReverse be the function that takes a 16-byte string and returns a copy where the order of the bytes has been reversed.

Now GHASH and POLYVAL can be defined in terms of one another:

POLYVAL(H, X_1, ..., X_n) =
ByteReverse(GHASH(mulX_GHASH(ByteReverse(H)), ByteReverse(X_1), ..., ByteReverse(X_n)))

GHASH(H, X_1, ..., X_n) =
ByteReverse(POLYVAL(mulX_POLYVAL(ByteReverse(H)), ByteReverse(X_1), ..., ByteReverse(X_n)))

As a worked example, let H = 25629347589242761d31f826ba4b757b, X_1 = 4f4f95668c83dfb6401762bb2d01a262 and X_2 = d1a24ddd2721d006bbe45f20d3c9f362. POLYVAL(H, X_1, X_2) = f7a3b47b846119fae5b7866cf5e5b77e. If we wished to calculate this given only an implementation of GHASH then the key for GHASH would be mulX_GHASH(ByteReverse(H)) = dcbaa5dd137c188ebb21492c23c9b112. Then ByteReverse(GHASH(dcba..., ByteReverse(X_1), ByteReverse(X_2))) = f7a3b47b846119fae5b7866cf5e5b77e, as required.

In the other direction, GHASH(H, X_1, X_2) = bd9b3997046731fb96251b91f9c99d7a. If we wished to calculate this given only an implementation of POLYVAL then we would first calculate the key for POLYVAL, mulX_POLYVAL(ByteReverse(H)), which is f6ea96744df0633aec8424b18e26c54a. Then ByteReverse(POLYVAL(f6ea..., ByteReverse(X_1), ByteReverse(X_2))) = bd9b3997046731fb96251b91f9c99d7a.

Appendix B. Test vectors

B.1. AEAD_AES_128_GCM_SIV

AEAD_AES_128_GCM_SIV:

AAD_len = 0 bytes
MSG_len = 0 bytes

BYTES ORDER
LSB-------------------------MSB

```
                                    000102030405060708090101112131415
                                    --------------------------------

   K1 = K =                         01000000000000000000000000000000
   NONCE =                          03000000000000000000000000000000

   AAD =

   MSG =

   PADDED_AAD =

   PADDED_MSG =

   Record_Hash_Key =                d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                         00000000000000000000000000000000

   POLYVAL xor N =                  d9b360279694941a2010be790ff81954

   TAG =                            dc20e2d83f25705bb49e439eca56de25

   CTRBLK =                         dc20e2d83f25705bb49e439eca56dea5

   Encryption_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                           dc20e2d83f25705bb49e439eca56de25

   AAD =

   CIPHERTEXT =

   Decrypted MSG =
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 8 bytes
                                               BYTES ORDER
                                    LSB-------------------------MSB
                                    000102030405060708090101112131415
                                    --------------------------------
```

```
   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           0100000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        00000000000000004000000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           578782fff6013b815b287c22493a364c

   CTRBLK =                        578782fff6013b815b287c22493a36cc

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          578782fff6013b815b287c22493a364c

   AAD =

   CIPHERTEXT =                    b5d839330ac7b786

   Decrypted MSG =                 0100000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 12 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000
```

```
   AAD =

   MSG =                          01000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                   01000000000000000000000000000000

   Record_Hash_Key =              d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =               4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                       00000000000000006000000000000000

   POLYVAL xor N =                d9b360279694941a2010be790ff81954

   TAG =                          a4978db357391a0bc4fdec8b0d106639

   CTRBLK =                       a4978db357391a0bc4fdec8b0d1066b9

   Encryption_Key =               4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                         a4978db357391a0bc4fdec8b0d106639

   AAD =

   CIPHERTEXT =                   7323ea61d05932260047d942

   Decrypted MSG =                01000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 16 bytes
                                            BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101112131415
                                  --------------------------------

   K1 = K =                       01000000000000000000000000000000
   NONCE =                        03000000000000000000000000000000

   AAD =

   MSG =                          01000000000000000000000000000000
```

```
   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        00000000000000008000000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           303aaf90f6fe21199c6068577437a0c4

   CTRBLK =                        303aaf90f6fe21199c6068577437a0c4

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          303aaf90f6fe21199c6068577437a0c4

   AAD =

   CIPHERTEXT =                    743f7c8077ab25f8624e2e948579cf77

   Decrypted MSG =                 01000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 32 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000000000000
                                   02000000000000000000000000000000

   PADDED_AAD =
```

```
   PADDED_MSG =                    01000000000000000000000000000000
                                   02000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        00000000000000000001000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           1a8e45dcd4578c667cd86847bf6155ff

   CTRBLK =                        1a8e45dcd4578c667cd86847bf6155ff

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          1a8e45dcd4578c667cd86847bf6155ff

   AAD =

   CIPHERTEXT =                    84e07e62ba83a6585417245d7ec413a9
                                   fe427d6315c09b57ce45f2e3936a9445

   Decrypted MSG =                 01000000000000000000000000000000
                                   02000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 48 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000000000000
                                   02000000000000000000000000000000
                                   03000000000000000000000000000000
```

```
   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000
                                   02000000000000000000000000000000
                                   03000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        00000000000000008001000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           5e6e311dbf395d35b0fe39c2714388f8

   CTRBLK =                        5e6e311dbf395d35b0fe39c2714388f8

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          5e6e311dbf395d35b0fe39c2714388f8

   AAD =

   CIPHERTEXT =                    3fd24ce1f5a67b75bf2351f181a475c7
                                   b800a5b4d3dcf70106b1eea82fa1d64d
                                   f42bf7226122fa92e17a40eeaac1201b

   Decrypted MSG =                 01000000000000000000000000000000
                                   02000000000000000000000000000000
                                   03000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 64 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =
```

```
   MSG =                          01000000000000000000000000000000
                                  02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                   01000000000000000000000000000000
                                  02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   Record_Hash_Key =              d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =               4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                       00000000000000000002000000000000

   POLYVAL xor N =                d9b360279694941a2010be790ff81954

   TAG =                          8a263dd317aa88d56bdf3936dba75bb8

   CTRBLK =                       8a263dd317aa88d56bdf3936dba75bb8

   Encryption_Key =               4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                         8a263dd317aa88d56bdf3936dba75bb8

   AAD =

   CIPHERTEXT =                   2433668f1058190f6d43e360f4f35cd8
                                  e475127cfca7028ea8ab5c20f7ab2af0
                                  2516a2bdcbc08d521be37ff28c152bba
                                  36697f25b4cd169c6590d1dd39566d3f

   Decrypted MSG =                01000000000000000000000000000000
                                  02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 8 bytes
                                                BYTES ORDER
```

```
                                LSB-------------------------MSB
                                000102030405060708090101112131415
                                --------------------------------

   K1 = K =                     01000000000000000000000000000000
   NONCE =                      03000000000000000000000000000000

   AAD =                        01

   MSG =                        0200000000000000

   PADDED_AAD =                 01000000000000000000000000000000

   PADDED_MSG =                 02000000000000000000000000000000

   Record_Hash_Key =            d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =             4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                     08000000000000004000000000000000

   POLYVAL xor N =              d9b360279694941a2010be790ff81954

   TAG =                        3b0a1a2560969cdf790d99759abd1508

   CTRBLK =                     3b0a1a2560969cdf790d99759abd1588

   Encryption_Key =             4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                       3b0a1a2560969cdf790d99759abd1508

   AAD =                        01

   CIPHERTEXT =                 1e6daba35669f427

   Decrypted MSG =              0200000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 12 bytes
                                          BYTES ORDER
                                LSB-------------------------MSB
                                000102030405060708090101112131415
                                --------------------------------
```

```
   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01

   MSG =                           02000000000000000000000000

   PADDED_AAD =                    01000000000000000000000000000000

   PADDED_MSG =                    02000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        08000000000000006000000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           08299c5102745aaa3a0c469fad9e075a

   CTRBLK =                        08299c5102745aaa3a0c469fad9e07da

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          08299c5102745aaa3a0c469fad9e075a

   AAD =                           01

   CIPHERTEXT =                    296c7889fd99f41917f44620

   Decrypted MSG =                 02000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 16 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000
```

```
   AAD =                          01

   MSG =                          02000000000000000000000000000000

   PADDED_AAD =                   01000000000000000000000000000000

   PADDED_MSG =                   02000000000000000000000000000000

   Record_Hash_Key =              d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =               4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                       08000000000000008000000000000000

   POLYVAL xor N =                d9b360279694941a2010be790ff81954

   TAG =                          8f8936ec039e4e4bb97ebd8c4457441f

   CTRBLK =                       8f8936ec039e4e4bb97ebd8c4457449f

   Encryption_Key =               4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                         8f8936ec039e4e4bb97ebd8c4457441f

   AAD =                          01

   CIPHERTEXT =                   e2b0c5da79a901c1745f700525cb335b

   Decrypted MSG =                02000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 32 bytes
                                        BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101112131415
                                  --------------------------------

   K1 = K =                       01000000000000000000000000000000
   NONCE =                        03000000000000000000000000000000

   AAD =                          01

   MSG =                          02000000000000000000000000000000
```

```
                                 03000000000000000000000000000000

   PADDED_AAD =                  01000000000000000000000000000000

   PADDED_MSG =                  02000000000000000000000000000000
                                 03000000000000000000000000000000

   Record_Hash_Key =             d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =              4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                      08000000000000000001000000000000

   POLYVAL xor N =               d9b360279694941a2010be790ff81954

   TAG =                         e6af6a7f87287da059a71684ed3498e1

   CTRBLK =                      e6af6a7f87287da059a71684ed3498e1

   Encryption_Key =              4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                        e6af6a7f87287da059a71684ed3498e1

   AAD =                         01

   CIPHERTEXT =                  620048ef3c1e73e57e02bb8562c416a3
                                 19e73e4caac8e96a1ecb2933145a1d71

   Decrypted MSG =               02000000000000000000000000000000
                                 03000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   *****************************
   Performing SIV_GCM - Two Keys:
   *****************************

   AAD_len = 1 bytes
   MSG_len = 48 bytes
                                             BYTES ORDER
                                 LSB--------------------------MSB
                                 00010203040506070809101112131415
                                 --------------------------------

   K1 = K =                      01000000000000000000000000000000
   NONCE =                       03000000000000000000000000000000

   AAD =                         01
```

```
   MSG =                          02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   PADDED_AAD =                   01000000000000000000000000000000

   PADDED_MSG =                   02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   Record_Hash_Key =              d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =               4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                       08000000000000008001000000000000

   POLYVAL xor N =                d9b360279694941a2010be790ff81954

   TAG =                          6a8cc3865f76897c2e4b245cf31c51f2

   CTRBLK =                       6a8cc3865f76897c2e4b245cf31c51f2

   Encryption_Key =               4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                         6a8cc3865f76897c2e4b245cf31c51f2

   AAD =                          01

   CIPHERTEXT =                   50c8303ea93925d64090d07bd109dfd9
                                  515a5a33431019c17d93465999a8b005
                                  3201d723120a8562b838cdff25bf9d1e

   Decrypted MSG =                02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 64 bytes
                                            BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101112131415
                                  --------------------------------
```

```
   K1 = K =                        01000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01

   MSG =                           02000000000000000000000000000000
                                   03000000000000000000000000000000
                                   04000000000000000000000000000000
                                   05000000000000000000000000000000

   PADDED_AAD =                    01000000000000000000000000000000

   PADDED_MSG =                    02000000000000000000000000000000
                                   03000000000000000000000000000000
                                   04000000000000000000000000000000
                                   05000000000000000000000000000000

   Record_Hash_Key =               d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                        08000000000000000002000000000000

   POLYVAL xor N =                 d9b360279694941a2010be790ff81954

   TAG =                           cdc46ae475563de037001ef84ae21744

   CTRBLK =                        cdc46ae475563de037001ef84ae217c4

   Encryption_Key =                4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                          cdc46ae475563de037001ef84ae21744

   AAD =                           01

   CIPHERTEXT =                    2f5c64059db55ee0fb847ed513003746
                                   aca4e61c711b5de2e7a77ffd02da42fe
                                   ec601910d3467bb8b36ebbaebce5fba3
                                   0d36c95f48a3e7980f0e7ac299332a80

   Decrypted MSG =                 02000000000000000000000000000000
                                   03000000000000000000000000000000
                                   04000000000000000000000000000000
                                   05000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
```

```
   ****************************

   AAD_len = 12 bytes
   MSG_len = 4 bytes
                                              BYTES ORDER
                                    LSB-------------------------MSB
                                    000102030405060708090101112131415
                                    --------------------------------

   K1 = K =                         01000000000000000000000000000000
   NONCE =                          03000000000000000000000000000000

   AAD =                            010000000000000000000000

   MSG =                            02000000

   PADDED_AAD =                     01000000000000000000000000000000

   PADDED_MSG =                     02000000000000000000000000000000

   Record_Hash_Key =                d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                         60000000000000002000000000000000

   POLYVAL xor N =                  d9b360279694941a2010be790ff81954

   TAG =                            07eb1f84fb28f8cb73de8e99e2f48a14

   CTRBLK =                         07eb1f84fb28f8cb73de8e99e2f48a94

   Encryption_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                           07eb1f84fb28f8cb73de8e99e2f48a14

   AAD =                            010000000000000000000000

   CIPHERTEXT =                     a8fe3e87

   Decrypted MSG =                  02000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 18 bytes
```

```
   MSG_len = 20 bytes
                                          BYTES ORDER
                                    LSB-------------------------MSB
                                    000102030405060708090101112131415
                                    --------------------------------

   K1 = K =                         01000000000000000000000000000000
   NONCE =                          03000000000000000000000000000000

   AAD =                            01000000000000000000000000000000
                                    0200

   MSG =                            03000000000000000000000000000000
                                    04000000

   PADDED_AAD =                     01000000000000000000000000000000
                                    02000000000000000000000000000000

   PADDED_MSG =                     03000000000000000000000000000000
                                    04000000000000000000000000000000

   Record_Hash_Key =                d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                         900000000000000a000000000000000

   POLYVAL xor N =                  d9b360279694941a2010be790ff81954

   TAG =                            24afc9805e976f451e6d87f6fe106514

   CTRBLK =                         24afc9805e976f451e6d87f6fe106594

   Encryption_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                           24afc9805e976f451e6d87f6fe106514

   AAD =                            01000000000000000000000000000000
                                    0200

   CIPHERTEXT =                     6bb0fecf5ded9b77f902c7d5da236a43
                                    91dd0297

   Decrypted MSG =                  03000000000000000000000000000000
                                    04000000
   SIV_GCM_2_KEYS Passed

   ****************************
```

```
   Performing SIV_GCM - Two Keys:
   ******************************

   AAD_len = 20 bytes
   MSG_len = 18 bytes
                                              BYTES ORDER
                                    LSB-------------------------MSB
                                    000102030405060708090101121314 15
                                    --------------------------------

   K1 = K =                         01000000000000000000000000000000
   NONCE =                          03000000000000000000000000000000

   AAD =                            01000000000000000000000000000000
                                    02000000

   MSG =                            03000000000000000000000000000000
                                    0400

   PADDED_AAD =                     01000000000000000000000000000000
                                    02000000000000000000000000000000

   PADDED_MSG =                     03000000000000000000000000000000
                                    04000000000000000000000000000000

   Record_Hash_Key =                d9b360279694941ac5dbc6987ada7377

   Record_Enc_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   LENBLK =                         a0000000000000090000000000000000

   POLYVAL xor N =                  d9b360279694941a2010be790ff81954

   TAG =                            bff9b2ef00fb47920cc72a0c0f13b9fd

   CTRBLK =                         bff9b2ef00fb47920cc72a0c0f13b9fd

   Encryption_Key =                 4004a0dcd862f2a57360219d2d44ef6c

   TAG' =                           bff9b2ef00fb47920cc72a0c0f13b9fd

   AAD =                            01000000000000000000000000000000
                                    02000000

   CIPHERTEXT =                     44d0aaf6fb2f1f34add5e8064e83e12a
                                    2ada

   Decrypted MSG =                  03000000000000000000000000000000
```

0400

SIV_GCM_2_KEYS Passed

AEAD_AES_256_GCM_SIV:

AAD_len = 0 bytes
MSG_len = 0 bytes

	BYTES ORDER
	LSB----------MSB
	000102030405060708090101112131415

K1 = K =	01000000000000000000000000000000
	00000000000000000000000000000000
NONCE =	03000000000000000000000000000000
AAD =	
MSG =	
PADDED_AAD =	
PADDED_MSG =	
LENBLK =	00000000000000000000000000000000
POLYVAL xor N =	03000000000000000000000000000000
with_MSbit_cleared =	03000000000000000000000000000000
TAG =	07f5f4169bbf55a8400cd47ea6fd400f
CTRBLK =	07f5f4169bbf55a8400cd47ea6fd408f
Record_Hash_Key =	b5d3c529dfafac43136d2d11be284d7f
Encryption_Key =	b914f4742be9e1d7a2f84addbf96dec3
	456e3c6c05ecc157cdbf0700fedad222
TAG' =	07f5f4169bbf55a8400cd47ea6fd400f
AAD =	
CIPHERTEXT =	

```
   Decrypted MSG =
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 8 bytes
                                        BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           0100000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000

   LENBLK =                        00000000000000004000000000000000

   POLYVAL xor N =                 06230f62f0eac8aa14fe4d646b59cd41

   with_MSbit_cleared =            06230f62f0eac8aa14fe4d646b59cd41

   TAG =                           843122130f7364b761e0b97427e3df28

   CTRBLK =                        843122130f7364b761e0b97427e3dfa8

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          843122130f7364b761e0b97427e3df28

   AAD =

   CIPHERTEXT =                    c2ef328e5c71c83b
```

```
   Decrypted MSG =                 0100000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 12 bytes
                                            BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000

   LENBLK =                        00000000000000006000000000000000

   POLYVAL xor N =                 6e81a24732fd6d03ae5af544720a1c13

   with_MSbit_cleared =            6e81a24732fd6d03ae5af544720a1c13

   TAG =                           8ca50da9ae6559e48fd10f6e5c9ca17e

   CTRBLK =                        8ca50da9ae6559e48fd10f6e5c9ca1fe

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          8ca50da9ae6559e48fd10f6e5c9ca17e

   AAD =

   CIPHERTEXT =                    9aab2aeb3faa0a34aea8e2b1
```

```
   Decrypted MSG =                 01000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 16 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000

   LENBLK =                        00000000000000008000000000000000

   POLYVAL xor N =                 77eee2bf7c9a165f8b25dea73db32a6d

   with_MSbit_cleared =            77eee2bf7c9a165f8b25dea73db32a6d

   TAG =                           c9eac6fa700942702e90862383c6c366

   CTRBLK =                        c9eac6fa700942702e90862383c6c3e6

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          c9eac6fa700942702e90862383c6c366

   AAD =

   CIPHERTEXT =                    85a01b63025ba19b7fd3ddfc033b3e76
```

```
   Decrypted MSG =                 01000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 32 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101121314 15
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000000000000
                                   02000000000000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000
                                   02000000000000000000000000000000

   LENBLK =                        00000000000000000001000000000000

   POLYVAL xor N =                 8a9b6381b3d46f0def7aa0517ba188f5

   with_MSbit_cleared =            8a9b6381b3d46f0def7aa0517ba18875

   TAG =                           e819e63abcd020b006a976397632eb5d

   CTRBLK =                        e819e63abcd020b006a976397632ebdd

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          e819e63abcd020b006a976397632eb5d

   AAD =
```

```
   CIPHERTEXT =                    4a6a9db4c8c6549201b9edb53006cba8
                                   21ec9cf850948a7c86c68ac7539d027f

   Decrypted MSG =                 01000000000000000000000000000000
                                   02000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 48 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =

   MSG =                           01000000000000000000000000000000
                                   02000000000000000000000000000000
                                   03000000000000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                    01000000000000000000000000000000
                                   02000000000000000000000000000000
                                   03000000000000000000000000000000

   LENBLK =                        00000000000000008001000000000000

   POLYVAL xor N =                 c2f8593d8fc29b0c290cae1992f71f51

   with_MSbit_cleared =            c2f8593d8fc29b0c290cae1992f71f51

   TAG =                           790bc96880a99ba804bd12c0e6a22cc4

   CTRBLK =                        790bc96880a99ba804bd12c0e6a22cc4

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3
```

```
                                456e3c6c05ecc157cdbf0700fedad222

   TAG' =                       790bc96880a99ba804bd12c0e6a22cc4

   AAD =

   CIPHERTEXT =                 c00d121893a9fa603f48ccc1ca3c57ce
                                7499245ea0046db16c53c7c66fe717e3
                                9cf6c748837b61f6ee3adcee17534ed5

   Decrypted MSG =              01000000000000000000000000000000
                                02000000000000000000000000000000
                                03000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 0 bytes
   MSG_len = 64 bytes
                                          BYTES ORDER
                                LSB-------------------------MSB
                                000102030405060708090101112131415
                                --------------------------------

   K1 = K =                     01000000000000000000000000000000
                                00000000000000000000000000000000
   NONCE =                      03000000000000000000000000000000

   AAD =

   MSG =                        01000000000000000000000000000000
                                02000000000000000000000000000000
                                03000000000000000000000000000000
                                04000000000000000000000000000000

   PADDED_AAD =

   PADDED_MSG =                 01000000000000000000000000000000
                                02000000000000000000000000000000
                                03000000000000000000000000000000
                                04000000000000000000000000000000

   LENBLK =                     00000000000000000002000000000000

   POLYVAL xor N =              6df38b06046c7c0e225efaef8e2ec4c4
```

```
   with_MSbit_cleared =          6df38b06046c7c0e225efaef8e2ec444

   TAG =                         112864c269fc0d9d88c61fa47e39aa08

   CTRBLK =                      112864c269fc0d9d88c61fa47e39aa88

   Record_Hash_Key =             b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =              b914f4742be9e1d7a2f84addbf96dec3

                                 456e3c6c05ecc157cdbf0700fedad222

   TAG' =                        112864c269fc0d9d88c61fa47e39aa08

   AAD =

   CIPHERTEXT =                  c2d5160a1f8683834910acdafc41fbb1
                                 632d4a353e8b905ec9a5499ac34f96c7
                                 e1049eb080883891a4db8caaa1f99dd0
                                 04d80487540735234e3744512c6f90ce

   Decrypted MSG =               01000000000000000000000000000000
                                 02000000000000000000000000000000
                                 03000000000000000000000000000000
                                 04000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 8 bytes
                                           BYTES ORDER
                                 LSB-------------------------MSB
                                 000102030405060708090101112131415
                                 --------------------------------

   K1 = K =                      01000000000000000000000000000000
                                 00000000000000000000000000000000
   NONCE =                       03000000000000000000000000000000

   AAD =                         01

   MSG =                         0200000000000000

   PADDED_AAD =                  01000000000000000000000000000000
```

```
   PADDED_MSG =                    02000000000000000000000000000000

   LENBLK =                        08000000000000004000000000000000

   POLYVAL xor N =                 37e57bafe011b9b36fc6821b7ffb3354

   with_MSbit_cleared =            37e57bafe011b9b36fc6821b7ffb3354

   TAG =                           91213f267e3b452f02d01ae33e4ec854

   CTRBLK =                        91213f267e3b452f02d01ae33e4ec8d4

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          91213f267e3b452f02d01ae33e4ec854

   AAD =                           01

   CIPHERTEXT =                    1de22967237a8132

   Decrypted MSG =                 0200000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 12 bytes
                                              BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01

   MSG =                           020000000000000000000000

   PADDED_AAD =                    01000000000000000000000000000000
```

```
   PADDED_MSG =                    02000000000000000000000000000000

   LENBLK =                        08000000000000006000000000000000

   POLYVAL xor N =                 5f47d68a22061c1ad5623a3b66a8e206

   with_MSbit_cleared =            5f47d68a22061c1ad5623a3b66a8e206

   TAG =                           c1a4a19ae800941ccdc57cc8413c277f

   CTRBLK =                        c1a4a19ae800941ccdc57cc8413c27ff

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          c1a4a19ae800941ccdc57cc8413c277f

   AAD =                           01

   CIPHERTEXT =                    163d6f9cc1b346cd453a2e4c

   Decrypted MSG =                 020000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 16 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101121314l5
                                   --------------------------------

   K1 = K =                        010000000000000000000000000000000
                                   000000000000000000000000000000000
   NONCE =                         030000000000000000000000000000000

   AAD =                           01

   MSG =                           020000000000000000000000000000000

   PADDED_AAD =                    010000000000000000000000000000000
```

```
   PADDED_MSG =                    02000000000000000000000000000000

   LENBLK =                        08000000000000008000000000000000

   POLYVAL xor N =                 462896726c616746f01d11d82911d478

   with_MSbit_cleared =            462896726c616746f01d11d82911d478

   TAG =                           b292d28ff61189e8e49f3875ef91aff7

   CTRBLK =                        b292d28ff61189e8e49f3875ef91aff7

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          b292d28ff61189e8e49f3875ef91aff7

   AAD =                           01

   CIPHERTEXT =                    c91545823cc24f17dbb0e9e807d5ec17

   Decrypted MSG =                 02000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 32 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01

   MSG =                           02000000000000000000000000000000
                                   03000000000000000000000000000000

   PADDED_AAD =                    01000000000000000000000000000000
```

```
   PADDED_MSG =                    02000000000000000000000000000000
                                   03000000000000000000000000000000

   LENBLK =                        08000000000000000001000000000000

   POLYVAL xor N =                 4d58c1e341c9bb0ae34eda9509dfc90c

   with_MSbit_cleared =            4d58c1e341c9bb0ae34eda9509dfc90c

   TAG =                           aea1bad12702e1965604374aab96dbbc

   CTRBLK =                        aea1bad12702e1965604374aab96dbbc

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3

                                   456e3c6c05ecc157cdbf0700fedad222

   TAG' =                          aea1bad12702e1965604374aab96dbbc

   AAD =                           01

   CIPHERTEXT =                    07dad364bfc2b9da89116d7bef6daaaf
                                   6f255510aa654f920ac81b94e8bad365

   Decrypted MSG =                 02000000000000000000000000000000
                                   03000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 48 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01

   MSG =                           02000000000000000000000000000000
```

```
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   PADDED_AAD =                   01000000000000000000000000000000

   PADDED_MSG =                   02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000

   LENBLK =                       08000000000000008001000000000000

   POLYVAL xor N =                2666a4aff9a525df9772c16d4eaf8d2a

   with_MSbit_cleared =           2666a4aff9a525df9772c16d4eaf8d2a

   TAG =                          03332742b228c647173616cfd44c54eb

   CTRBLK =                       03332742b228c647173616cfd44c54eb

   Record_Hash_Key =              b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =               b914f4742be9e1d7a2f84addbf96dec3

                                  456e3c6c05ecc157cdbf0700fedad222

   TAG' =                         03332742b228c647173616cfd44c54eb

   AAD =                          01

   CIPHERTEXT =                   c67a1f0f567a5198aa1fcc8e3f213143
                                  36f7f51ca8b1af61feac35a86416fa47
                                  fbca3b5f749cdf564527f2314f42fe25

   Decrypted MSG =                02000000000000000000000000000000
                                  03000000000000000000000000000000
                                  04000000000000000000000000000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 1 bytes
   MSG_len = 64 bytes
                                            BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101112131415
                                  --------------------------------
```

```
   K1 = K =                    01000000000000000000000000000000
                               00000000000000000000000000000000
   NONCE =                     03000000000000000000000000000000

   AAD =                       01

   MSG =                       02000000000000000000000000000000
                               03000000000000000000000000000000
                               04000000000000000000000000000000
                               05000000000000000000000000000000

   PADDED_AAD =                01000000000000000000000000000000

   PADDED_MSG =                02000000000000000000000000000000
                               03000000000000000000000000000000
                               04000000000000000000000000000000
                               05000000000000000000000000000000

   LENBLK =                    08000000000000000002000000000000

   POLYVAL xor N =             d958d2f61b0a9d343b2f37fb0c519733

   with_MSbit_cleared =        d958d2f61b0a9d343b2f37fb0c519733

   TAG =                       5bde0285037c5de81e5b570a049b62a0

   CTRBLK =                    5bde0285037c5de81e5b570a049b62a0

   Record_Hash_Key =           b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =            b914f4742be9e1d7a2f84addbf96dec3

                               456e3c6c05ecc157cdbf0700fedad222

   TAG' =                      5bde0285037c5de81e5b570a049b62a0

   AAD =                       01

   CIPHERTEXT =                67fd45e126bfb9a79930c43aad2d3696
                               7d3f0e4d217c1e551f59727870beefc9
                               8cb933a8fce9de887b1e40799988db1f
                               c3f91880ed405b2dd298318858467c89

   Decrypted MSG =             02000000000000000000000000000000
                               03000000000000000000000000000000
                               04000000000000000000000000000000
                               05000000000000000000000000000000
   SIV_GCM_2_KEYS Passed
```

```
   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 12 bytes
   MSG_len = 4 bytes
                                          BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101121314 15
                                  --------------------------------

   K1 = K =                       01000000000000000000000000000000
                                  00000000000000000000000000000000
   NONCE =                        03000000000000000000000000000000

   AAD =                          010000000000000000000000

   MSG =                          02000000

   PADDED_AAD =                   01000000000000000000000000000000

   PADDED_MSG =                   02000000000000000000000000000000

   LENBLK =                       60000000000000002000000000000000

   POLYVAL xor N =                6ec76ae84b88916e073a303aafde05cf

   with_MSbit_cleared =           6ec76ae84b88916e073a303aafde054f

   TAG =                          1835e517741dfddccfa07fa4661b74cf

   CTRBLK =                       1835e517741dfddccfa07fa4661b74cf

   Record_Hash_Key =              b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =               b914f4742be9e1d7a2f84addbf96dec3

                                  456e3c6c05ecc157cdbf0700fedad222

   TAG' =                         1835e517741dfddccfa07fa4661b74cf

   AAD =                          010000000000000000000000

   CIPHERTEXT =                   22b3f4cd

   Decrypted MSG =                02000000
   SIV_GCM_2_KEYS Passed
```

```
   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 18 bytes
   MSG_len = 20 bytes
                                          BYTES ORDER
                                  LSB-------------------------MSB
                                  000102030405060708090101121314 15
                                  --------------------------------

   K1 = K =                       01000000000000000000000000000000
                                  00000000000000000000000000000000
   NONCE =                        03000000000000000000000000000000

   AAD =                          01000000000000000000000000000000
                                  0200

   MSG =                          03000000000000000000000000000000
                                  04000000

   PADDED_AAD =                   01000000000000000000000000000000
                                  02000000000000000000000000000000

   PADDED_MSG =                   03000000000000000000000000000000
                                  04000000000000000000000000000000

   LENBLK =                       90000000000000a000000000000000

   POLYVAL xor N =                943ef4fd04bd31d193816ab26f8655ca

   with_MSbit_cleared =           943ef4fd04bd31d193816ab26f86554a

   TAG =                          b879ad976d8242acc188ab59cabfe307

   CTRBLK =                       b879ad976d8242acc188ab59cabfe387

   Record_Hash_Key =              b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =               b914f4742be9e1d7a2f84addbf96dec3

                                  456e3c6c05ecc157cdbf0700fedad222

   TAG' =                         b879ad976d8242acc188ab59cabfe307

   AAD =                          01000000000000000000000000000000
                                  0200
```

```
   CIPHERTEXT =                    43dd0163cdb48f9fe3212bf61b201976
                                   067f342b

   Decrypted MSG =                 03000000000000000000000000000000
                                   04000000
   SIV_GCM_2_KEYS Passed

   ****************************
   Performing SIV_GCM - Two Keys:
   ****************************

   AAD_len = 20 bytes
   MSG_len = 18 bytes
                                             BYTES ORDER
                                   LSB-------------------------MSB
                                   000102030405060708090101112131415
                                   --------------------------------

   K1 = K =                        01000000000000000000000000000000
                                   00000000000000000000000000000000
   NONCE =                         03000000000000000000000000000000

   AAD =                           01000000000000000000000000000000
                                   02000000

   MSG =                           03000000000000000000000000000000
                                   0400

   PADDED_AAD =                    01000000000000000000000000000000
                                   02000000000000000000000000000000

   PADDED_MSG =                    03000000000000000000000000000000
                                   04000000000000000000000000000000

   LENBLK =                        a0000000000000009000000000000000

   POLYVAL xor N =                 2fbb6b7ab2dbffefb797f825f826870c

   with_MSbit_cleared =            2fbb6b7ab2dbffefb797f825f826870c

   TAG =                           cfcdf5042112aa29685c912fc2056543

   CTRBLK =                        cfcdf5042112aa29685c912fc20565c3

   Record_Hash_Key =               b5d3c529dfafac43136d2d11be284d7f

   Encryption_Key =                b914f4742be9e1d7a2f84addbf96dec3
```

```
                                456e3c6c05ecc157cdbf0700fedad222

   TAG' =                       cfcdf5042112aa29685c912fc2056543

   AAD =                        01000000000000000000000000000000
                                02000000

   CIPHERTEXT =                 462401724b5ce6588d5a54aae5375513
                                a075

   Decrypted MSG =              03000000000000000000000000000000
                                0400
   SIV_GCM_2_KEYS Passed
```

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