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# **Draft Proposal for Tweakable Wide-block Encryption**

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**Abstract:** We describe the EME-32-AES tweakable block cipher and its use of for encryption of storage. EME-32-AES is a tweakable block cipher that acts on wide blocks of 512 bytes, and it uses as subroutine the AES block cipher (that acts on blocks of 16 bytes). Specifically, EME-32-AES encrypts and decrypts wide blocks of 512 bytes, under the control of a secret AES *key* (that can be 16, 24, or 32 bytes) and a non-secret 16-byte *tweak*. EME-32-AES is a concrete instantiation of the EME mode of operation, as described in reference [HR04]. When used to encrypt storage data, the tweak value is computed as the logical position of the current wide block within the scope of the current key.

The motivating application for EME-32-AES is encryption of storage at the sector level. In this application, sectors are typically of length 512 bytes, and one may use the address of the sector on the disk as the tweak value.

**Keywords:** Encryption, storage.

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## 1. Status summary

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## 2. Overview

### 2.1 Scope and purpose

The purpose of this document is to specify the EME-32-AES transform and its use for encryption of data at rest. The EME-32-AES transform acts on wide blocks of 512 bytes, under the control of a secret key and a non-secret tweak. It is implemented as a mode of operation for the AES block cipher (that has blocks of size 16 bytes). The security goal of EME-32-AES states that it should look like a block cipher (with “wide blocks” of size 512 bytes). Moreover, using the same key with different tweaks should look like using completely independent keys.

EME-32-AES is a concrete instantiation of the EME mode of operation, which is described in reference [HR04]. The EME mode of operation uses a block cipher with  $n$ -byte blocks, and turns it into a tweakable cipher with blocks of size upto  $8n^2$  bytes. It is proven in [HR04] that the EME mode indeed achieves the stated security goal, assuming that the underlying block cipher is secure.

An example application for this transform is encryption of storage at the sector level, where the encrypting device is not aware of high-level concepts like files and directories. The disk is often partitioned into fixed-length sectors (typically 512 bytes), and the encrypting device is given one sector at a time, in arbitrary order, to encrypt or decrypt. The device needs to operate on sectors as they arrive, independently of the rest. Moreover, the ciphertext must have the same length as its plaintext. On the other hand, it is possible to vary the encryption/decryption process, based on the location on the disk where the ciphertext is stored. The dependency on the location allows that identical plaintext sectors stored at different places on the disk will have unrelated ciphertexts.

This document includes the description of the EME-32-AES transform itself (in both encryption and decryption modes), as well as how it should be used for encryption of data at rest. The scope is limited to encryption of storage data, consisting of an integral number of 512-byte blocks. Throughout this document, a block of 512 consecutive bytes is referred to as a “wide block”. Encryption of storage data that uses blocks of different size (or variable length blocks) is expected to be out of scope for this document.

### 2.2 Related work

Efforts to construct a block cipher with a large block-size from one with a smaller block-size go back to Luby and Rackoff [LR88], whose work can be viewed as doubling the block-size. They were also the first to formally define the security goal of a block cipher. The first attempt to directly construct a cipher with very large blocks from one with small blocks is due to Zheng, Matsumoto, and Imai [ZMI89]. Naor and Reingold describe in [NR98,NR99] an elegant approach doing just that, using a layer of ECB encryption that is “sandwiched” between two layers of non-cryptographic hashing. In practice, however, instantiating the layers of “non-cryptographic hashing” turn out to be problematic. A mode of operation similar to EME (called CMC) was proposed by Halevi and Rogaway in [HR03]. The main difference between CMC and EME is that the latter is parallelizable, whereas the former is not. A different approach for constructing a block cipher with large blocks is to build it cipher from scratch, as with BEAR, LION [AB96], and Mercy [C00].

The formal definition of the security goal of a tweakable block-cipher is due to Liskov, Rivest, and Wagner [LRW02], where they also show how (narrow-block) tweakable ciphers can be built from standard block ciphers. An earlier work by Schroepel suggested the idea of a tweakable block-cipher, by designing a cipher that natively incorporates a tweak [S98].

### 3. References

- [R1] ANSI/ISO 9899-1990, Programming Language—C.<sup>1,2</sup>
- [R2] NIST FIPS-197, Federal Information Processing Standard (FIPS) for the Advanced Encryption Standard.<sup>3</sup>

All the standards listed are normative references. Informative references are given in Annex A. At the time of publication, the editions indicated were valid.

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<sup>1</sup> Replaces ANSI X3.159-1989.

<sup>2</sup> ISO documents are available from ISO Central Secretariat, 1 rue de Varembe, Case Postale 56, CH-1211, Genève 20, Switzerland/Suisse; and from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036-8002, USA

<sup>3</sup> FIPS publications are available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA, USA. FIPS-197 is also available on-line from <http://csrc.nist.gov/CryptoToolkit/aes/>

## 4. Definitions

### 4.1 Conformance levels

**4.1.1 expected:** A key word used to describe the behavior of the hardware or software in the design models *assumed* by this specification. Other hardware and software design models may also be implemented.

**4.1.2 may:** A key word indicating flexibility of choice with *no implied preference*.

**4.1.3 shall:** A key word indicating a mandatory requirement. Designers are *required* to implement all such mandatory requirements.

**4.1.4 should:** A key word indicating flexibility of choice with a strongly preferred alternative. Equivalent to the phrase *is recommended*.

**4.1.5 reserved fields:** A set of bits within a data structure that is defined in this specification as reserved, and is not otherwise used. Implementations of this specification shall zero these fields. Future revisions of this specification, however, may define their usage.

**4.1.6 reserved values:** A set of values for a field that are defined in this specification as reserved, and are not otherwise used. Implementations of this specification shall not generate these values for the field. Future revisions of this specification, however, may define their usage.

NOTE — These conformance definitions are used throughout IEEE standards and should therefore never be changed.

### 4.2 Glossary of terms

**4.2.1 byte:** Eight bits of data, used as a synonym for octet.

**4.2.2 doublet:** Two bytes of data.

**4.2.3 quadlet:** Four bytes of data.

**4.2.4 octlet:** Eight bytes of data.

**3.2.5 block:** Sixteen bytes of data.

**3.2.6 wide block:** Five hundred and twelve bytes of data.

### 4.3 Acronyms and abbreviations

IEEE The Institute of Electrical and Electronics Engineers, Inc.

### 4.4 Numerical values

Decimal, hexadecimal, and binary numbers are used within this document. For clarity, decimal numbers are generally used to represent counts, hexadecimal numbers are used to represent addresses, and binary numbers are used to describe bit patterns within binary fields.

Decimal numbers are represented in their usual 0, 1, 2, ... format. Hexadecimal numbers are represented by a string of one or more hexadecimal (0-9,A-F) digits followed by the subscript 16, except in C-code contexts, where they are written as `0x123EF2` etc. Binary numbers are represented by a string of one or more binary (0,1) digits, followed by the subscript 2. Thus the decimal number “26” may also be represented as “ $1A_{16}$ ” or “ $11010_2$ ”.

### 4.5 Field names

This document describes values that are in memory-resident or control-and-status registers (CSRs). For clarity, names of these values have an italics font and contain the context as well as field names, as illustrated in Table 4.1.

**Table 4.1 — Names of registers and fields**

<b>Name</b>	<b>Description</b>
<i>MoverCsr.control</i>	The mover’s control register.
<i>Command.code</i>	The code field within a command entry
<i>Status.count</i>	The count field within a status entry

Note that run-together names like “*MoverCsr*” are preferred because they are more compact than underscore-separated names (like “*Mover\_Csr*”). The use of multiword names with spaces (like “Mover CSR” is avoided, to avoid confusion between commonly used capitalized key words and the capitalized word used at the start of each sentence. Capitalization may, however, be useful for differentiating between different types of key words. For example: the upper case *MoverCsr*, *Command*, and *Status* names refer to CSR registers and the lower case *control*, *code*, and *count* names refer to fields within these registers.

### 4.6 Notations for block encryption and decryption

Subject to the procedures described in publication [R2] (AES), we denote by  $C = \text{AES-enc}(K; P)$  the operation of applying the encryption procedure from [R2], when  $K$  is an array of 16, 24 or 32 bytes that is used as the encryption key, and  $P$  is a block of 16 bytes. The result of this operation is a block of 16 bytes, which is denoted  $C$ . Similarly, we denote by  $P = \text{AES-dec}(K; C)$  the operation of applying the decryption procedure from [R2], when  $K$  is an array of 16, 24 or 32 bytes that is used as the encryption key, and  $C$  is a block of 16 bytes. The result of this operation is a block of 16 bytes, which is denoted  $P$ .

## 4.7 C-code notation

The behavior of many commands is frequently specified by C code, such as in Equation 4.1. To differentiate this code from textual descriptions, such C code listings are formatted using a fixed-width Courier font. Similar C-code segments are included within some figures.

```
// Return maximum of a and b values
Max(a,b) {
    if (a<b)
        return(LT);
    if (a>b)
        return(GT);
    return(EQ);
}
```

4.1

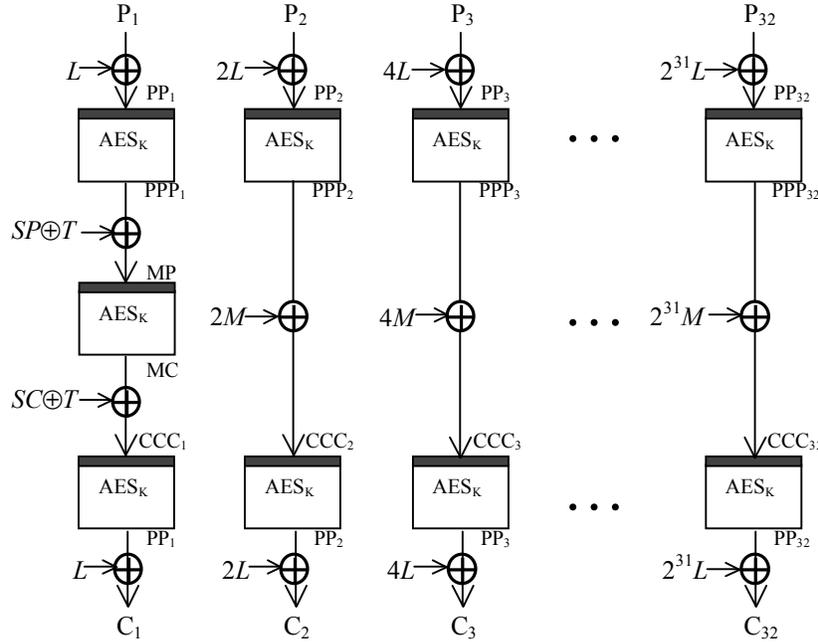
Since the meaning of many C code operators are not obvious to the casual reader, their meanings are summarized in Table 4.2.

**Table 4.2—C code expressions**

Expression	Description
$\sim i$	Bitwise complement of integer $i$
$i \wedge j$	Bitwise EXOR of integers $i$ and $j$
$i \& j$	Bitwise AND of integers $i$ and $j$
$i \ll j$	Left shift of bits in $i$ by value of $j$
$i * j$	Arithmetic multiplication of integers $i$ and $j$
$!i$	Logical negation of Boolean value $i$
$i \&\& j$	Logical AND of Boolean $i$ and $j$ values
$i \ \  j$	Logical OR of Boolean $i$ and $j$ values
$i \wedge = j$	Equivalent to $i = i \wedge j$ .
$i == j$	Equality test, true if $i$ equals $j$
$i != j$	Equality test, true if $i$ does not equal $j$
$i < j$	Inequality test, true if $i$ is less than $j$
$i > j$	Inequality test, true if $i$ is greater than $j$

## 5. The EME-32-AES transform

In this section we describe the EME-32-AES transform itself. That is, the procedures to be followed when encrypting or decrypting a wide block, given the secret key and the public tweak value. A pictorial illustration of the encryption procedure is provided in Figure 5.1. In that figure, all the lines represent 16-byte blocks, and the boxes represent the AES encryption procedure, all using the same key. The symbol  $\oplus$  denotes bit-wise exclusive-or (xor) of two 16-byte blocks, and multiplications by powers of two are implemented via the procedure described in Section 5.1. A complete description can be found in Section 5.2.



**Figure 5.1. An illustration of EME encryption,  $C_{1..32} = \text{EME}_K(T; P_{1..32})$ . We set  $L=2 \cdot \text{AES}_K(0)$ ,  $SP=PPP_2 \oplus \dots \oplus PPP_{32}$ ,  $M=MP \oplus MC$ , and  $SC=CCC_2 \oplus \dots \oplus CCC_{32}$**

### 5.1 Multiplication by two in the finite field $\text{GF}(2^{128})$

We now describe a procedure for multiplying a 16-byte block by the constant “two” in the finite field  $\text{GF}(2^{128})$ . Both the input and the output of this procedure are 16-byte blocks. When these blocks are interpreted as binary polynomials of degree 127, the procedure computes  $output = x \cdot input$  modulo  $P_{128}$ , where  $P_{128}$  is the polynomial  $P_{128}(x) = x^{128} + x^7 + x^2 + x + 1$ . The procedure is implemented as follows:

First, we compute a *Mask* block that depends on the highest bit in the last byte of the input block. If that bit is zero (i.e., if the value of the last byte is less than 128), then the mask is set to the all-zero block. If the bit is one (i.e., if the value of the last byte is more than 127), then the value of the *Mask* block is set to the constant

$$Mask = 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 00\ 87_{16}$$

Namely, in the latter case the first byte of the *Mask* block is set to the constant 135 (hexadecimal  $87_{16}$ ), and all the other bytes are set to zero.

Then, the input block is copied to a temporary block *Temp*, where the entire block is shifted by one bit toward the highest bit. Specifically, let the value of the  $i^{\text{th}}$  input byte be  $b_i$  and the value of the  $(i-1)^{\text{st}}$  input

byte be  $b_{i-1}$ . If  $b_{i-1}$  is less than 128, then the  $i^{\text{th}}$  byte in the block  $Temp$  is set to  $2b_i$  modulo 256, and if  $b_{i-1}$  is more than 127 then the  $i^{\text{th}}$  byte in the block  $Temp$  is set to  $2b_i+1$  modulo 256. Finally, the output block is set to the bit-wise exclusive-or (xor) of the blocks  $Temp$  and  $Mask$ . A C-code for this procedure is given in Figure 5.2.

```

void multByTwo(unsigned char output[16], unsigned char input[16])
{
    int j;
    unsigned char temp[16]; /* a temporary array, just in case input and */
                          /* output point to the same memory location */
    temp[0] = 2 * input[0];
    if (input[15] >= 128) temp[0] ^= 135;
    for (j=1; j<16; j++) {
        temp[j] = 2 * input[j];
        if (input[j-1] >= 128) temp[j] += 1;
    }
    for (j=0; j<16; j++) output[j] = temp[j];
}

```

Figure 5.2. A “C” code for the `multByTwo` procedure.

## 5.2 The EME encryption procedure

The EME encryption procedure takes as input an AES key  $K$  (which must be an array of 16, 24 or 32 bytes), a 512-byte wide block  $P$  (for Plaintext) and a 16-byte block  $T$  (for Tweak). It produces as output a 512-byte wide block  $C$  (for Ciphertext). The procedure works as follows:

1. A 16-byte block  $L$  is computed as  $L = 2 \cdot \text{AES-enc}(K; \underline{0})$ , where AES-enc is the AES encryption procedure using  $K$  as the key,  $\underline{0}$  is a 16-byte block with all the bytes set to zero, and the multiplication by 2 is done using the procedure from Section 5.1.
2. The input wide block  $P$  is broken into 32 blocks  $P_1 P_2 \dots P_{32}$ , where  $P_1$  consists of the first 16 bytes in  $P$ ,  $P_2$  consists of the next 16 bytes, etc. In general, for  $j=1, 2, \dots, 32$ , the block  $P_j$  consists of bytes number  $16j-15$  through  $16j$  (indexing starts at one).
3. For  $j=1, 2, \dots, 32$ , a 16-byte block  $PP_j$  is computed as  $PP_j = P_j \oplus (2^{j-1} \cdot L)$ , where ‘ $\oplus$ ’ denotes bit-wise exclusive or, and multiplication by powers of two is done via repeated applications of the procedure from Section 5.1. For example, the first three blocks are computed as  $PP_1 = P_1 \oplus L$ ,  $PP_2 = P_2 \oplus (2 \cdot L)$ , and  $PP_3 = P_3 \oplus (2 \cdot 2 \cdot L)$ .
4. For  $j=1, 2, \dots, 32$ , a 16-byte block  $PPP_j$  is computed as  $PPP_j = \text{AES-enc}(K; PP_j)$ .
5. A 16-byte block  $SP$  is computed as the xor-sum of the blocks  $PPP_2$  through  $PPP_{32}$ ,  $SP = PPP_2 \oplus PPP_3 \oplus \dots \oplus PPP_{32}$ . Then a 16-byte block  $MP$  is computed as  $MP = PPP_1 \oplus SP \oplus T$  ( $T$  is the “tweak”).
6. A 16-byte block  $MC$  is computed as  $MC = \text{AES-enc}(K; MP)$ . Then a 16-byte block  $M$  is computed as the bit-wise exclusive-or (xor) of  $MP$  and  $MC$ ,  $M = MP \oplus MC$ .
7. For  $j=2, 3, \dots, 32$ , a 16-byte block  $CCC_j$  is computed as  $CCC_j = PPP_j \oplus (2^{j-1} \cdot M)$ , where multiplication by powers of two is done via repeated applications of the procedure from Section 5.1. For example, the first two blocks are computed as  $CCC_2 = PPP_2 \oplus (2 \cdot M)$ , and  $CCC_3 = PPP_3 \oplus (2 \cdot 2 \cdot M)$ .

8. A 16-byte block  $SC$  is computed as the xor-sum of the blocks  $CCC_2$  through  $CCC_{32}$ , namely  $SC = CCC_2 \oplus CCC_3 \oplus \dots \oplus CCC_{32}$ . Then, a 16-byte block  $CCC_1$  is computed as  $CCC_1 = MC \oplus SC \oplus T$ , where  $T$  is the input “tweak”.
9. For  $j=1, 2, \dots, 32$ , a 16-byte block  $CC_j$  is computed as  $CC_j = \text{AES-enc}(K; CCC_j)$ , and then a 16-byte block  $C_j$  is computed as  $C_j = CC_j \oplus (2^{j-1} \cdot L)$ , where multiplication by powers of two is done via repeated applications of the procedure from Section 5.1.
10. Finally, the 32 blocks  $C_1$  through  $C_{32}$  are concatenated to form the output wide block  $C$ . That is, the first 16 bytes in  $C$  come from  $C_1$ , the next 16 bytes from  $C_2$ , etc. In general, for  $j=1, 2, \dots, 32$ , bytes number  $16j-15$  through  $16j$  in  $C$  come from block  $C_j$  (indexing starts at one).

A C-code for this procedure is given in Figure 5.3. This procedure employs many calls to the AES encryption procedure, all using the same key  $K$ . Since the key-setup time for AES is significant, an implementation **may** perform it just once, and then use the resulting key-schedule in all the encryption calls. Moreover, as the computation of the block  $L$  does not depend on the input wide block  $P$  or the input tweak  $T$ , an implementation **may** compute the value of  $L$  off-line, before learning either  $P$  or  $T$ . In fact, an implementation **may** even store the key-schedule and the block  $L$  between different EME calls.

### 5.3 The EME decryption procedure

The EME decryption procedure takes as input an AES key  $K$  (which must be an array of 16, 24 or 32 bytes), a 512-byte wide block  $C$  (for Ciphertext) and a 16-byte block  $T$  (for Tweak). It produces as output a 512-byte wide block  $P$  (for Plaintext). The procedure is very similar to the encryption procedure. In fact, a “C” code for the decryption procedure can be obtained from the “C” code in Figure 5.3, simply by replacing all but the first call to `encryptAES` (i.e. all calls except the call to `encryptAES(zero, K, zero)`) by calls to `decryptAES`. The decryption procedure works as follows:

1. A 16-byte block  $L$  is computed as  $L = 2 \cdot \text{AES-enc}(K; \underline{0})$ , where `AES-enc` is the AES encryption procedure using  $K$  as the key,  $\underline{0}$  is a 16-byte block with all the bytes set to zero, and the multiplication by 2 is done using the procedure from Section 5.1.
2. The input wide block  $C$  is broken into 32 blocks  $C_1 C_2 \dots C_{32}$ , where  $C_1$  consists of the first 16 bytes in  $C$ ,  $C_2$  consists of the next 16 bytes, etc. In general, for  $j=1, 2, \dots, 32$ , the block  $C_j$  consists of bytes number  $16j-15$  through  $16j$  (indexing starts at one).
3. For  $j=1, 2, \dots, 32$ , a 16-byte block  $CC_j$  is computed as  $CC_j = C_j \oplus (2^{j-1} \cdot L)$ , where multiplication by powers of two is done via repeated applications of the procedure from Section 5.1.
4. For  $j=1, 2, \dots, 32$ , a 16-byte block  $CCC_j$  is computed as  $CCC_j = \text{AES-dec}(K; CC_j)$ .
5. A 16-byte block  $SC$  is computed as the xor-sum of the blocks  $CCC_2$  through  $CCC_{32}$ , namely  $SC = CCC_2 \oplus CCC_3 \oplus \dots \oplus CCC_{32}$ .
6. A 16-byte block  $MC$  is computed as  $MP = CCC_1 \oplus SC \oplus T$ , where  $T$  is the input “tweak”. Then a 16-byte block  $MP$  is computed as  $MP = \text{AES-dec}(K; MC)$ . Next a 16-byte block  $M$  is computed as the bit-wise exclusive-or (xor) of  $MC$  and  $MP$ ,  $M = MC \oplus MP$ .
7. For  $j=2, 3, \dots, 32$ , a 16-byte block  $PPP_j$  is computed as  $PPP_j = CCC_j \oplus (2^{j-1} \cdot M)$ , where multiplication by powers of two is done via repeated applications of the procedure from Section 5.1.

8. A 16-byte block  $SP$  is computed as the xor-sum of the blocks  $PPP_2$  through  $PPP_{32}$ , namely  $SP = PPP_2 \oplus PPP_3 \oplus \dots \oplus PPP_{32}$ . Then, a 16-byte block  $PPP_1$  is computed as  $PPP_1 = MP \oplus SP \oplus T$ , where  $T$  is the input “tweak”.
9. For  $j=1, 2, \dots, 32$ , a 16-byte block  $PP_j$  is computed as  $PP_j = \text{AES-dec}(K; PPP_j)$ , and then a 16-byte block  $P_j$  is computed as  $P_j = PP_j \oplus (2^{j-1} \cdot L)$ , where multiplication by powers of two is done via repeated applications of the procedure from Section 5.1.
10. Finally, the 32 blocks  $P_1$  through  $P_{32}$  are concatenated to form the output wide block  $\mathbf{P}$ . That is, the first 16 bytes in  $\mathbf{P}$  come from  $P_1$ , the next 16 bytes from  $P_2$ , etc. In general, for  $j=1, 2, \dots, 32$ , bytes number  $16j-15$  through  $16j$  in  $\mathbf{P}$  come from block  $P_j$  (indexing starts at one).

```

/* The function encryptAES implements the AES encryption procedure. It is
 * assumed that this procedure has external means for determining the key
 * length (16, 24 or 32 bytes).
 */
extern void encryptAES(unsigned char out[16],
                      unsigned char key[], unsigned char in[16]);

/* The function xorBlocks computes bit-wise exclusive-or of two blocks */
extern void xorBlocks(unsigned char out[16],
                     unsigned char in1[16], unsigned char in2[16]);

/* The function multByTwo is described in Figure 5.2 */
extern void multByTwo(unsigned char out [16], unsigned char in[16]);

void encryptEME(unsigned char C[512], unsigned char K[],
               unsigned char T[16], unsigned char P[512])
{
    int i,j;
    unsigned char L[16], M[16], MP[16], MC[16];
    unsigned char temp[512]; /* a temporary array, just in case P and C */
                          /* point to the same memory location */
    unsigned char zero[16] = {0,0,0,0, 0,0,0,0, 0,0,0,0, 0,0,0,0};

    encryptAES(zero, K, zero); /* set L = 2*AES-enc(K; 0) */
    multByTwo(L, zero);

    for (j=0; j<32; j++) {
        xorBlocks(&temp[j*16], &P[j*16], L); /* PPj = 2**(j-1)*L xor Pj */
        encryptAES(&temp[j*16], K, &temp[j*16]); /* PPPj = AES-enc(K; PPj) */
        multByTwo(L, L);
    }

    xorBlocks(MP, temp, T); /* MP = (xorSum PPPj) xor T */
    for (j=1; j<32; j++)
        xorBlocks(MP, MP, &temp[j*16]);
    encryptAES(MC, K, MP); /* MC = AES-enc(K; MP) */
    xorBlocks(M, MP, MC); /* M = MP xor MC */

    for (j=1; j<32; j++) {
        multByTwo(M, M);
        xorBlocks(&temp[j*16], &temp[j*16], M); /* CCCj = 2**(j-1)*M xor PPPj */
    }
    xorBlocks(temp, MC, T); /* CCC1 = (xorSum CCCj) xor T xor MC */
    for (j=1; j<32; j++)
        xorBlocks(temp, temp, &temp[j*16]);

    multByTwo(L, zero); /* reset L = 2*AES-enc(K; 0) */
    for (j=0; j<32; j++) {
        encryptAES(&temp[j*16], K, &temp[j*16]); /* CCj = AES-enc(K; CCCj) */
        xorBlocks(&C[j*16], &temp[j*16], L); /* Cj = 2**(j-1)*L xor CCj */
        multByTwo(L, L);
    }
}

```

**Figure 5.3. A “C” code for the EME encryption procedure.**

## 6. Using EME-32-AES for encryption of storage

The scope of this document is limited to direct application of the EME-32-AES transform to encrypt or decrypt data at rest, when this data consists of an integral number of wide blocks, each of size 512 byte. To use this standard, an AES key **must** be associated with an ordered sequence of wide blocks, numbered consecutively 1 through N, where 1 is the index of the first logical wide block for this key, and N is the index of the last one. The sequence of wide blocks that are associated with an AES key is called the *SCOPE* of that key. In order to encrypt or decrypt a wide block using an AES key, the index of the wide block within the scope of the key **must** be known.

To encrypt a plaintext wide block with index J, the positive integer J is first encoded as a 16-byte block  $T_J$ , as explained in Section 6.1 below. Then the EME-32-AES encryption transform is applied to this wide block, using the given key and the tweak value  $T_J$ , as described in Section 5.2. The result of the transformation is a ciphertext wide block. Similarly, to decrypt a ciphertext wide block with index J, the positive integer J is encoded as a 16-byte block  $T_J$ , then the EME-32-AES decryption transform is applied to this wide block using the given key and the tweak value  $T_J$ , as described in Section 5.3, and the result is a plaintext wide block.

In a typical application for storage encryption, the index of a wide block can be computed from the location where this wide block is stored and the scope of the key. For example, when encrypting a disk with 512-byte sectors, the scope of a key typically includes a range of logically consecutive sectors on the disk, and the index of a given sector would be its position within that sequence. In this example, the scope of a key is defined using two integers, specifying the first and last logical sectors that are associated with this key (call them X and Y). Then, a sector that is stored in logical location Z on the disk (where  $X \leq Z \leq Y$ ) will have index  $J = Z - X + 1$  within the scope of that key.

It is stressed that an AES secret key **must not** be associated with more than one scope. The reason is that encrypting more than one wide block with the same AES key and the same index, introduces security vulnerabilities that can potentially be used in an attack on the system.

### 6.1 Encoding the tweak values

A positive integer J (smaller than  $2^{128}$ ) is encoded as a 16-byte block T using big-endian notation. That is, the integer J is represented in base-256 notation, where the most significant byte is stored as the first byte in the block T and the least significant byte is stored as the last byte. Using “C” notations, we view T as an array of sixteen `unsigned char`, indexed from 0 (first) to 15 (last), with each byte representing a number between 0 and 255, then the integer J is

$$J = T[0] \cdot 256^{15} + T[1] \cdot 256^{14} + T[2] \cdot 256^{13} + T[3] \cdot 256^{12} + T[4] \cdot 256^{11} + T[5] \cdot 256^{10} + T[6] \cdot 256^9 \\ + T[7] \cdot 256^8 + T[8] \cdot 256^7 + T[9] \cdot 256^6 + T[10] \cdot 256^5 + T[11] \cdot 256^4 + T[12] \cdot 256^3 + T[13] \cdot 256^2 \\ + T[14] \cdot 256 + T[15]$$

# Annexes

## Annex A: Bibliography (informative)

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