Comparative Study of Cryptographic Algorithms

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Abstract: This paper pinpoints on the resource utilization and analysis of the performance of different cryptographic algorithms. Security is the most challenging issue that involves computers and communication and has to face prime risks. To overcome this security concern numerous cryptographic encryption procedures exists and do compare seven different algorithms namely DES, Triple DES, Blowfish, Twofish, AES and RSA.

Keywords: Cryptography, Symmetric, Asymmetric, Triple DES, Blowfish, Twofish, AES, RSA

1. INTRODUCTION
The conversion of plaintext to cipher text is encryption and the reverse process is decryption. The type and length of the keys depends on the encryption algorithm and the measures of security needed. The use of Single key pertains to encryption and decryption in symmetric else it is asymmetric.

With this key, the message is encrypted by the sender and is decrypted by the recipient, the key security is a challenge.

1.1 Cryptography Goals
The security system secrecy is ensured by a set of security functions which are the aim of the system. The goals are as listed below:
• Authentication - the sender identity and the receiver identity is verified prior to sending and receiving messages.
• Confidentiality - only the people who are authenticated can read and interpret the message.
• Integrity - the message is secure from any modification between sender and receiver.
• Non-repudiation - neither the sender or the receiver cannot mistakenly refuse of sending a message
• Service Reliability and Availability - The availability and the services gets affected when intruders attack the secure systems.

1.2 Data Encryption Standard (DES)
Data Encryption Standard (DES) is a symmetric key block cipher. DES was found in 1972 by IBM using the data encryption algorithm. Apparently no weakness has been found yet and the only risk is brute-force. It was accepted by the government of USA as standard encryption algorithm. It has a key of 64 bits and the size of the block is 64 bits. As restriction has been put by NSA regarding usage of DES with 56-bit key size, so DES avoids 8 bits from the 64 bit keys and then compresses the 56 bit keys derived from 64 bit keys to encrypt data in a block size of 64-bits [6].

Figure 1: Key schedules for Encryption and Decryption [11]

Figure 2: Encryption and Decryption using DES[12]
A 64 bit cipher text is originated.

Due to the technological advancement many intrusions and possiblity to break the encrypted code was detected. To improve the security the encryption is performed thrice (3DES).

1.3 Triple DES

Triple DES was formulated to reinstate the original DES algorithm [4], which hackers learned to defeat with comparative easiness. Earlier, Triple DES uses three independent keys. The standard encryption method is similar to the original DES but applied 3 times to increment the encryption level. The attacks of brute force in DES as well as the attack of meet-in-the-middle occurred in 2-DES can be removed. The advantage is proven reliability and longer key size reduces the time taken to break DES and eliminates the shortcut attacks. [6]

Triple Data Encryption Algorithm (TDEA) and the standard ANS X9.52 have Block cipher with secret symmetric key and have a block length of 64 bits and the size of the key is 56 bits, 112 bits or 168 bits.

3DES was designed because DES algorithm, developed in the 1970s uses 56-bits key. The security in effect provided by 3DES is just 112 bits because of the meet-in-the-middle attacks. Triple DES executes three times slower than DES, but security aspects are more if used properly. The procedure for encryption and decrypting the same, except the reverse execution. In DES, data is encrypted and decrypted in 64-bit chunks. For DES the input key size is 64 bits and the actual key adopted by DES is of the size 56 bits.

The parity bit is the least significant (right-most) bit in each single byte and is set such that there is everytime an odd number of 1s in each byte. The bits of parity are avoided, so seven of the most significant bits of each byte are used, emanating in a key size of 56 bits. Hence the effective strength of the key for Triple DES is literally 168 bits due to the fact that the three keys contains 8 parity bits each that is not used during the process of encryption.

- All keys being independent
- Key 1 and key 2 being independent keys
- All three keys being identical

Algorithm

Run DES three times:

ECB mode:
- If K2 = K3, this is DES

Backwards compatibility
Known not to be just DES with K4 Has 112 bits of security, not 3 x 56 = 168

Further, Table 3 shows the algorithm for 3DES. It accepts a secret key of 168 bits that is divided into three keys of 56 bits.

- Encryption adopting the first secret key
- Decryption adopting the second secret key
- Encryption adopting the third secret key

Encryption: c = E3 (D2 (E1 (m)))
Decryption: m = D1 (E2 (D3(c)))

Using decryption in the second step and during encryption the algorithm provides backward compatibility within the usual DES algorithm. In these cases the first and second secret keys or the second and third secret keys are the same key combinations.

- c = E3 (D1 (E1 (m))) = E3 (m)
- c = E3 (D3 (E1 (m))) = E1 (m)

Hence, it is sensible to apply 3DES cipher with a secret key of 112-bits. In this case first and third secret keys are the same.

- c = E1 (D2 (E1 (m)))

Triple DES is beneficial because it has an enormous sized key length, which is longer than most key lengths affiliated with other encryption modes. DES algorithm was replaced by the Advanced Encryption Standard and Triple DES is now considered to be obsolete. It is derived from the single DES but the method is used in triplicate and includes three sub keys and key padding whenever necessary. Keys must be increased to 64 bits in length Known for its backwards compatibility and flexibility can easily be converted for Triple DES inclusion.[6]

Triple DES has short and weak encryption keys and has shorter block size. AES has a better encryption mechanism and hence the performance.
1.4 Blowfish

Blowfish encryption algorithm needs a 32-bit microprocessor with one byte for each 26 clock cycles. Blowfish holds 16 cycles. Each round consists of XOR operation and a function. Every single round comprise of key expansion and the encryption of data. Key expansion is generally used for making the primary contents of one array and data encryption uses a 16 rounds Feistel network methods. [4] Plain text and key are the inputs of this algorithm. A 64-bit plain text taken is divided into two 32 bits data and at each round the given key is expanded and stored in 18 p-array and gives 32 bits key as input and XORed with previous round data. Then, for j = 1 to 14:

\[ x_L = x_L \oplus P_i \]
\[ x_R = F(x_L) \oplus x_R \]

Swap \( x_L \) and \( x_R \)

After the sixteen rounds, swap \( x_L \) and \( x_R \) again to undo the last swap. Then, \( x_R = x_R \oplus P_{15} \) and \( x_L = x_L \oplus P_{16} \). Finally, merge \( x_L \) and \( x_R \) to obtain the ciphertext.

The phrases used in Twofish are:

1.5.1 Fiestal Network

Functions are transformed to permutations. Horst Fiestal [9] invented this design of Lucifer and propelled by DES. The constituent of Fiestal network is the F-function. It maps an input string to an output string using a key. [2]

1.5.2 Diffusion

A minimal change in the plaintext affects many bits of the ciphertext to maintain convolution between plain and ciphertext. Diffusion is attained by executing a certain permutation and carry out a functional operation. [10]

1.5.3 Confusion

The relationship among the cipher text and sub key can be made complex by creating “confusion” by handling relations. [10]

1.5.4 S-boxes

An S-box is a table-driven non-linear replacement function used in almost all block ciphers. The input size and output size respectively of S-boxes change and will be created randomly or algorithmically. [7]

1.5.5 MDS Matrices

A Maximum Distance Separable (MDS) [7] code is a linear mapping from the elements of the \( a \) and \( b \) field over a stipulated field, thereby creating a composite vector of \( a + b \) elements, which has the property of the minimum number of non-zero elements in any vector which is non-zero is at least \( b + 1 \) [8]. Reed-Solomon (RS) error-correcting codes are known as MDS. An inevitable condition for a \( a \times b \) matrix to be MDS is that all mixture of square sub matrices, procured by discarding rows or columns, are non-singular.

1.5.6 Pseudo Hadamard Transforms

A pseudo Hadamard transforms (PHT) [7] is a simple operation that mixes and runs quickly in software. It is applied for diffusion. For given two inputs \( a \& b \), the 32-bit PHT is defined as

\[ a_0 = a + b \mod 2^{32} \ldots (1) \]
\[ b_0 = a + 2b \mod 2^{32} \ldots (2) \]
1.5.7 Whitening
Whitening [7], the method of XORing key material prior to the first round and beyond the last round. It was observed that whitening substantially increases the difficulty of key search attacks against the remainder of the cipher.

1.6 RSA
This is public key encryption algorithm developed by Ron Rivest, Adi Shamir and Leonard Adelman in 1977. It is the well-known asymmetric key algorithm for cryptography. It may use to provide both secrecy and digital signature. RSA applies the prime number to generate the public and private key based on mathematical fact and taking the product of large numbers together. The algorithm implements the block size data where plaintext and cipher text are integral values between 0 and n1 for some values of n. The length of n is observed to be 1024 bits or 309 decimal digits. Apparently two distinct keys are used for encryption and decryption purposes. The sender knows encryption key and receiver knows decryption key.

![RSA Algorithm](image)

**Algorithm:**

Choose large prime numbers r and s such that r~±s.
Compute n=rs
Compute φ (rs) = (r-1)(s-1)
Choose the public key e such that gcd (φ (n), e) =1; 1<e< φ (n)
Select the private key d such that
d*e mod φ (n) =1
So in RSA algorithm encryption and decryption are performed as-
Encryption
Calculate cipher text CT from plaintext message M such that
CT=M^e mod n
Decryption M=CT^d mod n=M^ed mod n

1.7 Advanced Encryption Standard (AES)
U.S. Government and different other organizations have acquired the Advanced Encryption Standard (AES) algorithm as a reliable standard. [1] It is highly efficient in 128-bit form, the algorithm uses keys of 192 and 256 bits for heavy duty encryption purposes is quite considered sealed to all attacks, with the exclusion of brute force, which strive to decipher messages using all possible combinations in the 128, 192, or 256-bit cipher. The experts of security trust that AES will be finally addressed as the actual standard for encryption of data in private sector.[1][5]

![AES Algorithm](image)

**Algorithm:**

1. “SubBytes”, a non-linear transformation is a substitution of bytes for each byte of the block.
2. “ShiftRows” transformation iteratively shifts (permutes) the bytes inside the block
3. “MixColumns” transformation binds the 4-bytes together thereby forming the 4-term polynomials and multiplies the polynomials with a fixed polynomial mod (x^4+1).
4. “AddRoundKey” transformation along with the data block will add the round key.

The iterated transform (or round), in most ciphers, generally have a Feistel Structure. Normally, in this structure, the transitional state bits are transposed without changing the value to another position (permutation). AES lacks a Feistel structure but have three distinct invertible transforms based on the Wide Trial Strategy design method.
### Table of Comparison

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<th>AES</th>
<th>RSA</th>
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<tr>
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<td>Diffie and Hellman</td>
<td>Bruce Schneier</td>
<td>Bruce Schneier</td>
<td>Vincent Rijmen and Joan Daemen</td>
<td>Ron Rivest, Adi Shamir, Leonard Adleman</td>
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<tr>
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<td>Symmetric block</td>
<td>Symmetric block</td>
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<td>128, 192 or 256</td>
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<td>1024 - 4096</td>
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<tr>
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<td>64</td>
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<td>XOR, Fixed S-boxes</td>
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<td>-</td>
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<td>-</td>
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<td>Not Secure Enough</td>
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<td>Replacement of DES, Excellent Security</td>
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<td></td>
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<tr>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
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</table>

### 3. CONCLUSION
Cryptographic techniques and tools do play a vital role in designing emerging network security technologies. Among the discussed five algorithms AES is best in terms of energy consumption, performance and resource utilization. AES algorithm is brisky, and is best adapted for use in both hardware and software environments.

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