



US007092524B1

(12) **United States Patent**
Timmel

(10) **Patent No.:** **US 7,092,524 B1**
(45) **Date of Patent:** **Aug. 15, 2006**

(54) **DEVICE FOR AND METHOD OF
CRYPTOGRAPHICALLY WRAPPING
INFORMATION**

6,829,355 B1 * 12/2004 Lilly 380/28
6,907,127 B1 * 6/2005 Kravitz et al. 380/277
6,941,459 B1 * 9/2005 Hind et al. 713/167
2003/0002662 A1 * 1/2003 Nishioka et al. 380/30

(75) Inventor: **Paul Stephen Timmel**, Baltimore, MD
(US)

OTHER PUBLICATIONS

Fips Pub 46-3 Des, Oct. 25, 1999, Dept. of Commerce.
Fips Pub 197, Aes, Nov. 26, 2001, Dept. of Commerce.
AFC2630, 1999, The Internet Society.

* cited by examiner

(73) Assignee: **The United States of America as
represented by the National Security
Agency**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 683 days.

Primary Examiner—Emmanuel L. Moise

Assistant Examiner—Shewaye Gelagay

(74) *Attorney, Agent, or Firm*—Robert D. Morelli

(21) Appl. No.: **10/299,094**

(57) **ABSTRACT**

(22) Filed: **Nov. 15, 2002**

(51) **Int. Cl.**
H04K 1/00 (2006.01)
H04L 9/00 (2006.01)

(52) **U.S. Cl.** **380/28**; 380/22; 380/42;
713/189; 713/180

(58) **Field of Classification Search** 380/22
See application file for complete search history.

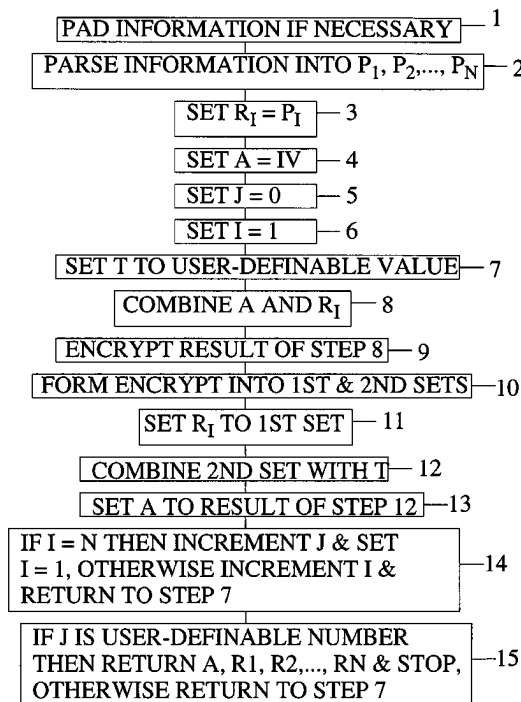
(56) **References Cited**

U.S. PATENT DOCUMENTS

4,924,515 A * 5/1990 Matyas et al. 380/280
5,995,625 A * 11/1999 Sudia et al. 705/51
6,256,733 B1 7/2001 Thakkar et al.
6,260,142 B1 7/2001 Thakkar et al.

A device for and method of cryptographically wrapping information by first constructing information to be wrapped into an even multiple of y bits. Information to be wrapped is parsed into equal blocks $P_1, P_2, \dots, P_n$. Next, registers R_i are loaded with the blocks P_i . Next, an initialization vector IV is stored into a register A . Set $j=0$. Set $i=1$. Set $t=(n \times j)+i$. Concatenate A and R_i . Encrypt the result of the last step to form $2y$ encrypted bits. Divide the encrypted bits into a first set of y bits and a second set of y bits. Set R_i equal to the first set. Combine the second set with t using a user-definable function. Set A equal to the combination. If $i=n$ then increment j and reset $i=1$; otherwise, increment i . If j is equal to a user-definable number then return $A, R_1, R_2, \dots, R_n$ as the cryptographically wrapped information and stop. Otherwise, return to the step where t is set.

16 Claims, 4 Drawing Sheets



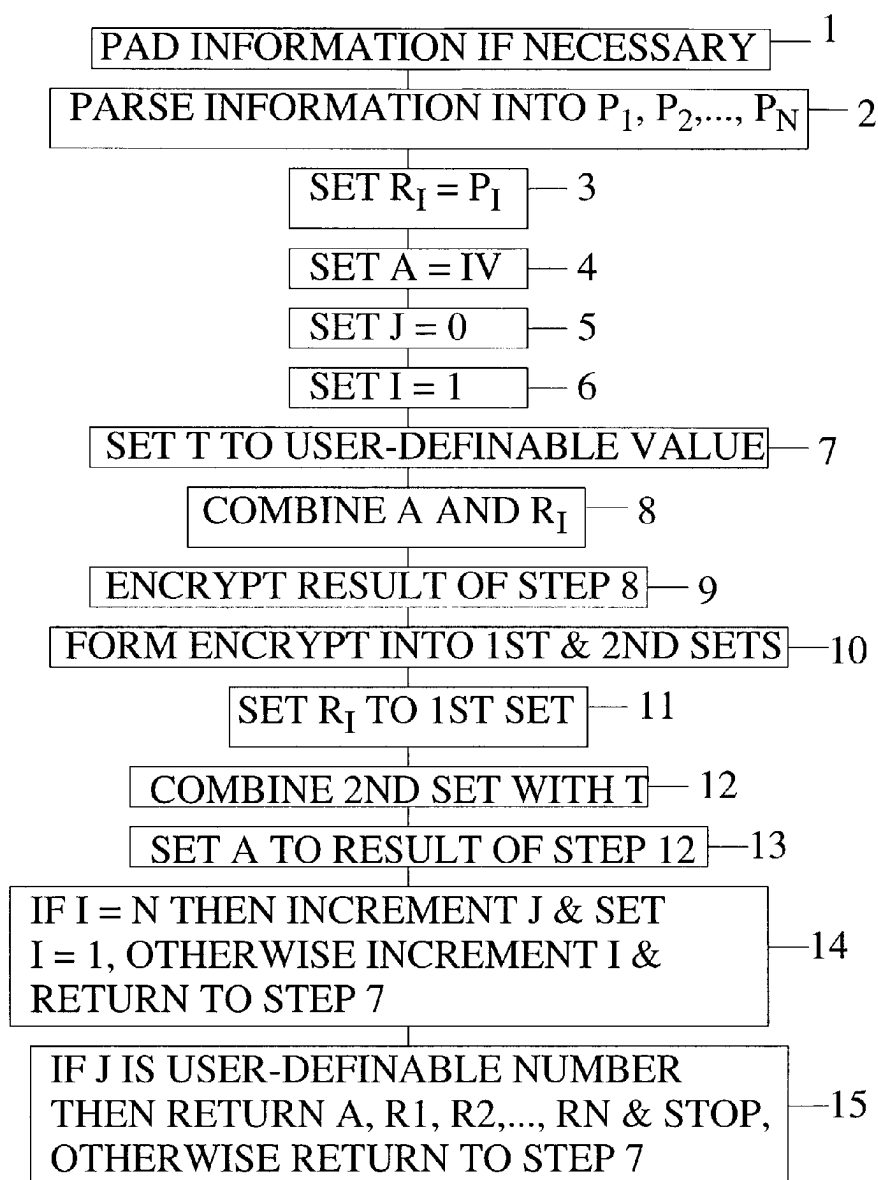


FIG. 1

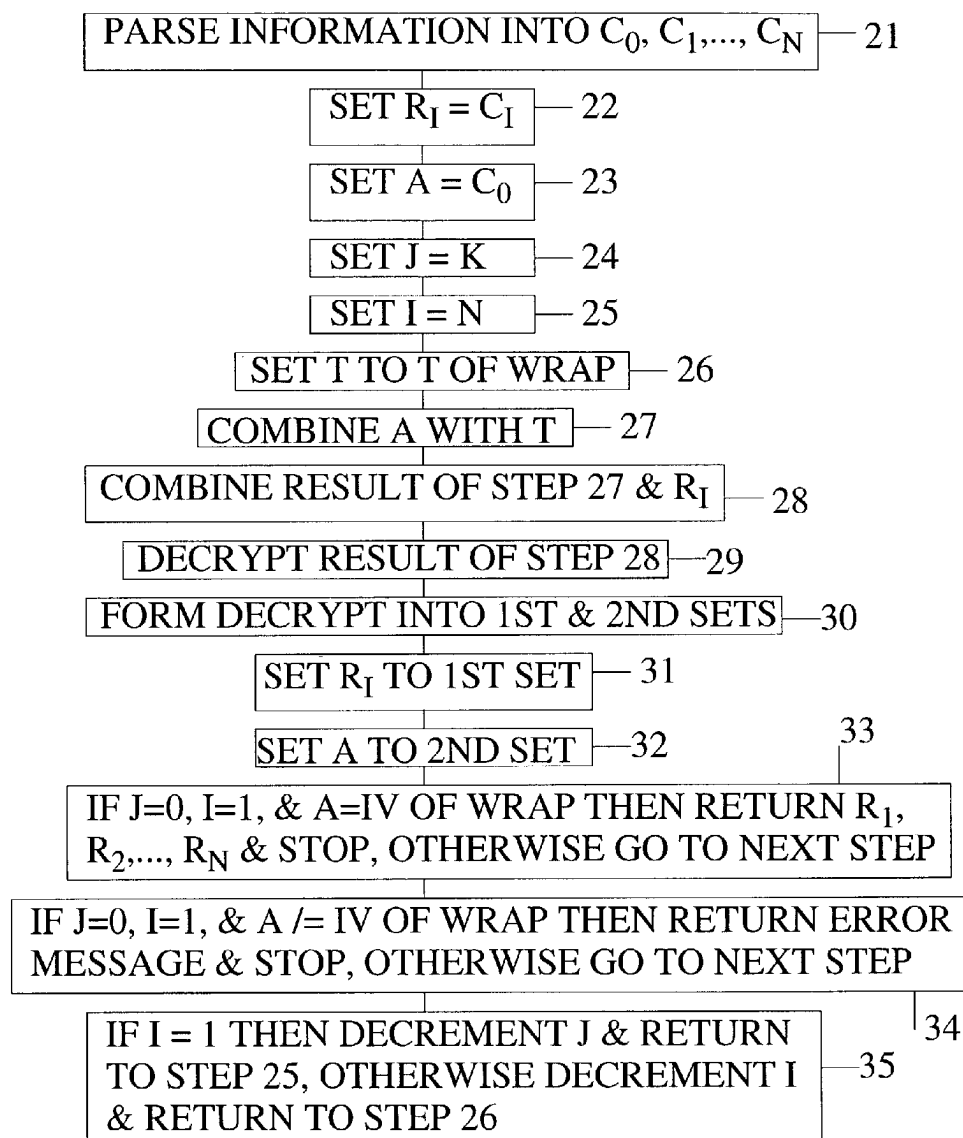


FIG. 2

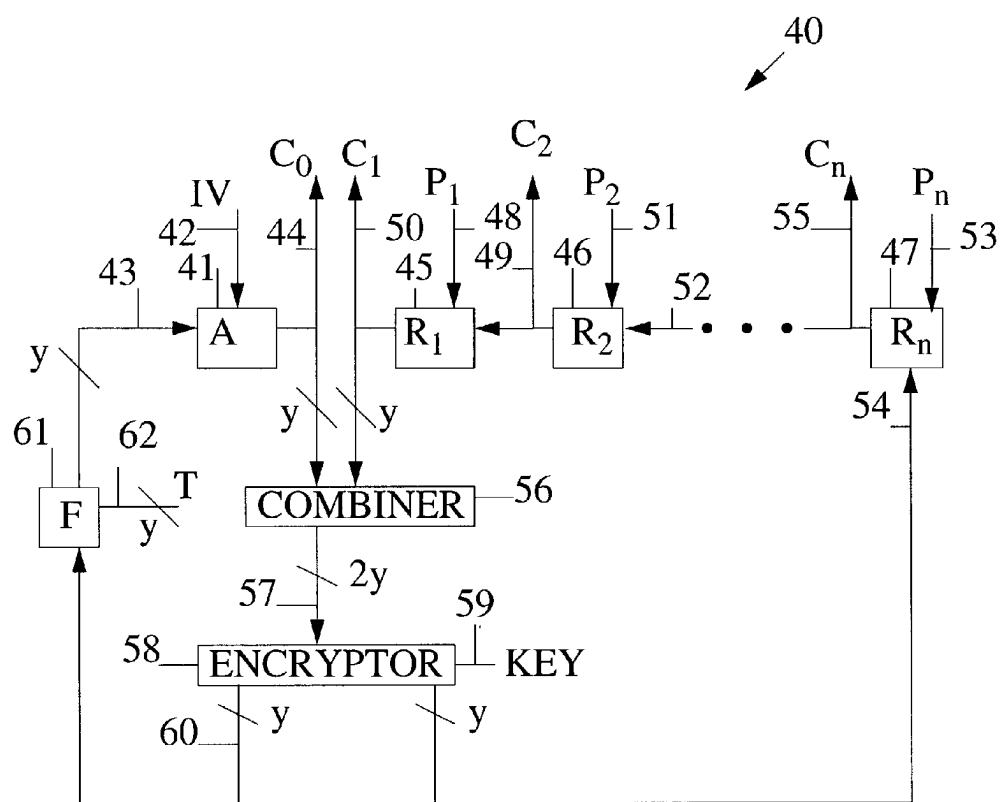


FIG. 3

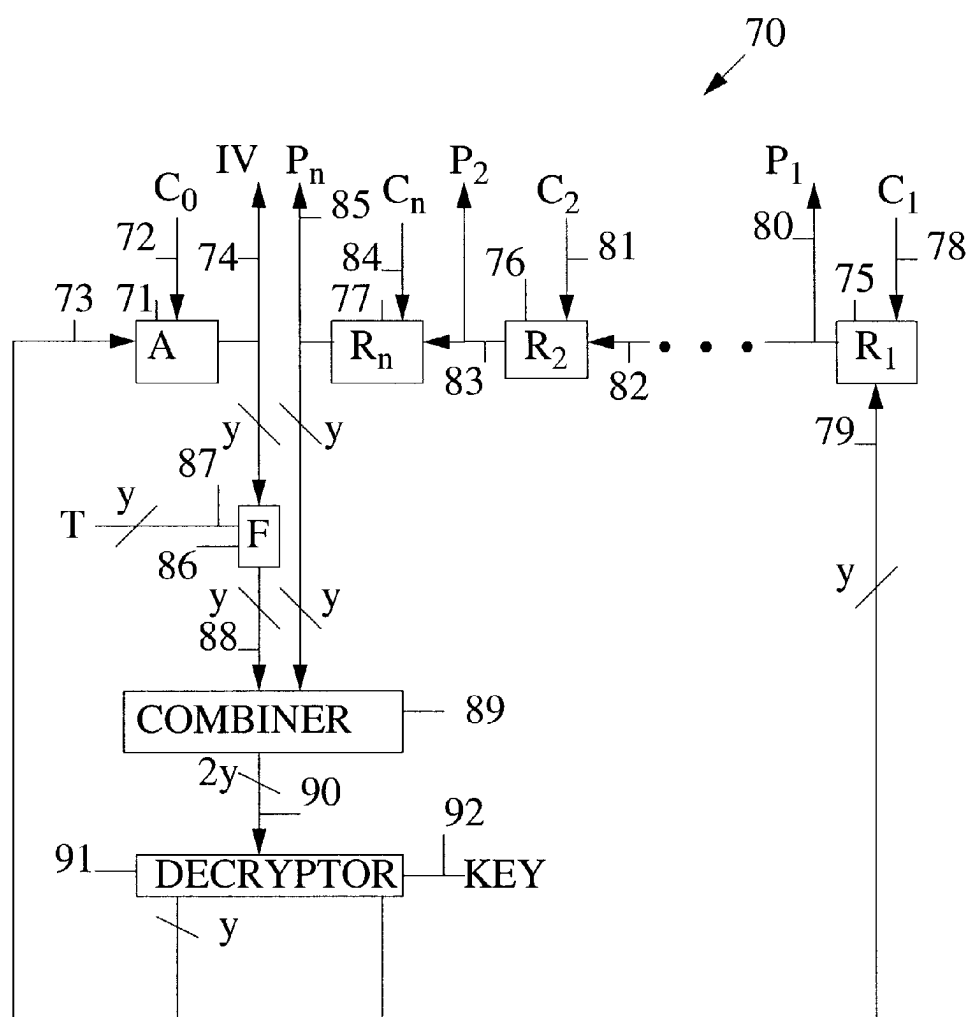


FIG. 4

1

DEVICE FOR AND METHOD OF CRYPTOGRAPHICALLY WRAPPING INFORMATION

FIELD OF THE INVENTION

This invention relates to cryptography and, more particularly, to key management.

BACKGROUND OF THE INVENTION

The National Institute of Standards and Technology (NIST), an agency of the U.S. Department of Commerce's Technology Administration, announced the approval of the Federal Information Processing Standard (FIPS) for the Advanced Encryption Standard (AES) as described in FIPS Publication 197 (FIPS PUB 197), which is hereby incorporated by reference into the present specification. This standard specifies a symmetric encryption algorithm that may be used by U.S. Government organizations to protect sensitive, but unclassified, information.

The AES was designed to replace the Digital Encryption Standard (DES). However, Triple DES remains an approved algorithm for U.S. Government use for the foreseeable future. Single DES is being phased out of use, and is currently permitted only in legacy systems. DES and Triple DES are described in FIPS PUB 46-3, which is incorporated by reference into the specification of the present invention.

The length of a cryptographic key (hereinafter referred to as a key) used with AES may be either 128 bits, 192 bits, or 256 bits. For these key lengths, there are 3.4×10^{38} possible 128-bit keys, 6.2×10^{57} possible 192-bit keys, and 1.1×10^{77} possible 256-bit keys or on the order of 10^{21} more keys than are possible with the 56-bit key required by DES (i.e., 7.2×10^{16} possible 56-bit keys).

Any cryptographic method is rendered useless if an adversary can obtain the key used to encrypt information, which is commonly referred to as a content-encryption key or CEK. Therefore, a secure key management is needed for any encryption method including AES.

One approach to key management is to protect the CEK by encrypting it with another cryptographic key, which is commonly referred to as a key-encryption key or KEK. Two such methods are described in a document published in 1999 by The Internet Society concerning Cryptographic Message Syntax entitled "RFC2630." This document describes two methods of encrypting, or wrapping, CEKs for use with Triple DES and RC2, respectively.

The first step of the Triple DES key wrapping method is setting odd parity for each of the DES key octets comprising the CEK.

The second step of the Triple DES key wrapping method is forming ICV by computing an 8 octet key checksum value on CEK. The preferred method of forming ICV is by computing a 20 octet message digest on the CEK using the Secure Hashing Algorithm (SHA-1) and using the most significant, or first, eight octets of the message digest value as ICV.

The third step of the Triple-DES key wrapping method is forming CEKICV by concatenating CEK and ICV.

The fourth step of the Triple-DES key-wrapping method is generating an initialization vector (IV) as 8 random octets.

The fifth step of the Triple-DES key-wrapping method is forming TEMP1 by encrypting CEKICV in DES Cipher Block Chaining (CBC) mode using a KEK and IV.

The sixth step of the Triple-DES key-wrapping method is forming TEMP2 by concatenating IV and TEMP1.

2

The seventh step of the Triple-DES key-wrapping method is forming TEMP3 by reversing the order of the octets in TEMP2. That is, swapping the most significant, or first, octet with the least significant, or last, octet, and so on.

The eighth, and last, step of the Triple-DES key-wrapping method is encrypting TEMP3 in CBC mode using the KEK and 0x4adda22c79e82105 as IV. The length of the resulting ciphertext is 40 octets.

This Triple DES key wrapping method requires that a different IV be used when the same CEK is wrapped using a different KEK.

The first step of the RC2 key wrapping method is setting LENGTH equal to the length of the CEK, where LENGTH is a single octet.

The second step of the RC2 key wrapping method is forming LCEK by concatenating LENGTH and CEK.

The third step of the RC2 key wrapping method is forming LCEKPAD by concatenating LCEL with PAD, where PAD is the fewest number, including zero, of random octets that make the length of LCEKPAD a multiple of 8.

The fourth step of the RC2 key wrapping method is forming ICV by computing an 8 octet key checksum value on LCEKPAD. The preferred method of forming ICV is by computing a 20 octet message digest on the LCEKPAD using the Secure Hashing Algorithm (SHA-1) and using the most significant, or first, eight octets of the message digest value as ICV.

The fifth step of the RC2 key wrapping method is forming LCEKPADICV by concatenating LCEKPAD with ICV.

The sixth step of the RC2 key wrapping method is forming an initialization vector (IV) by generating 8 random octets.

The seventh step of the RC2 key wrapping method is forming TEMP1 by encrypting LCEKPADICV in CBC mode using a KEK and IV.

The eighth step of the RC2 key wrapping method is forming TEMP2 by concatenating IV and TEMP1.

The ninth step of the RC2 key wrapping method is forming TEMP3 by reversing the order of the octets in TEMP2. That is, swapping the most significant, or first, octet with the least significant, or last, octet, and so on.

The tenth, and last, step of the RC2 key wrapping method is encrypting TEMP3 in CBC mode using the KEK and 0x4adda22c79e82105 as IV. The length of the resulting ciphertext is 40 octets.

This RC2 key wrapping method requires that a different IV be used when the same CEK is wrapped using a different KEK.

U.S. Pat. No. 5,995,625, entitled "ELECTRONIC CRYPTOGRAPHIC PACKING," discloses a method of unwrapping wrapped digital data by obtaining an acceptance phrase from a user, deriving a cryptographic key from the acceptance phrase, and unwrapping the wrapped digital data using the derived cryptographic key. The present invention does not derive a key from an acceptance phrase provided by a user. The present invention also differs from U.S. Pat. No. 5,995,625 in other ways as described below. U.S. Pat. No. 5,995,625 is hereby incorporated by reference into the specification of the present invention.

U.S. Pat. Nos. 6,256,733 and 6,260,142, both entitled "ACCESS AND STORAGE OF SECURE GROUP COMMUNICATION CRYPTOGRAPHIC KEYS," disclose a device for and method of securing stored security credentials by encrypting, by various members of a group, at least a portion of the stored security credentials. The present invention does not require actions by members of a group. The present invention also differs from U.S. Pat. Nos. 6,256,733

and 6,260,142 in other ways as described below. U.S. Pat. Nos. 6,256,733 and 6,260,142 are hereby incorporated by reference into the specification of the present invention.

The present invention is such a secure key management method for AES.

SUMMARY OF THE INVENTION

It is an object of the present invention to cryptographically wrap information so that the wrapped information is at least as wide as the output of an encryptor used to wrap the information.

It is another object of the present invention to cryptographically wrap information that includes integrity data so that the wrapped information and integrity data is at least as wide as the output of an encryptor used to wrap the information.

The present invention is a device for and method of cryptographically wrapping information.

If the information to be wrapped is not an even multiple of y bits then the information is made to be so.

Next, the information is parsed into blocks $P_1, P_2, \dots, P_n$, where each block is y -bits.

Next, n registers in a shift-register are loaded with the blocks.

Next, a register is loaded with an initialization vector IV , where IV is y -bits.

Next, the following method is conducted or implemented in a device.

Set $j=0$.

Set $i=1$.

Set t to a user-definable value.

Combine A and R_i .

Encrypt the combination of A and R_i .

Form a first y -bit string and a second y -bit string from the encrypted result, in an invertible manner.

Set R_i equal to the first y -bit string.

Combine the second y -bit string with t .

Set A equal to the combination of the second y -bit string with t .

If $i=n$ then increment j and reset $i=1$. Otherwise, increment i .

If j is equal to a user-definable number then return $A, R_1, R_2, \dots, R_n$ as the cryptographically wrapped information and stop. Otherwise, return to the step where t is set.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a flowchart of the cryptographic wrapping method of the present invention;

FIG. 2 is a flowchart of the cryptographic unwrapping method of the present invention;

FIG. 3 is a schematic of the cryptographic wrapping device of the present invention; and

FIG. 4 is a schematic of the cryptographic unwrapping device of the present invention.

DETAILED DESCRIPTION

The present invention is a device for and method of encrypting, or cryptographically wrapping, information so that the wrapped information is at least as wide as the output of an encryptor used to wrap the information. In the preferred embodiment, the information to be wrapped is a content-encryption-key (CEK), which is used to encrypt plaintext. Wrapping a CEK aids in protecting the CEK from compromise. However, the present invention may be used to

wrap information of any type. Furthermore, additional information such as integrity data may be included with the information to be wrapped.

FIG. 1 is a list of the wrapping steps according to the present invention.

The first step 1 of the wrapping method is padding, if necessary, the information to be wrapped so that the length of the result is an even multiple of y bits, where y is equal to half of the number of outputs bits of the encryptor used in the method. Any suitable padding scheme may be used (e.g., pad with zeros, pad with ones, pad with a random number, pad with a predetermined string of ones and zeros, pad at the beginning, pad at the end, pad anywhere within the information to be wrapped). In the preferred embodiment, the Advanced Encryption Standard (AES) is used as the encryptor. Since AES has an output of 128 bits, y is, preferably, 64 bits.

The second step 2 of the present wrapping method is parsing the result of step 1 into $P_1, P_2, \dots, P_n$, where P_i has a length of y bits. In the preferred embodiment P_i has a length of 64 bits.

The third step 3 of the present wrapping method is setting $R_i=P_i$, where $i=1, 2, \dots, n$, where n is equal to the length of the information to be wrapped divided by y . The present invention may be used for any value of n .

The fourth step 4 of the present wrapping method is setting A equal to a user-definable initialization vector (IV), where IV has a length equal to y . The IV is the additional information (e.g., integrity data) that a user may add too the information to be wrapped.

The fifth step 5 of the present wrapping method is setting $j=0$.

The sixth step 6 of the present wrapping method is setting $i=1$.

The seventh step 7 of the present wrapping method is setting t to a user-definable value. In the preferred embodiment, $t=(n \times j)+i$.

The eighth step 8 of the present method is combining A and R_i in an invertible manner to form a bit string of $2y$ bits. In the preferred embodiment, A and R_i are concatenated so that A forms the high order bits of the result, and R_i forms the low order bits. However, any other suitable combination of A and R_i may be used in the present invention.

The ninth step 9 of the present wrapping method is encrypting the result of the eighth step 8 using an encryptor that has an output that is $2y$ bits in length. In the preferred embodiment, AES is used as the encryptor. The output of AES is 128 bits in length. Therefore, y is 64 bits when AES is used as the encryptor. AES allows the use of three different length encryption keys (i.e., 128 bits, 196 bits, and 256 bits). The greater the bits in the AES key, the greater the security in the output of AES. When the AES key is used to encrypt a CEK, the AES key is commonly referred to as a key-encryption key (KEK).

The tenth step 10 of the present wrapping method is forming, in an invertible manner, a first user-definable set of y bits and a second user-definable set of y bits from the result of the ninth step 9. In the preferred embodiment, the first user-definable set of y bits is the 64 least significant bits of the result of the ninth step 9, and the second user-definable set of y bits is the 64 most significant bits of the result of the ninth step 9. However, any other suitable two groupings of the result of the ninth step 9 are possible (e.g., a user-definable linear combination of bits from the result of the ninth step 9).

The eleventh step 11 of the present wrapping method is setting R_i equal to the first user-definable set.

The twelfth step **12** of the present method is combining the second user-definable set with t using a user-definable invertible function. In the preferred embodiment, the user-definable invertible function is a bit-wise exclusive-or function (XOR). However, any other suitable invertible function may be used (e.g., modular adder, modular subtractor).

The thirteenth step **13** of the present wrapping method is setting A equal to the result of the twelfth step **12**.

If $i=n$ then the fourteenth step **14** of the present wrapping method is incrementing j and setting $i=1$. Otherwise, incrementing i .

If j is equal to a user-definable number then the fifteenth step **15** of the present wrapping method is returning $A, R_1, R_2, \dots, R_n$ as the wrapped information and stopping. Otherwise returning to the seventh step **7**. The user-definable number determines the number of cycles for the wrapping method and, therefore, the total number of steps in the method. In the preferred embodiment, the user-definable number is 6. If the user-definable number is 6 then the total number of steps of the present wrapping method is $6n$.

FIG. **2** is a list of steps for unwrapping information that was wrapped using the method of FIG. **1**.

The first step **21** of the present unwrapping method is parsing the wrapped information into $C_0, C_1, \dots, C_n$, where C_i has a length of y bits. The y value and encryptor used in the unwrap method must be the same as those used to wrap the information.

The second step **22** of the present unwrapping method is setting $R_i=C_i$, where $i=1, 2, \dots, n$, where n is the same as that used to wrap the information.

The third step **23** of the present unwrapping method is setting $A=C_0$.

The fourth step **24** of the present unwrapping method is setting $j=k-1$, where k is a user-definable positive integer. The value of k must be the same as the user-definable number used to wrap the information. In the preferred embodiment, k is 6.

The fifth step **25** of the present unwrapping method is setting $i=n$, where n must be the same as the value of n used to wrap the information (i.e., the number of y -bit blocks in the information to be wrapped).

The sixth step **26** of the present unwrapping method is setting t equal to the value of t used to wrap the information.

The seventh step **27** of the present unwrapping method is combining A with t using a user-definable function that is the inverse of the user-definable invertible function used to wrap the information. Note that XOR is the inverse of XOR.

The eighth step **28** of the unwrapping method is combining the result of the seventh step **27** and R_i in a manner that is the inverse of the method used during the wrapping of the information to form the first user-definable set of y bits and the second user-definable set of y bits.

The ninth step **29** of the present unwrapping method is decrypting the result of the eighth step **28**. The decryptor must perform the inverse of the encryptor used to wrap the information.

The tenth step **30** of the present wrapping method is forming a first user-definable set of y bits and a second user-definable set of y bits from the result of the ninth step **29** in a manner that is the inverse of the method used to combine A and R_i during the wrapping of the information. In the preferred embodiment, the first user-definable set of y bits is the 64 least significant bits of the result of the ninth step **29**, and the second user-definable set of y bits is the 64 most significant bits of the result of the ninth step **29**.

The eleventh step **31** of the present unwrapping method is setting R_i equal to the first user-definable set of y bits.

The twelfth step **32** of the present unwrapping method is setting A equal to the second user-definable set of y bits.

If j is equal to 0, i is equal to 1, and A is equal to the IV used to wrap the information then the thirteenth step **33** of the present unwrapping method is returning $R_1, R_2, \dots, R_n$ as the unwrapped information and stopping. Otherwise, proceeding to the next step.

If j is equal to 0, i is equal to 1, and A is not equal to the IV used to wrap the information then the fourteenth step **34** of the present unwrapping method is returning an error message and stopping. Otherwise, proceeding to the next step.

If $i=1$ then the fifteenth step **35** of the present unwrapping method is decrementing j and returning to step **25**. Otherwise, decrementing i and returning to the sixth step **26**.

FIG. **3** is a schematic of the wrapping device **40** of the present invention.

The wrapping device **40** includes an A register **41** for receiving an initialization vector (IV). The IV is additional data (e.g., integrity data) that will be wrapped with the other information to be wrapped. The A register **41** has a y -bit input **42** for receiving the IV, a y -bit input **43** for receiving data from the wrapping device **40**, and a y -bit output **44** at which will appear a y -bit portion of the wrapped information (i.e., C_0) after the wrapping device **40** has been stepped a user-definable number of times. Note that the input **42** for receiving the IV may be combined with the input **43** if properly configured. In the preferred embodiment, y is 64.

The wrapping device **40** also includes n registers $R_1, R_2, \dots, R_n$, **45, 46, 47** connected as a shift-register, where each is identical to the A register **41**.

The R_1 register **45** has a y -bit input **48** for receiving a portion of the information to be wrapped (i.e., P_1), a y -bit input **49** for receiving input from the R_2 register **46**, and a y -bit output **50**. In the preferred embodiment, the information to be wrapped is a CEK and the portions received into each R register **45, 46, 47** (i.e., $P_1, P_2, \dots, P_n$, respectively). Note that an input to an R register **45, 46, 47** for receiving a portion of the information to be wrapped may be the same as the corresponding input for receiving data from another R register **46, 47** or the wrapping device **40** if properly configured. After the wrapping device **40** is stepped a user-definable number of times, a y -bit portion (i.e., C_1) of the wrapped information will appear at the output **50** of the R_1 register **45**.

The R_2 register **46** has a y -bit input **51** for receiving a portion of the information to be wrapped (i.e., P_2), a y -bit input **52** for receiving input from the preceding R register in the shift-register chain, and a y -bit output **49**. After the wrapping device **40** is stepped a user-definable number of times, a y -bit portion (i.e., C_2) of the wrapped information will appear at the output **49** of the R_2 register **46**.

The R_n register **47** (i.e., the right-most register in the shift-register) has a y -bit input **53** for receiving a portion of the information to be wrapped (i.e., P_n), a y -bit input **54** for receiving input from the wrapping device **40**, and a y -bit output **49**. After the wrapping device **40** is stepped a user-definable number of times, a y -bit portion (i.e., C_n) of the wrapped information will appear at the output **55** of the R_n register **47**.

The output **44** of the A register **41** and the output **50** of the R_1 register **45** are connected to a combiner **56** which combines its inputs in a user-definable manner. In the preferred embodiment, the combiner **56** concatenates its inputs so that the output **44** of the A register **41** constitutes the most significant bits of the output **57** of the combiner **56** and the output **50** of the R_1 register **45** constitute the least

significant bits of the output **57** of the combiner **56**. However, any other suitable invertible function may be performed by the combiner **56**. The output **57** of the combiner **56** is $2y$ bits.

The output **57** of the combiner **56** is connected to the input of an encryptor **58** that accepts $2y$ bits, encrypts the same using an encryption key via a encryption-key input **59**, and produces $2y$ encrypted bits, half of which appears at a first output bus **54** and the other half of which appears at a second output bus **60**. In the preferred embodiment, AES is used as the encryptor. AES accepts 128 bits, which forces y to be 64, encrypts the same using an encryption key of one of three widths (i.e., 128 bits, 192 bits, and 256 bits), and produces a 128-bit encrypted output. The more bits in the encryption key, the harder it is for an adversary to defeat the encryption process. In the preferred embodiment, the first output bus **54** of the encryptor **58** contains the least significant half of the encryptor's output in order, and the second output bus **60** of the encryptor **58** contains the most significant half of the encryptor's output in order. However, any other suitable invertible two groupings of the output bits of the encryptor **58** onto the first output bus **54** and the second output bus **60** may be used.

The first output bus **54** of the encryptor **58** is connected to the input of the R_n register **47**.

The second output bus **60** of the encryptor **58** is connected to a first input of a function block **F 61**. The function block **F 61** has a second input for receiving a y -bit user-definable value T . The function block **F 61** performs a user-definable invertible function on its two inputs and produces a y -bit output that is connected to the input **43** of the A register **41**. In the preferred embodiment, the function performed by the function block **F 61** is a bit-wise exclusive-or function. However, any other suitable invertible function (e.g., modular adder, modular subtractor) may be performed by the function block **F 61**.

FIG. 4 is a schematic of the unwrapping device **70** of the present invention.

The unwrapping device **70** includes an A register **71** for receiving a y -bit portion (i.e., C_0) of wrapped information. The A register **71** has a y -bit input **72** for receiving C_0 , a y -bit input **73** for receiving data from the unwrapping device **70**, and a y -bit output **74** at which will appear the IV used during the wrapping operation after the unwrapping device has been stepped the same number of times as was the corresponding wrapping device. Note that the input **72** for receiving the C_0 may be combined with the input **73** if properly configured. The y in the unwrapping device **70** must be the same as in the corresponding wrapping device.

The unwrapping device **70** also includes n registers $R_1, R_2, \dots, R_n$, **75, 76, 77** connected as a shift-register, where each is identical to the A register **71**.

The R_1 register **75** has a y -bit input **78** for receiving a portion of the information to be unwrapped (i.e., C_1), a y -bit input **79** for receiving input from the unwrapping device **70**, and a y -bit output **80** at which will appear the y -bit portion (i.e., P_1) of the unwrapped information after the unwrapping device has been stepped the same number of times as was the corresponding wrapping device. Note that an input to an R register **75, 76, 77** for receiving a portion of the information to be unwrapped may be the same as the corresponding input for receiving data from another R register **75, 76** or the wrapping device **70** if properly configured.

The R_2 register **76** has a y -bit input **81** for receiving a portion of the information to be unwrapped (i.e., C_2), a y -bit input **82** for receiving input from the preceding R register in the shift-register chain, and a y -bit output **83** at which will

appear a y -bit portion (i.e., P_2) of the unwrapped information after the unwrapping device **70** is stepped the same number of times as was the corresponding wrapping device.

The R_n register **77** (i.e., the left-most register in the shift-register) has a y -bit input **84** for receiving a portion of the information to be unwrapped (i.e., C_n), a y -bit input **83** for receiving input from the R_2 register **76**, and a y -bit output **85** at which will appear a y -bit portion (i.e., P_n) of the unwrapped information after the unwrapping device **70** is stepped the same number of times as was the corresponding wrapping device.

The output **74** of the A register **71** is connected to a first input of a function block **F 86**. The function block **F 86** has a second input for receiving a y -bit user-definable value T . The function block **F 86** performs the inverse function of function block used to wrap the information on its two inputs and produces a y -bit output **88** that is connected to a first input of a combiner **89**.

The y -bit output **85** of the R_n register **77** is connected to a second input of the combiner **89**. The combiner **89** produces the inverse of that produced by the combiner used in the device to wrap the information. In the preferred embodiment, the combiner **89** concatenates its inputs so that the output **88** of the function block **F 86** constitutes the most significant bits of the output **90** of the combiner **89** and the output **85** of the R_n register **77** constitute the least significant bits of the output **90** of the combiner **89**. The output **90** of the combiner **89** is $2y$ bits.

The output **90** of the combiner **89** is connected to the input of an decryptor **91** that accepts $2y$ bits, decrypts the same in the inverse manner of the encryption in the corresponding wrapping device using an appropriate decryption key via a encryption-key input **92**, and produces $2y$ encrypted bits, half of which appears at a first output bus **79** and the other half of which appears at a second output bus **73**. The first output bus **79** of the decryptor **91** contains the same bits as did the output of R_i register in the device used to wrap the information. The second output bus **73** contains the same bits as did the output of A register in the device used to wrap the information.

The first output bus **79** of the decryptor **91** is connected to the input of the R_1 register **75**.

The second output bus **73** of the decryptor **91** is connected to the input of the A register **71**.

What is claimed is:

1. A method of cryptographically wrapping information, comprising the steps of:

- (a) if the information is not an even multiple of y bits then padding the information to a length that is an even multiple of y bits;
- (b) parsing the result of step (a) into $P_1, P_2, \dots, P_n$, where P_i has a length of y bits for $i=1$,
- (c) setting $R_i=P_i$, where $i=1, 2, \dots, n$, where n is equal to the length of the information divided by y ;
- (d) setting A equal to a user-definable initialization vector IV, where IV has a length equal to y ;
- (e) setting $j=0$;
- (f) setting $i=1$;
- (g) setting t to a user-definable value;
- (h) combining A and R_i ;
- (i) encrypting the result of step (h) using an encryptor that puts out $2y$ bits;
- (j) forming a first user-definable set of y bits and a second user-definable set of y bits from the result of step (i) in an invertible manner;
- (k) setting R_j equal to the first user-definable set of y bits;

9

- (l) combining the second user-definable set of y bits with t using a user-definable function;
 - (m) setting A equal to the result of step (l);
 - (n) if $i=n$ then incrementing j and reset $i=1$, otherwise incrementing i; and
 - (o) if j is equal to a user-definable number then returning $A, R_1, R_2, \dots, R_n$ as the cryptographically wrapped information and stopping, otherwise returning to step (g).
2. The method of claim 1, wherein said step of padding the information to a length that is an even multiple of y bits is selected from the group of padding steps comprising padding with zeros, padding with ones, padding with a random number, padding with a predetermined string of ones and zeros, padding a first end of the information, padding a second end of the information, padding within the information, and any combination thereof.
3. The method of claim 1, wherein said step of padding the information to a length that is an even multiple of y bits is comprised of the step of padding the information to a length that is an even multiple of y bits, where y is 64.
4. The method of claim 1, wherein said step of combining A and R_i is comprised of the step of concatenating A and R_i so that A constitutes high order bits and R_i constitutes low order bits.
5. The method of claim 1, wherein said step of setting t to a user-definable value is comprised of the step of setting $t=(n \times j)+i$.
6. The method of claim 1, wherein said step of encrypting the result of step (h) using an encryptor that puts out 2y bits is comprised of the step of encrypting the result of step (h) using the Advanced Encryption Standard.
7. The method of claim 1, wherein said step of forming a first user-definable set of y bits and a second user-definable set of y bits from the result of step (i) is comprised of forming a first user-definable set of the 64 least significant bits and a second user-definable set of 64 most significant bits from the result of step (i).
8. The method of claim 1, wherein said step of combining the second user-definable set with t using a user-definable function is comprised of the step of combining the second user-definable set with t using a user-definable function selected from the group of functions comprising a bit-wise exclusive-or function, a modular addition function, and a modular subtraction function.
9. The method of claim 1, wherein said step of returning $A, R_1, R_2, \dots, R_n$ as the cryptographically wrapped information and stopping if j is equal to a user-definable number is comprised of the step of returning $A, R_1, R_2, \dots, R_n$ as the cryptographically wrapped information and stopping if j is equal to 6.
10. A method of cryptographically unwrapping cryptographically wrapped information, comprising the steps of:
- (a) parsing the wrapped information into $C_0, C_1, \dots, C_n$, where C_i has a length of y bits, where y is the same as that used in forming the wrapped information;
 - (b) setting $R_i=C_i$, where $i=1, 2, \dots, n$, where n is the same as that used in forming the wrapped information;
 - (c) setting $A=C_0$;
 - (d) setting $j=k-1$, where k is the same as a user-definable number used to form the wrapped information;
 - (e) setting $i=n$;
 - (f) setting t to the same value of t used to form the wrapped information;
 - (g) combining A with t using a function that is the inverse of a function used to combine corresponding values to form the wrapped information;

10

- (h) combining the result of step (g) and R_i in a manner that is the inverse of a method used during the wrapping of the information to form two user-definable sets of y bits;
 - (i) decrypting the result of step (h), using the inverse function of an encryptor used to form the wrapped information;
 - (j) forming a first user-definable set of y bits and a second user-definable set of y bits from the result of step (i) in a manner that is the inverse of that to combine A and R_i to form the wrapped information;
 - (k) setting R_i equal to the first user-definable set of y bits;
 - (l) setting A equal to the second user-definable set of y bits;
 - (m) if $j=0, i=1$, and $A=IV$ used to form the wrapped information then returning $R_1, R_2, \dots, R_n$ as the unwrapped information and stopping, otherwise proceeding to the next step;
 - (n) if $j=0, i=1$, and A is not equal to IV then returning an error message and stopping, otherwise, proceeding to the next step; and
 - (o) if $i=1$ then decrementing j and returning to step (e), otherwise decrementing i and returning to step (f).
11. A device for cryptographically wrapping information, comprising:
- (a) a first register A, having a first y-bit input, a second y-bit input, and a y-bit output;
 - (b) n registers $R_1, R_2, \dots, R_n$, connected as a shift-register, where each of the n registers $R_1, R_2, \dots, R_n$ has a first y-bit input, a second y-bit input, and a y-bit output;
 - (c) a combiner, having a first input connected to the output of the first register A, having a second input connected to the output of register R_i ;
 - (d) an encryptor, having a first input connected to the output of the combiner, having a second input, and having a 2y-bit output configured as a first y-bit output bus connected to the second input of register R_n and a second y-bit bus; and
 - (e) a function block, having a first input connected to the second y-bit output bus of the encryptor, having a second input for receiving a y-bit user-definable value T, and having a y-bit output connected to the second input of the first register A.
12. The device of claim 11, wherein y is 64.
13. The device of claim 11, wherein the combiner is a concatenator.
14. The device of claim 11, wherein the encryptor is the Advanced Encryption Standard, having the a first 64-bit output bus that carries the least significant bits of the output of the combiner and a second 64-bit bus that carries the most significant bits of the output of the combiner.
15. The device of claim 11, wherein the function block is a function block selected from the group of function blocks comprising a bit-wise exclusive-or function block, a modular adder, and a modular subtractor.
16. A device for cryptographically unwrapping cryptographically wrapped information, comprising:
- (a) a first register A, having a first y-bit input, where y is the same as that used to form the wrapped information, a second y-bit input, and a y-bit output;
 - (b) n registers $R_1, R_2, \dots, R_n$, connected as a shift-register, where each of the n registers has a first y-bit input, a second y-bit input, and a y-bit output;
 - (c) a function block, having a first input connected to the output of the first register A, having a second input, and

11

having a y-bit output that performs an inverse function of a function block used to form the wrapped information;

- (d) a combiner, having a first input connected to the output of the function block, having a second input connected to the y-bit output of register R_m , and having a 2y-bit output, where the combiner performs an inverse function of a combiner used to form the wrapped information; and
- (e) a decryptor that performs the inverse of an encryptor used to form the wrapped information, having a first

12

input connected to the output of the combiner, having a second input for receiving a decryption key that will invert an encryption process used to form the wrapped information, and having a 2y-bit output configured as an output of the encryptor used to form the wrapped information having a first y-bit bus connected to the input of register R_1 and a second y-bit bus connected to the input of the first register A.

* * * * *