Performance Analysis of Data Encryption Algorithms

Abdel-Karim Al Tamimi, aa7@wustl.edu

Abstract

The two main characteristics that identify and differentiate one encryption algorithm from another are its ability to secure the protected data against attacks and its speed and efficiency in doing so. This paper provides a performance comparison between four of the most common encryption algorithms: DES, 3DES, Blowfish and AES (Rijndael). The comparison has been conducted by running several encryption settings to process different sizes of data blocks to evaluate the algorithm's encryption/decryption speed. Simulation has been conducted using C# language.

Keywords : Encryption Algorithm, Performance,Analysis, AES, DES, Blowfish, TripleDES, Cryptography

---

Table of Contents

See Also : Security in Wireless Data Networks , Network Security Concepts: Review

1. Introduction

As the importance and the value of exchanged data over the Internet or other media types are increasing, the search for the best solution to offer the necessary protection against the data thieves' attacks along with providing these services under timely manner is one of the most active subjects in the security related communities.

This paper tries to present a fair comparison between the most common and used algorithms in the data encryption field. Since our main concern here is the performance of these algorithms under different settings, the presented comparison takes into consideration the behavior and the performance of the algorithm when different data loads are used.

Section 2 will give a quick overview of cryptography and its main usages in our daily life; in addition to that it will explain some of the most used terms in cryptography along with a brief description of each of the compared algorithm to allow the reader to understand the key differences between them.Section 3 will show the results achieved by other contributions and their conclusions. Section 4 will walk through the used setup environment and settings and the used system components. Section 5 illustrates the performance evaluation methodology and the chosen settings to allow a better comparison. Section 6 gives a thorough discussion about the simulation results, and finally section 7 concludes this paper by summaries the key points and other related considerations.

2. Cryptography: Overview

An overview of the main goals behind using cryptography will be discussed in this section along with the common terms used in this field.

Cryptography is usually referred to as "the study of secret", while nowadays is most attached to the definition of encryption. Encryption is the process of converting plain text "unhidden" to a cryptic text "hidden" to secure it against data thieves. This process has another part where cryptic text needs to be decrypted on the other end to be understood. Fig.1 shows the simple flow of commonly used encryption algorithms.

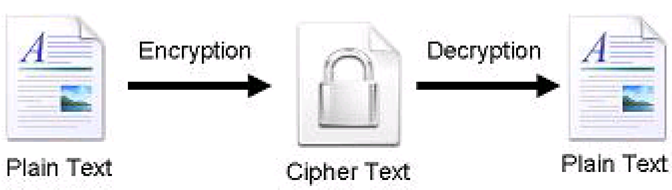


Fig.1 Encryption-Decryption Flow

As defined in RFC 2828 [RFC2828], cryptographic system is "a set of cryptographic algorithms together with the key management processes that support use of the algorithms in some application context." This definition defines the whole mechanism that provides the necessary level of security comprised of network protocols and data encryption algorithms.

2.1 Cryptography Goals

This section explains the five main goals behind using Cryptography.

Every security system must provide a bundle of security functions that can assure the secrecy of the system. These functions are usually referred to as the goals of the security system. These goals can be listed under the following five main categories[Earle2005]:

Authentication: This means that before sending and receiving data using the system, the receiver and sender identity should be verified.

Secrecy or Confidentiality: Usually this function (feature) is how most people identify a secure system. It means that only the authenticated people are able to interpret the message (date) content and no one else.

Integrity: Integrity means that the content of the communicated data is assured to be free from any type of modification between the end points (sender and receiver). The basic form of integrity is packet check sum in IPv4 packets.

Non-Repudiation: This function implies that neither the sender nor the receiver can falsely deny that they have sent a certain message.

Service Reliability and Availability: Since secure systems usually get attacked by intruders, which may affect their availability and type of service to their users. Such systems should provide a way to grant their users the quality of service they expect.

2.2 Block Ciphers and Stream Ciphers

One of the main categorization methods for encryption techniques commonly used is based on the form of the input data they operate on. The two types are Block Cipher and Stream Cipher. This section discusses the main features in the two types, operation mode, and compares between them in terms of security and performance.

2.2.1 Block Cipher

Before starting to describe the key characteristics of block cipher, the definition of cipher word must be presented. "A cipher is an algorithm for performing encryption (reverse is decryption) "[Wikipedia-BC].

In this method data is encrypted and decrypted if data is in from of blocks. In its simplest mode, you divide the plain text into blocks which are then fed into the cipher system to produce blocks of cipher text.

ECB(Electronic Codebook Mode) is the basic form of clock cipher where data blocks are encrypted directly to generate its correspondent ciphered blocks (shown in Fig. 2). More discussion about modes of operations will be discussed later.

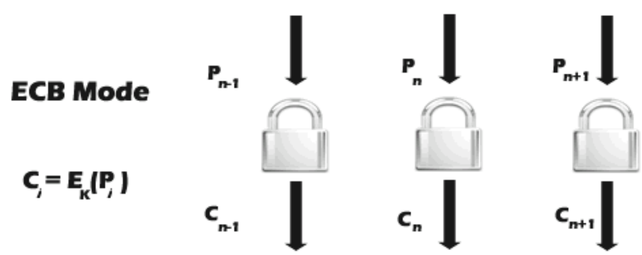


Fig.2 Block Cipher ECB Mode.

2.2.2 Stream Ciphers

Stream cipher functions on a stream of data by operating on it bit by bit. Stream cipher consists of two major components: a key stream generator, and a mixing function. Mixing function is usually just an XOR function, while key stream generator is the main unit in stream cipher encryption technique. For example, if the key stream generator produces a series of zeros, the outputted ciphered stream will be identical to the original plain text. Figure 3 shows the operation of the simple mode in stream cipher.

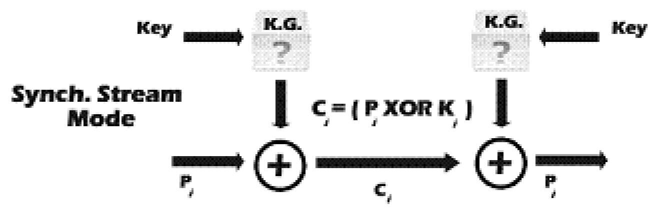


Fig. 3 Stream Cipher (Simple Mode)

2.3 Mode of Operations

This section explains the two most common modes of operations in Block Cipher encryption-ECB and CBC- with a quick visit to other modes.

There are many variances of block cipher, where different techniques are used to strengthen the security of the system. The most common methods are: ECB (Electronic Codebook Mode), CBC (Chain Block Chaining Mode), and OFB (Output Feedback Mode). ECB mode is the CBC mode uses the cipher block from the previous step of encryption in the current one, which forms a chain-like encryption process. OFB operates on plain text in away similar to stream cipher that will be described below, where the encryption key used in every step depends on the encryption key from the previous step.

There are many other modes like CTR (counter), CFB (Cipher Feedback), or 3DES specific modes that are not discussed in this paper due to the fact that in this paper the main concentration will be on ECB and CBC modes.

2.4 Symmetric and Asymmetric encryptions

Data encryption procedures are mainly categorized into two categories depending on the type of security keys used to encrypt/decrypt the secured data. These two categories are: Asymmetric and Symmetric encryption techniques

2.4.1 Symmetric Encryption

In this type of encryption, the sender and the receiver agree on a secret (shared) key. Then they use this secret key to encrypt and decrypt their sent messages. Fig. 4 shows the process of symmetric cryptography. Node A and B first agree on the encryption technique to be used in encryption and decryption of communicated data. Then they agree on the secret key that both of them will use in this connection. After the encryption setup finishes, node A starts sending its data encrypted with the shared key, on the other side node B uses the same key to decrypt the encrypted messages.

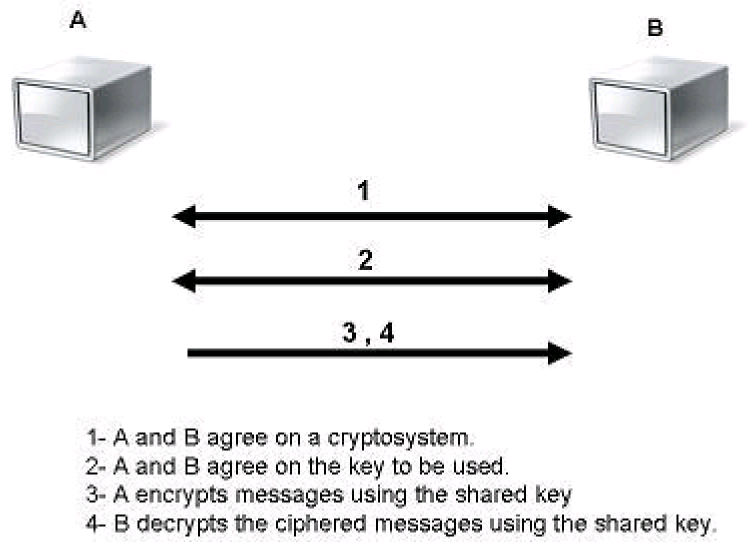


Fig.4 Symmetric Encryption

The main concern behind symmetric encryption is how to share the secret key securely between the two peers. If the key gets known for any reason, the whole system collapses. The key management for this type of encryption is troublesome, especially if a unique secret key is used for each peer-to-peer connection, then the total number of secret keys to be saved and managed for n-nodes will be n(n-1)/2 [Edney2003] .

2.4.2 Asymmetric Encryption

Asymmetric encryption is the other type of encryption where two keys are used. To explain more, what Key1 can encrypt only Key2 can decrypt, and vice versa. It is also known as Public Key Cryptography (PKC), because users tend to use two keys: public key, which is known to the public, and private key which is known only to the user. Figure 5 below illustrates the use of the two keys between node A and node B. After agreeing on the type of encryption to be used in the connection, node B sends its public key to node A. Node A uses the received public key to encrypt its messages. Then when the encrypted messages arrive, node B uses its private key to decrypt them.

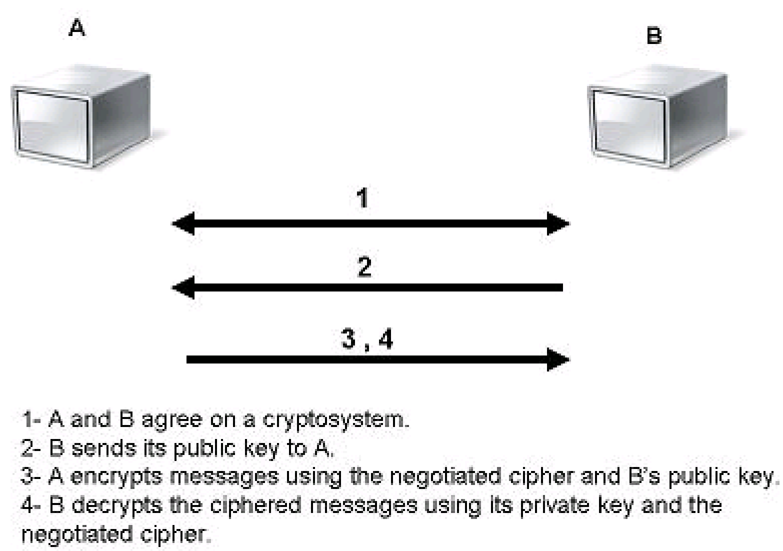


Fig.5 Asymmetric Encryption

This capability surmounts the symmetric encryption problem of managing secret keys. But on the other hand, this unique feature of public key encryption makes it mathematically more prone to attacks. Moreover, asymmetric encryption techniques are almost 1000 times slower than symmetric techniques, because they require more computational processing power[Edney2003] [Hardjono2005] .

To get the benefits of both methods, a hybrid technique is usually used. In this technique, asymmetric encryption is used to exchange the secret key, symmetric encryption is then used to transfer data between sender and receiver.

2.5 Compared Algorithms

This section intends to give the readers the necessary background to understand the key differences between the compared algorithms.

DES: (Data Encryption Standard), was the first encryption standard to be recommended by NIST (National Institute of Standards and Technology). It is based on the IBM proposed algorithm called Lucifer. DES became a standard in 1974 [TropSoft] . Since that time, many attacks and methods recorded that exploit the weaknesses of DES, which made it an insecure block cipher.

3DES: As an enhancement of DES, the3DES (Triple DES) encryption standard was proposed. In this standard the encryption method is similar to the one in original DES but applied 3 times to increase the encryption level. But it is a known fact that 3DES is slower than other block cipher methods.

AES: (Advanced Encryption Standard), is the new encryption standard recommended by NIST to replace DES. Rijndael (pronounced Rain Doll) algorithm was selected in 1997 after a competition to select the best encryption standard. Brute force attack is the only effective attack known against it, in which the attacker tries to test all the characters combinations to unlock the encryption. Both AES and DES are block ciphers.

Blowfish: It is one of the most common public domain encryption algorithms provided by Bruce Schneier - one of the world's leading cryptologists, and the president of Counterpane Systems, a consulting firm specializing in cryptography and computer security.

Blowfish is a variable length key, 64-bit block cipher. The Blowfish algorithm was first introduced in 1993.This algorithm can be optimized in hardware applications though it's mostly used in software applications. Though it suffers from weak keys problem, no attack is known to be successful against [BRUCE1996][Nadeem2005].

In this section a brief description of the compared encryption algorithms have been introduced. This introductions to each algorithm are to provided the minimum information to distinguish the main differences between them.

3. Related Work Results

To give more prospective about the performance of the compared algorithms, this section discusses the results obtained from other resources.

One of the known cryptography libraries is Crypto++ [Crypto++]. Crypto++ Library is a free C++ class library of cryptographic schemes. Currently the library consists of the following, some of which are other people's code, repackaged into classes.

Table 1 contains the speed benchmarks for some of the most commonly used cryptographic algorithms. All were coded in C++, compiled with Microsoft Visual C++ .NET 2003 (whole program optimization, optimize for speed, P4 code generation), and ran on a Pentium 4 2.1 GHz processor under Windows XP SP 1. 386 assembly routines were used for multiple-precision addition and subtraction. SSE2 intrinsics were used for multiple-precision multiplication.

It can be noticed from the table that not all the modes have been tried for all the algorithms. Nonetheless, these results are good to have an indication about what the presented comparison results should look like.

Also it is shown that Blowfish and AES have the best performance among others. And both of them are known to have better encryption (i.e. stronger against data attacks) than the other two.

Algorithm	**Megabytes(2^20 bytes) Processed**	**Time Taken**	**MB/Second**
Blowfish	256	3.976	64.386
Rijndael (128-bit key)	256	4.196	61.010
Rijndael (192-bit key)	256	4.817	53.145
Rijndael (256-bit key)	256	5.308	48.229
Rijndael (128) CTR	256	4.436	57.710
Rijndael (128) OFB	256	4.837	52.925
Rijndael (128) CFB	256	5.378	47.601
Rijndael (128) CBC	256	4.617	55.447
DES	128	5.998	21.340
(3DES)DES-XEX3	128	6.159	20.783
(3DES)DES-EDE3	64	6.499	9.848

Table 1 Comparison results using Crypto++

[Nadeem2005] In this paper, the popular secret key algorithms including DES, 3DES, AES (Rijndael), Blowfish, were implemented, and their performance was compared by encrypting input files of varying contents and sizes. The algorithms were implemented in a uniform language (Java), using their standard specifications, and were tested on two different hardware platforms, to compare their performance.

Tables 2 and 3 show the results of their experiments, where they have conducted it on two different machines: P-II 266 MHz and P-4 2.4 GHz.

Input Size (bytes)	**DES**	**3DES**	**AES**	**BF**
20,527	24	72	39	19
36,002	48	123	74	35
45,911	57	158	94	46
59,852	74	202	125	58
69,545	83	243	143	67
137,325	160	461	285	136
158,959	190	543	324	158

166,364	198	569	355	162
191,383	227	655	378	176
232,398	276	799	460	219
Average Time	134	383	228	108
Bytes/sec	835	292	491	1,036

Table 2 Comparative execution times (in seconds) of encryption algorithms in ECB mode on a P-II 266 MHz machine

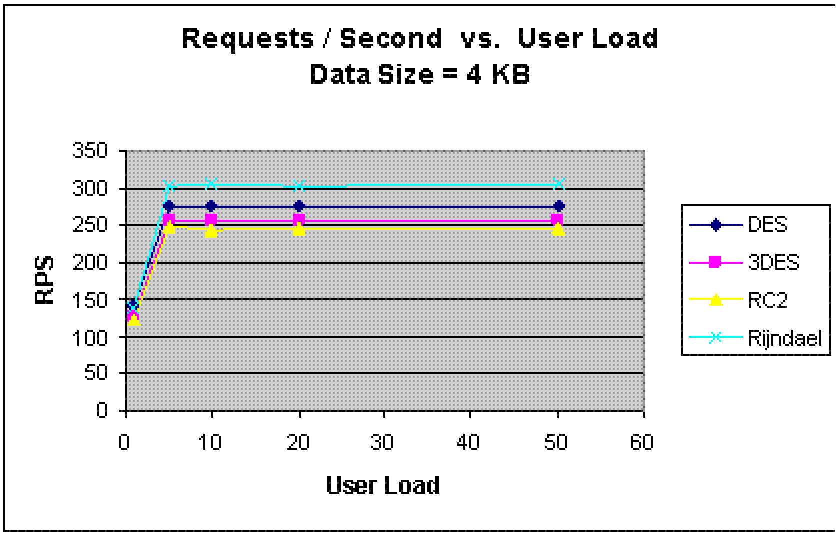
Input Size (bytes)	**DES**	**3DES**	**AES**	**BF**
20,527	2	7	4	2
36,002	4	13	6	3
45,911	5	17	8	4
59,852	7	23	11	6
69,545	9	26	13	7
137,325	17	51	26	14
158,959	20	60	30	16
166,364	21	62	31	17
191,383	24	72	36	19
232,398	30	87	44	24
Average Time	14	42	21	11
Bytes/sec	7,988	2,663	5,320	10,167

Table 3 Comparative execution times (in seconds) of encryption algorithms in ECB mode on a P-4 2.4 GHz machine

From the results it is easy to observe that Blowfish has an advantage over other algorithms in terms of throughput. [Nadeem2005] has also conducted comparison between the algorithms in stream mode using CBC, but since this paper is more focused on block cipher the results were omitted.

The results showed that Blowfish has a very good performance compared to other algorithms. Also it showed that AES has a better performance than 3DES and DES. Amazingly it shows also that 3DES has almost 1/3 throughput of DES, or in other words it needs 3 times than DES to process the same amount of data.

[Dhawan2002] has also done experiments for comparing the performance of the different encryption algorithms implemented inside .NET framework. Their results are close to the ones shown before (Figure 6).



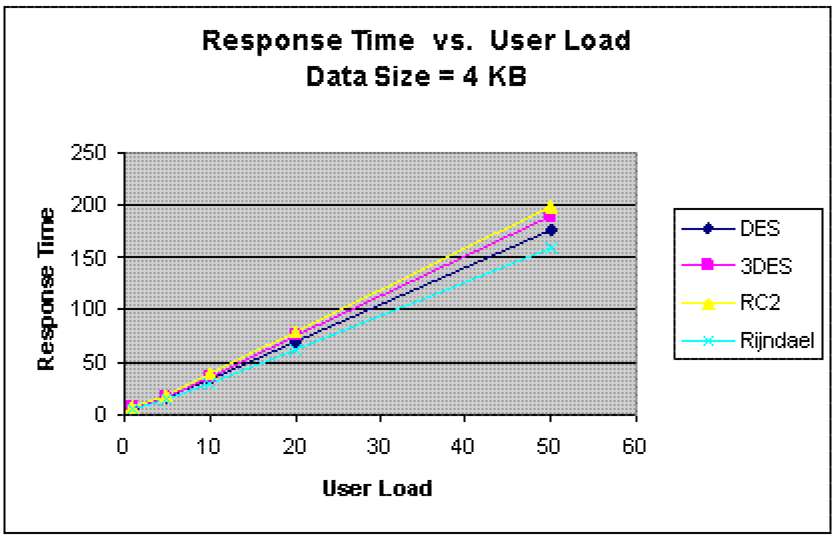


Fig. 6 Comparison results using .NET implemntations[Dhawan2002]

The comparison was performed on the following algorithms: DES, Triple DES (3DES), RC2 and AES (Rijndael). The results shows that AES outperformed other algorithms in both the number of requests processes per second in different user loads, and in the response time in different user-load situations.

This section gave an overview of comparison results achieved by other people in the field.

4. Simulation Setup

This section describes the simulation environment and the used system components.

As mentioned this simulation uses the provided classes in .NET environment to simulate the performance of DES, 3DES and AES (Rijndael). Blowfish implementation used here is the one provided by Markus Hahn [BlowFish.NET] under the name Blowfish.NET. This implementation is thoroughly tested and is optimized to give the maximum performance for the algorithm.

The implementation uses managed wrappers for DES, 3DES and Rijndael available in System.Security.Cryptography that wraps unmanaged implementations available in CryptoAPI. These are DESCryptoServiceProvider, TripleDESCryptoServiceProvider and RijndaelManaged respectively. There is only a pure managed implementation of Rijndael available in System.Security.Cryptography, which was used in the tests.

Table 4 shows the algorithms settings used in this experiment. These settings are used to compare the results initially with the result obtained from [Dhawan2002].

Algorithm	**Key Size** **(Bits)**	**Block Size** **(Bits)**
DES	64	64
3DES	192	64
Rijndael	256	128
Blowfish	448	64

Table 4 Algorithms settings

3DES and AES support other settings, but these settings represent the maximum security settings they can offer. Longer key lengths mean more effort must be put forward to break the encrypted data security.

Since the evaluation test is meant to evaluate the results when using block cipher, due to the memory constraints on the test machine (1 GB) the test will break the load data blocks into smaller sizes .The load data are divided into the data blocks and they are created using the RandomNumberGenerator class available in System.Security.Cryptography namespace.

5. Performance Evaluation Methodology

This section describes the techniques and simulation choices made to evaluate the performance of the compared algorithms. In addition to that, this section will discuss the methodology related parameters like: system parameters, experiment factor(s), and experiment initial settings.

5.1 System Parameters

The experiments are conducted using 3500+ AMD 64bit processor with 1GB of RAM. The simulation program is compiled using the default settings in .NET 2003 visual studio for C# windows applications. The experiments will be performed couple of times to assure that the results are consistent and are valid to compare the different algorithms.

5.2 Experiment Factors

In order to evaluate the performance of the compared algorithms, the parameters that the algorithms must be tested for must be determined.

Since the security features of each algorithm as their strength against cryptographic attacks is already known and discussed. The chosen factor here to determine the performance is the algorithm's speed to encrypt/decrypt data blocks of various sizes.

5.3 Simulation Procedure

By considering different sizes of data blocks (0.5MB to 20MB) the algorithms were evaluated in terms of the time required to encrypt and decrypt the data block. All the implementations were exact to make sure that the results will be relatively fair and accurate.

The Simulation program (shown below in Fig. 7) accepts three inputs: Algorithm, Cipher Mode and data block size. After a successful execution, the data generated, encrypted, and decrypted are shown. Notice that most of the characters can not appear since they do not have character representation. Another comparison is made after the successful encryption/decryption process to make sure that all the data are processed in the right way by comparing the generated data (the original data blocks) and the decrypted data block generated from the process.

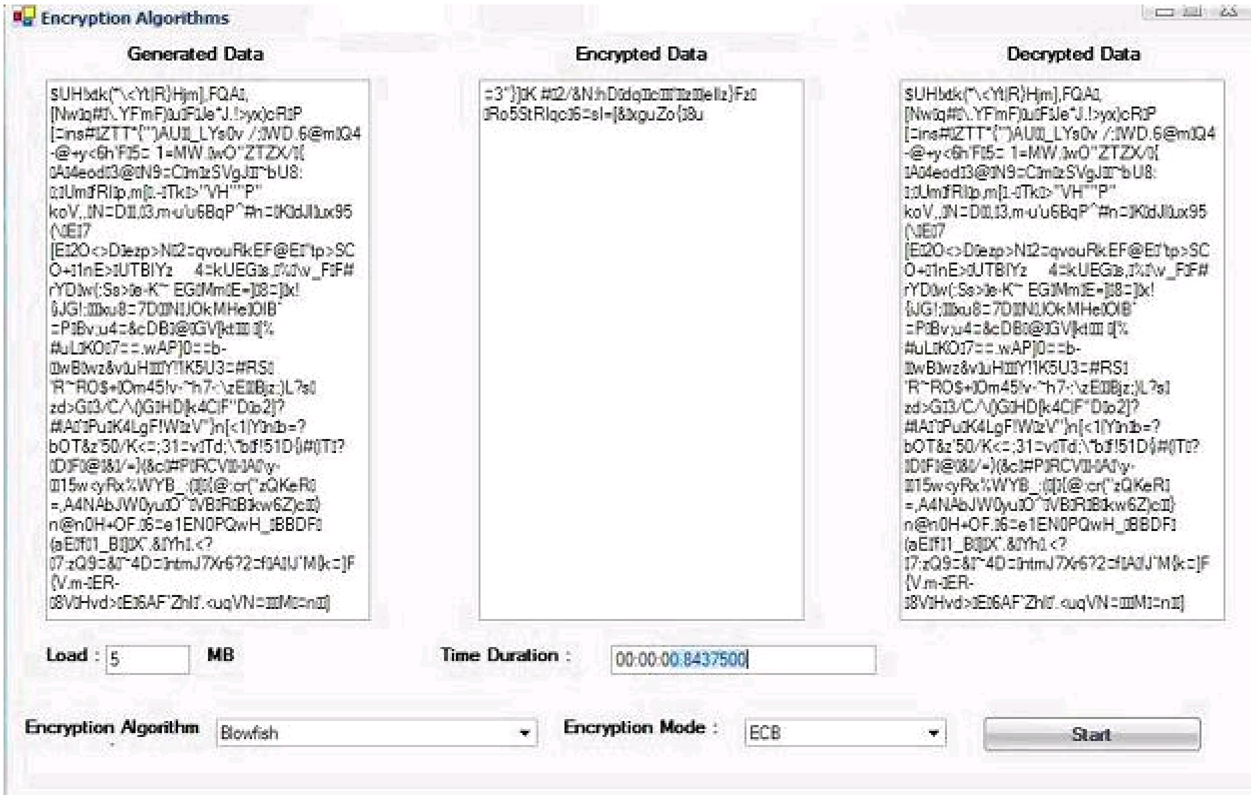


Fig.7 GUI of the simulation program

6. Simulation Results

This section will show the results obtained from running the simulation program using different data loads. The results show the impact of changing data load on each algorithm and the impact of Cipher Mode (Encryption Mode) used.

6.1 Performance Results with ECB

The first set of experiments were conducted using ECB mode, the results are shown in figure 8 below. The results show the superiority of Blowfish algorithm over other algorithms in terms of the processing time. It shows also that AES consumes more resources when the data block size is relatively big. The results shown here are different from the results obtained by [Dhawan2002] since the data block sizes used here are much larger than the ones used in their experiment.

Another point can be noticed here that 3DES requires always more time than DES because of its triple phase encryption characteristic. Blowfish ,although it has a long key (448 bit) , outperformed other encryption algorithms. DES and 3DES are known to have worm holes in their security mechanism, Blowfish and AES, on the other hand, do not have any so far.

These results have nothing to do with the other loads on the computer since each single experiment was conducted multiple times resulting in almost the same expected result. DES, 3DES and AES implementation in .NET is considered to be the best in the market.

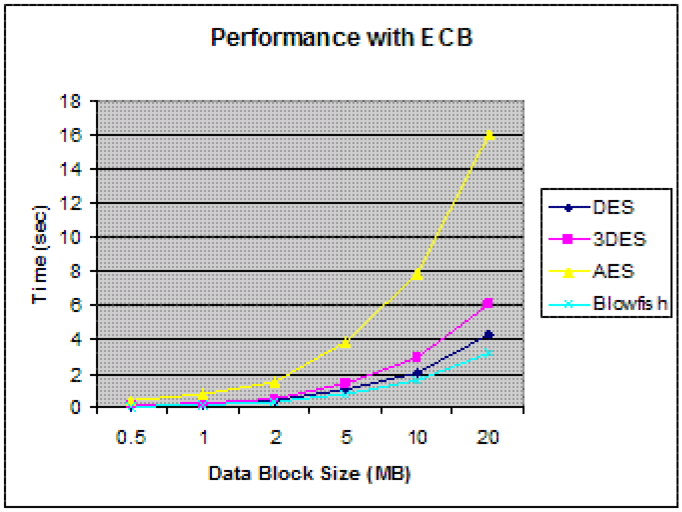


Fig.8 Performance Results with ECB Mode

6.2 Performance Results with CBC

As expected CBC requires more processing time than ECB because of its key-chaining nature. The results show in Fig. 9 indicates also that the extra time added is not significant for many applications, knowing that CBC is much better than ECB in terms of protection. The difference between the two modes is hard to see by the naked eye, the results showed that the average difference between ECB and CBC is 0.059896 second, which is relatively small.

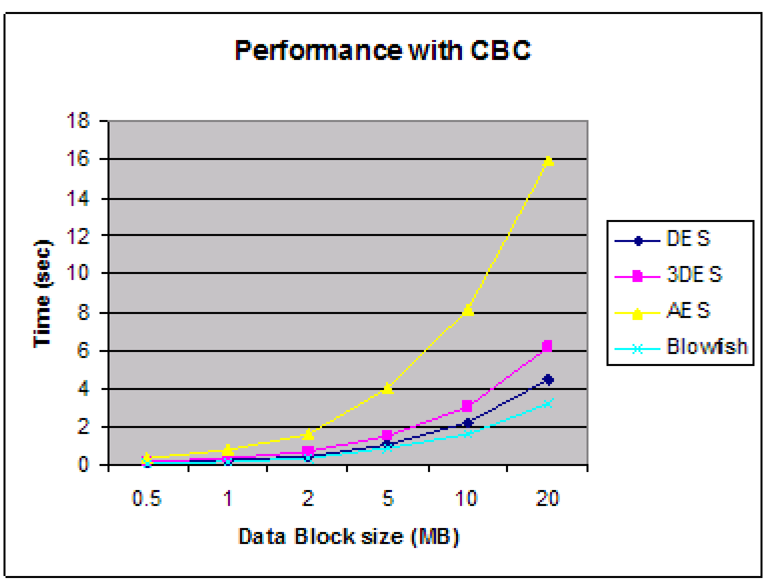


Fig. 9 Performance Results with CBC Mode

This section showed the simulation results obtained by running the four compared encryption algorithms using different Cipher Modes. Different load have been used to determine the processing power and performance of the compared algorithms.

7. Conclusion

The presented simulation results showed that Blowfish has a better performance than other common encryption algorithms used. Since Blowfish has not any known security weak points so far, which makes it an excellent candidate to be considered as a standard encryption algorithm. AES showed poor performance results compared to other algorithms since it requires more processing power. Using CBC mode has added extra processing time, but overall it was relatively negligible especially for certain application that requires more secure encryption to a relatively large data blocks.

References

1. [RFC2828],"Internet Security Glossary", http://www.faqs.org/rfcs/rfc2828.html
2. [Nadeem2005]Aamer Nadeem et al, "A Performance Comparison of Data Encryption Algorithms", IEEE 2005
3. [Earle2005] "Wireless Security Handbook,". Auerbach Publications 2005
4. [Dhawan2002] Priya Dhawan., "Performance Comparison: Security Design Choices," Microsoft Developer Network October 2002. http://msdn2.microsoft.com/en-us/library/ms978415.aspx
5. [Edney2003]," Real 802.11 Security: Wi-Fi Protected Access and 802.11i ,". Addison Wesley 2003
6. [Wikipedia-BC] "Block Cipher", http://en.wikipedia.org/wiki/Block_cipher
7. [Hardjono2005]," Security In Wireless LANS And MANS ,". Artech House Publishers 2005
8. [TropSoft] "DES Overview", http://www.tropsoft.com/strongenc/des.htm [Explains how DES works in details, features and weaknesses]
9. [Bruce1996] BRUCE SCHNEIER, "Applied Cryptography" , John Wiley & Sons, Inc 1996
10. [Crypto++]"Crypto++ benchmark", http://www.eskimo.com/~weidai/benchmarks.html [Results of comparing tens of encryption algorithms using different settings].
11. [Blowfish.NET] "Coder's Lagoon",http://www.hotpixel.net/software.html [List of resources to be used under GNU]

Acronyms

3DES	Triple Data Encryption Standard
AES	Advanced encryption Standard
CBC	Chain Block Chaining Mode
CTR	Counter Mode
CFB	Cipher Feedback Mode
ECB	Electronic Codebook Mode
NIST	National Institute of Standards and Technology
OFB	Output Feedback Mode
PKC	Public Key Cryptography

This report is available on-line at http://www.cse.wustl.edu/~jain/cse567-06/encryption_perf.htm
List of other reports in this series
Back to Raj Jain's home page