IDEA Encryption Algorithm

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Introduction

Improvements in the speed and power of microprocessor chips have meant that the Data Encryption Standard with its 56-bit key is subject to brute-force attacks that can be carried out by organizations of moderate size. The IDEA algorithm is interesting in its own right. It includes some steps which, at first, make it appear that it might be a non-invertible hash function instead of a block cipher. Also, it is interesting in that it entirely avoids the use of any lookup tables or S-boxes.

Literature Survey

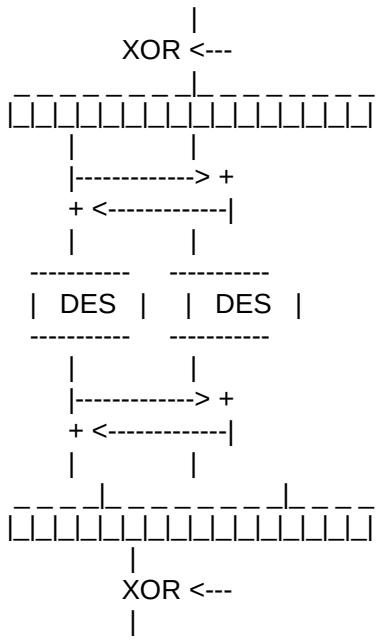
In the post-DES period many block cipher algorithms were proposed like BLOWFISH, FEAL, SAFER, NEWDES, REDOC-II, etc. At the same time, IDEA was created in Switzerland without any guidance from NSA and hence it is free from secret trapdoors.

Background

Because block cipher modes give block ciphers the flexibility of also serving in applications which can make use of stream ciphers, a block cipher was sought. A block length of 128 bits, making dictionary attacks more difficult, is specified, and key lengths of 128, 192, and 256 bits are to be allowed for in the designs submitted.

A larger block length also increases the speed of encipherment, by allowing more text to be enciphered at once. Where a 56-bit key does not provide enough security at present, it is possible to use Triple-DES (enciphering in DES three times over, using either two or three different keys - and with the middle encipherment done in deciphering mode for compatibility reasons) and therefore one of the goals to be met by any submitted cipher is that it be faster than Triple DES.

An idea that might occur upon first hearing about the AES effort: could a simple construction like the following, operating at speeds only slightly slower than those of single DES, provide adequate strength:



one might ask. However, while it seems that the series of byte substitutions, followed by a Pseudo-Hadamard Transform, mixes together the two halves of the block well enough, attacks are possible against this type of construction that make it not much stronger than normal DES, at least in theory. If the Pseudo-Hadamard Transform, however, is replaced by something better, such as the mask-driven bit swap used in the cipher ICE, where a mask selects bits to be swapped between a pair of words, and we further enhance it by using a 4 of 8 code to ensure each byte includes both swapped and non-swapped bits, one might have something usable. The additional XOR whitening is applicable, if otherwise all sixteen bytes go through the same byte substitution.

With a better initial mixing step, and a willingness to go to double-DES speeds, though, this approach could lead to something adequate.

As block ciphers like Blowfish demonstrate, it is possible to do better than DES at faster speeds, and DES is designed for hardware implementation, and is unnecessarily slow in software. Thus, something that is designed for fast software encryption, with the required security, will be more optimal if it comes from a fresh design process.

Theory

The IDEA algorithm is interesting in its own right. It includes some steps which, at first, make it appear that it might be a non-invertible hash function instead of a block cipher. Also, it is interesting in that it entirely avoids the use of any lookup tables or S-boxes.

IDEA uses 52 subkeys, each 16 bits long. Two are used during each round proper, and four are used before every round and after the last round. It has eight rounds.

The plaintext block in IDEA is divided into four quarters, each 16 bits long. Three operations are used in IDEA to combine two 16 bit values to produce a 16 bit result, addition, XOR, and multiplication. Addition is normal addition with carries, modulo 65,536. Multiplication, as used in IDEA, requires some explanation.

Multiplication by zero always produces zero, and is not invertible. Multiplication modulo n is also not invertible whenever it is by a number which is not relatively prime to n. The way multiplication is used in IDEA, it is necessary that it be always invertible. This is true of multiplication IDEA style.

The number 65,537, which is 2^16+1, is a prime number. (Incidentally, 2^8+1, or 257, is also prime, and so is 2^4+1, or 17, but 2^32+1 is not prime, so IDEA cannot be trivially scaled up to a 128-bit block size.) Thus, if one forms a multiplication table for the numbers from 1 through 65,536, each row and column will contain every number once only, forming a Latin square, and providing an invertible operation. The numbers that 16 bits normally represent are from 0 to 65,535 (or, perhaps even more commonly, from -32,768 to 32,767). In IDEA, for purposes of multiplication, a 16 bit word containing all zeroes is considered to represent the number 65,536; other numbers are represented in conventional unsigned notation, and multiplication is modulo the prime number 65,537.

Algorithm

Let the four quarters of the plaintext be called A, B, C, and D, and the 52 subkeys called K(1) through K(52).

Before round 1, or as the first part of it, the following is done:

Multiply A by K(1). Add K(2) to B. Add K(3) to C. Multiply D by K(4).

Round 1 proper consists of the following:

Calculate A xor C (call it E) and B xor D (call it F).

Multiply E by K(5). Add the new value of E to F.

Multiply the new value of F by K(6). Add the result, which is also the new value of F, to E.

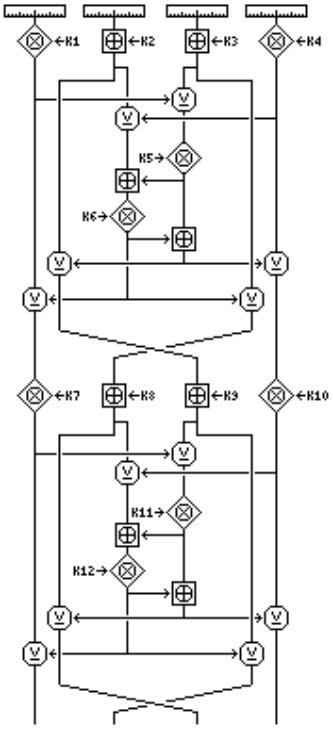
Change both A and C by XORing the current value of F with each of them; change both B and D by XORing the current value of E with each of them.

Swap B and C

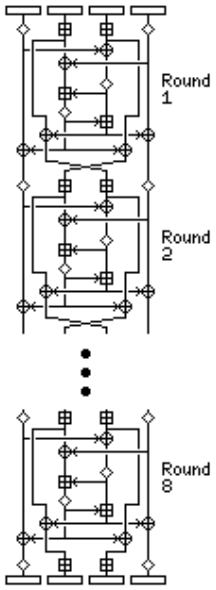
Repeat all of this eight times, or seven more times, using K(7) through K(12) the second time, up to K(43) through K(48) the eighth time. Note that the swap of B and C is *not* performed after round 8.

Then multiply A by K(49). Add K(50) to B. Add K(51) to C. Multiply D by K(52).

The intricacies of IDEA encryption may be made somewhat clearer by examining the following diagrams:



Details:



Overview:

Decryption

How can the round in IDEA be reversed, since all four quarters of the block are changed at the same time, based on a function of all four of their old values? Well, the trick to that is that A xor C isn't changed when both A and C are XORed by the same value, that value cancels out, no matter what that value might be. And the same applies to B xor D. And since the values used are functions of (A xor C) and (B xor D), they are still available.

This cross-footed round, rather than a Feistel round, is the most striking distinguishing factor of IDEA, although its use of multiplication, addition, and XOR to avoid the use of S-boxes is also important.

Those that are added are replaced by their two's complement. Those that are multiplied in are replaced by their multiplicative inverse, modulo 65,537, in IDEA notation when used to change blocks directly, but those used to calculate the cross-footed F-functions are not changed. Keys XORed in would not need to be changed, but there aren't any such keys in IDEA. Due to the placement of the swap, the first four keys for decryption are moved somewhat differently than the other keys used for the same operation between rounds.

The decryption key schedule is:

The first four subkeys for decryption are:

KD(1) = 1/K(49)

KD(2) = -K(50)

KD(3) = -K(51)

KD(4) = 1/K(52)

and they do not quite follow the same pattern as the remaining subkeys which follow.

The following is repeated eight times, adding 6 to every decryption key's index and subtracting 6 from every encryption key's index:

KD(5) = K(47)

KD(6) = K(48)

KD(7) = 1/K(43)

KD(8) = -K(45)

KD(9) = -K(44)

KD(10) = 1/K(46)

Subkey Generation

The 128-bit key of IDEA is taken as the first eight subkeys, K(1) through K(8). The next eight subkeys are obtained the same way, after a 25-bit circular left shift, and this is repeated until all encryption subkeys are derived.

This method of subkey generation is regular, and this may be a weakness. However, IDEA is considered to be highly secure, having stood up to all forms of attack so far tried by the academic community.

Conclusion

IDEA offers a vast improvement over commonly used security programs that implement the DES standard (an algorithm limited by a 56-Bit key). IDEA has a key length of 128-Bits, thereby dramatically increasing security. IDEA is used worldwide by military and government organizations, as well as financial institutions, and telecommunications industries – by more than 80 partners worldwide.

Additionally, IDEA offers a series of advantages based on its mathematical structure: it encrypts and decrypts faster than other algorithms and due to its standardized interfaces can easily be implemented in existing products. “IDEA is recognized as being strong, small and fast. This accounts for why IDEA can be easily adapted to future requirements and can thus meet the expectations of this promising market.”

Appendices

“Unbalanced Feistel Networks and Block-Cipher Design”, Bruce Schneier, John Kelsey

“The Security of the RC-6 Block Cipher”, Ronald Rivest.

“Cryptanalitic Attacks on Pseudorandom Number Generators”, Bruce Schneier, John Kelsey, etc.

“A Self-Study Course in Block-Cipher Cryptanalysis”, Bruce Schneier

“On the Weak Keys of Blowfish”. Serge Vaudenay.

“Improved Differential Attacks on RC-5”, Lars R. Knudsen, Willi Meier.

Attacks on Shamir's "RSA for paranoids", Henri Gilbert, etc.