Tradeoffs between Energy Consumption and Security of Symmetric Encryption Algorithms

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***Abstract*—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. Encryption algorithms play a main role in information security systems. On the other side, those algorithms consume a significant amount of computing resources such as CPU time, memory, and battery power. But Resources in the wireless environment are limited. There is limited battery power available. Technologies such as CPU and memory are increasing and so is their need for power, but battery technology is increasing at a much slower rate, forming a "battery gap". Because of this, battery capacity plays a major role in the usability of the devices. The increasing demand for services on wireless devices has pushed technical research into finding ways to overcome these limitations. This paper provides evaluation of six of the most common encryption algorithms namely: AES (Rijndael), DES, 3DES, RC2, Blowfish, and RC6. We examine a method for analyzing trade-offs between energy and security. We suggest approach to reduce the energy consumption of security protocols. A comparison has been conducted for those encryption algorithms at different settings for each algorithm such as different sizes of data blocks, different data types, battery power consumption, different key size and finally encryption/decryption speed.**

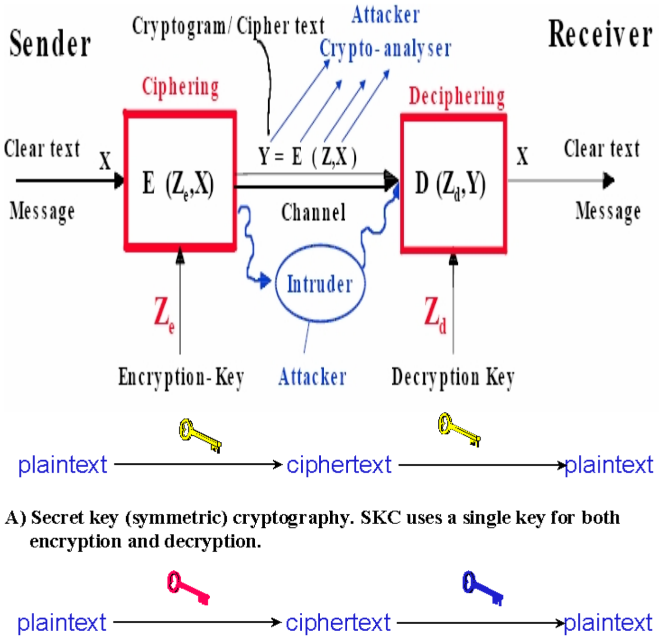
***Keywords*—Encryption techniques, Computer security, AES, DES, RC2, 3DES, Blowfish, and RC6**

I. INTRODUCTION

Cryptographic algorithms are categorized into Symmetric (private) and Asymmetric (public) keys encryption. In Asymmetric keys, two keys are used: private and public keys. Public key is used for encryption and private key is used for decryption (E.g. RSA and Digital Signatures). However, public key encryption is based on mathematical functions, computationally intensive and is not very efficient for small mobile devices [1]. Asymmetric encryption techniques are almost 1000 times slower than Symmetric techniques, because they require more computational processing power [2].

In Symmetric keys encryption or secret key encryption, only one key is used to encrypt and decrypt data. The key should be distributed before transmission between entities.

Strength of Symmetric key encryption depends on the size of the key used. For the same algorithm, encryption using longer key is harder to break than the one done using smaller key. There are many examples of strong and weak keys of cryptography algorithms Like RC2, DES, 3DES, RC6, Blowfish, and AES. RC2 uses one 64-bit key.DES uses one 64-bits key. Triple DES (3DES) uses three 64-bits keys while AES uses various (128, 192, 256) bits keys. Blowfish uses various (32-448); default 128bits while RC6 uses various (128, 192, 256) bits keys [1-5]. The most common classification of encryption techniques can be shown in Fig. 1.



A) Secret key (symmetric) cryptography. SKC uses a single key for both encryption and decryption.

B) Public key (asymmetric) cryptography. PKC uses two keys, one for encryption and the other for decryption.

Fig.1 Symmetric (private) Key Encryption VS Public Key Encryption

Brief definitions of the most common encryption techniques are given as follows:

DES: (Data Encryption Standard) was the first encryption standard to be recommended by NIST (National Institute of Standards and Technology).DES is (64 bits key size with 64 bits block size). Since that time, many attacks and methods recorded the weaknesses of DES, which made it an insecure block cipher [3], [4].

3DES is an enhancement of DES; it is 64 bit block size with 192 bits key size. In this standard the encryption method is similar to the one in the original DES but applied 3 times to increase the encryption level and the average safe time. It is a known fact that 3DES is slower than other block cipher methods [3].

RC2 is a block cipher with 64-bits block cipher with a variable key size that -bit block - can be used as a replacement for the DES algorithm ranges from 8 to128 bits.

RC2 is vulnerable to a related-key attack using 234 chosen plaintexts [3].

Blowfish is block cipher 64. It takes a variable-length key, ranging from 32 bits to 448 bits; default 128 bits. Blowfish is unpatented, license-free, and is available free for all uses. Blowfish has variants of 14 rounds or less. Blowfish is successor to Twofish [5].

AES (previously called Rijndael) [20], [21], [22] is a block cipher.It has variable key length of 128, 192, or 256 bits; default 256. It encrypts data blocks of 128 bits in 10, 12 and 14 round depending on the key size. AES encryption is fast and flexible; it can be implemented on various platforms especially in small devices [6]. Also, AES has been carefully tested for many security applications [3], [7].

RC6 is block cipher [23], [24], [25] derived from RC5. It was designed to meet the requirements of the Advanced Encryption Standard competition. RC6 proper has a block size of 128 bits and supports key sizes of 128, 192 and 256 bits. Some references consider RC6 as Advanced Encryption Standard [8].

This paper examines a method for evaluating performance of selected symmetric encryption of various algorithms on power consumption, encryption time and throughput. Encryption algorithms consume a significant amount of computing resources such as CPU time, memory, and battery power. Battery technology is increasing at a slower rate than other technologies. This causes a “battery gap” [9], [10].We need a way to make decisions about energy consumption and security to reduce the consumption of battery powered devices. This study evaluates six different encryption algorithms namely; AES, DES, 3DES, RC6, Blowfish, and RC2. The performance measure of encryption schemes will be conducted in terms of energy, changing data types -such as text or document, Audio data, video data, and Pictures data- power consumption, changing packet size and changing key size for the selected cryptographic algorithms.

This paper is organized as follows. Related work is described in Section 2. A view of simulation and experimental design is given in section 3. Simulation results are shown in section 4. Finally the conclusions are drawn in section 5.

II. RELATED WORK

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

It was concluded in [11] that AES is faster and more efficient than other encryption algorithms. When the transmission of data is considered there is insignificant difference in performance of different symmetric key schemes (most of the resources are consumed for data transmission rather than computation).

A study in [12] is conducted for different popular secret key algorithms such as DES, 3DES, AES, and Blowfish. They were implemented, and their performance was compared by encrypting input files of varying contents and sizes. The results showed that Blowfish had a very good performance compared to other algorithms. Also it showed that AES had a better performance than 3DES and DES. It also shows 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.

A study in [13] is conducted for different popular secret key algorithms such as RC4, AES, and XOR. They were implemented, and their performance was compared by encrypting for real time video streaming of varying contents. The results showed; encryption delay overhead using AES is less than the overhead using RC4 and XOR algorithm. Therefore, AES is a feasible solution to secure real time video transmissions.

In [14] a study of security measure level has been proposed for a web programming language to analyze four Web browsers. This study considers measuring the performances of encryption process at the programming language’s script with the Web browsers. This is followed by conducting tests simulation in order to obtain the best encryption algorithm versus Web browser.

It was shown in [1] that energy consumption of different common symmetric key encryptions on handheld devices. It is found that after only 600 encryptions of a 5 MB file using Triple-DES the remaining battery power is 45% and subsequent encryptions are not possible as the battery dies rapidly.

In [17] Crypto++ Library is a free C++ class library of cryptographic schemes. It evaluates the most commonly used cryptographic algorithms. 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.

III. EXPERIMENTAL DESIGN

For our experiment, we use a laptop IV 2.4 GHz CPU, in which performance data is collected. In the experiments, the laptop encrypts a different file size ranges from 321 K byte to 7.139Mega Byte139MegaBytes for text data, from 33 Kbytes to 8, 262 Kbytes for audio data, from 28 Kbytes to 131 Kbytes for pictures(Images) and from 4, 006 Kbytes to 5, 073 Kbytes for video files.

Several performance metrics are collected:

12- Power consumption.
13- Encryption time.
14- CPU process time.
15- CPU clock cycles

For computation of the energy cost of encryption, we use the same techniques as described in [18]. We present a basic cost of encryption represented by the product of the total number of clock cycles taken by the encryption and the average current drawn by each CPU clock cycle. The basic encryption cost is in unit of ampere-cycle. To calculate the total energy cost, we divide the ampere-cycles by the clock frequency in cycles/second of a processor; we obtain the energy cost of encryption in ampere-seconds. Then, we multiply the ampere-seconds with the processor’s operating voltage, and we obtain the energy cost in Joule.

By using the cycles, the operating voltage of the CPU, and the average current drawn for each cycle, we can calculate the energy consumption of cryptographic functions. For example, in average, each cycle consumes approximately 270 mA on an Intel 486DX2 processor [18] or 180 mA on Intel Strong ARM [19]. However, currently we could not find any energy consumption benchmark for an Intel Pentium VI 2.4

GHz which is used in our measurements; we assume it is close to100 mA. For a sample calculation, with a 700 MHz CPU operating at 1.35 Volt, an encryption with 20, 000 cycles would consume about 5.71 x 10-3 mA-second or 7.7 µ Joule. Since for a given hardware Vcc are fixed.

The encryption time is considered the time that an encryption algorithm takes to produce a cipher text from a plaintext. Encryption time is used to calculate the throughput of an encryption scheme. It indicates the speed of encryption. The throughput of the encryption scheme is calculated as the total plaintext in bytes encrypted divided by the encryption time [15].

The CPU process time is the time that a CPU is committed only to the particular process of calculations. It reflects the load of the CPU. The more CPU time is used in the encryption process, the higher is the load of the CPU.

The CPU clock cycles are metric, reflecting the energy consumption of the CPU while operating on encryption operations. Each cycle of CPU will consume a small amount of energy.

The following tasks that will be performed are shown as follows:

5. A comparison is conducted between the results of the selected different encryption and decryption schemes in terms of the encryption time, battery power and throughputs.
6. A study is performed on the effect of changing packet size on power consumption, throughput, and CPU work load for each selected cryptographic algorithms.
7. A study is performed on the effect of changing data types -such as text or document, Audio file, Video file and images- for each selected cryptographic algorithms on power consumption.
8. A study is performed on the effect of changing key size for selected cryptographic algorithms on power consumption.

IV. EXPERIMENTAL RESULTS

A. The effect of changing packet size for cryptography algorithm on power consumption (text files)

a Encryption of different packet size

1 CPU work load

In Fig. 2, we show the performance of cryptographic algorithms in terms of sharing the CPU load for encryption process. With a different data block size

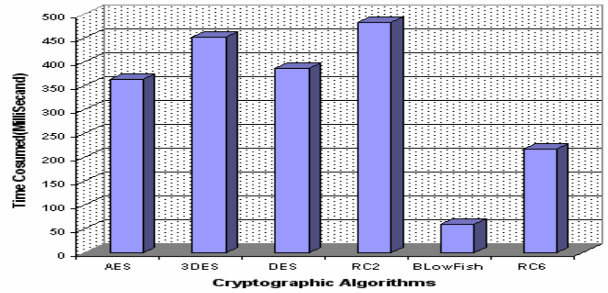


Fig. 2 Time consumption for encrypt different Text Data (Millisecond)

2 Encryption throughput

The throughput of the encryption scheme is calculated by dividing the total plaintext in Megabytes encrypted on the total encryption time for each algorithm in. As the throughput value is increased, the power consumption of this encryption technique is decreased.

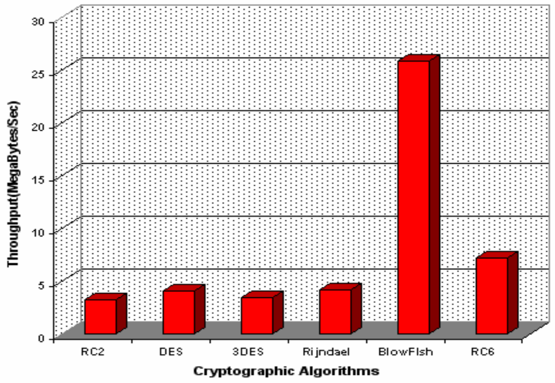


Fig. 3 Throughput of each encryption algorithm (Megabyte/Sec)

3 Power consumption

In Fig.4, we show the performance of cryptography algorithms in terms of Power consumption for encryption process. With a different data block size

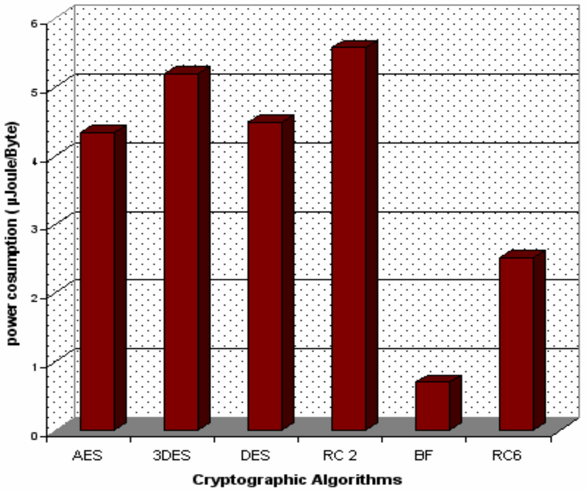


Fig. 4 Power consumption for encrypt different Text document Files (microJoule/Byte)

The results show the superiority of Blowfish algorithm over other algorithms in terms of the power consumption, processing time, and throughput (when we encrypt the same data by using Blowfish and AES, we found that Blowfish requires approximately 16% of the power which is consumed for AES). Another point can be noticed here that RC6 requires less power, and less time than all algorithms except Blowfish (when we encrypt the same data by using RC6 and AES, we found that RC6 requires approximately 58% of the power which is consumed for AES). A third point can be noticed here that AES has an advantage over other 3DES, DES and RC2 in terms of power consumption, time consumption, and throughput. A fourth point can be noticed here that 3DES has low performance in terms of power consumption and throughput when compared with DES. It requires always more time than DES because of its triple phase encryption characteristics. Finally, it is found that RC2 has low performance and low throughput when compared with other five algorithms in spite of the small key size used.

b Decryption of different packet size

1 CPU work load

Experimental results for this compassion point are shown Fig.5

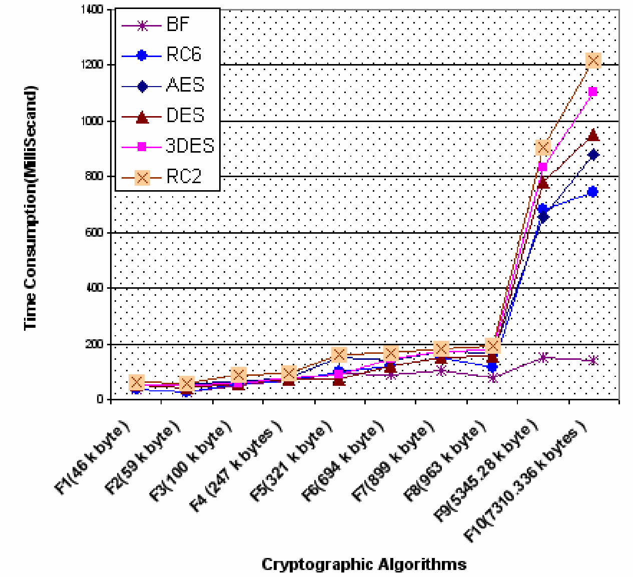


Fig. 5 Time consumption for decrypting different Text Data (Millisecond)

2 Decryption throughput

Experimental results for this compassion point are shown Fig.6

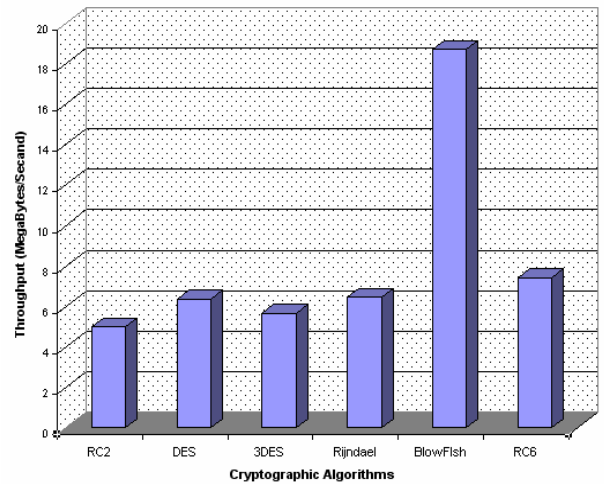


Fig. 6 Throughput of each decryption algorithm (Megabyte/Sec)

3 Power consumption

Experimental results for this compassion point are shown Fig.7

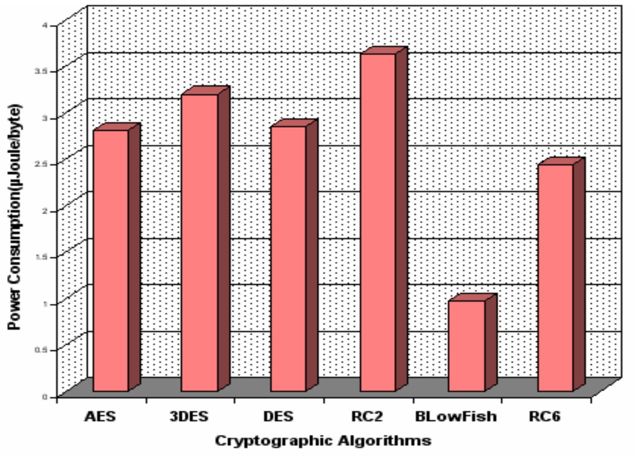


Fig. 7 Power consumption for Decrypt different Text document Files (Micro Joule/Byte)

Experimental results for this compassion point are shown Fig. 5, Fig. 6, and Fig. 7 at decryption stage. We can find that in decryption Blowfish is better than the other algorithms in throughput and power consumption (when we decrypt the same data by using Blowfish and AES, we found that Blowfish requires approximately 34% of the power which is consumed for AES). The second point which should be noticed here is that RC6 requires less time than all algorithms except Blowfish (when we decrypt the same data by using RC6 and AES, we found that RC6 requires approximately 87% of the power which is consumed for AES). A third point that can be noticed is that AES has an advantage over other 3DES, DES RC2.The fourth point that can be considered is that RC2 still has low performance of these algorithm. Finally, Triple DES (3DES) still requires more time than DES.

B. The effect of changing file type (Audio files) for cryptography algorithm on power consumption.

a Encryption of different Audio files (different sizes)

1 Encryption throughput

In the previous section, the comparison between encryption algorithms has been conducted at text and document data files. Now we will make a comparison between other types of data (Audio file) to check which one can perform better in this case. Simulation results for audio data type are shown Fig. 8 at encryption.

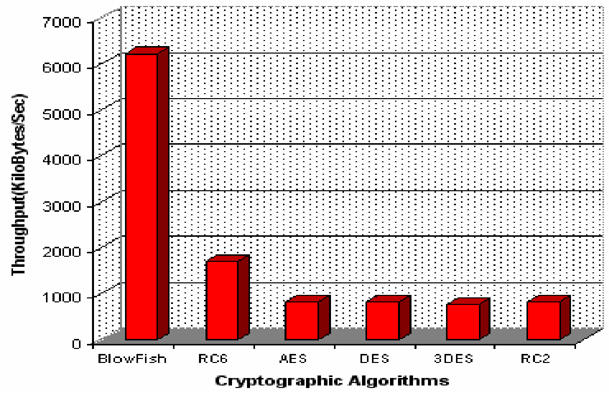


Fig. 8 Throughput of each encryption algorithm (Kilobytes/Second)

2 CPU work load

In Fig. 9, we show the performance of cryptographic algorithms in terms of sharing the CPU load for encryption process. With a different audio block size

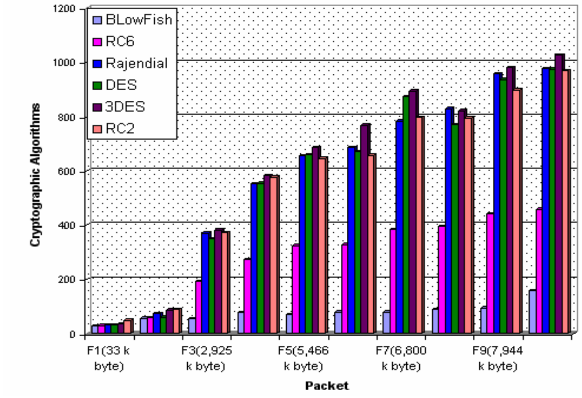


Fig. 9 Time consumption for encrypt different Audio Files (Millisecond)

.3Power consumption

In Fig. 10, we show the performance of cryptographic algorithms in terms of Power consumption for encryption process. With a different audio block size

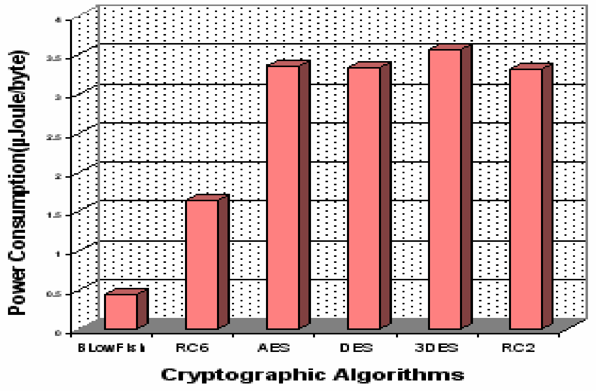


Fig. 10 Power consumption for encrypt different Audio Files

(Micro Joule/Byte)

Results show the superiority of Blowfish algorithm over other algorithms in terms of the power consumption, processing time (CPU work load), and throughput (when we encrypt the same data by using Blowfish and AES, we found that Blowfish requires approximately 13% of the power which is consumed for AES). Another point that can be noticed here is that RC6 requires less power consumption and less time than all algorithms except Blowfish (when we encrypt the same data by using RC6 and AES, we found that RC6 requires approximately 48% of the power which is consumed for AES). A third point can be noticed here is that AES has an advantage over other 3DES, DES and RC2 in terms of time consumption and throughput especially in small size file. A fourth point can be noticed here is that 3DES has low performance in terms of power consumption and throughput when compared with DES. It requires always more time than DES. Finally, it is found that RC2 has low performance and low throughput when compared to the other five algorithms in spite of the small key size used.

b Decryption of different Audio files (different sizes)

1 Decryption throughput

Experimental results for this compassion point are shown Fig.11

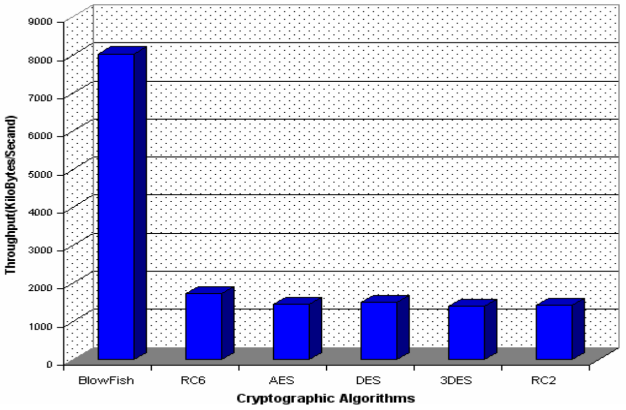


Fig. 11 Throughput of each Decryption algorithm (Kilobytes/Second)

2 CPU work load

Experimental results for this compassion point are shown Fig. 12.

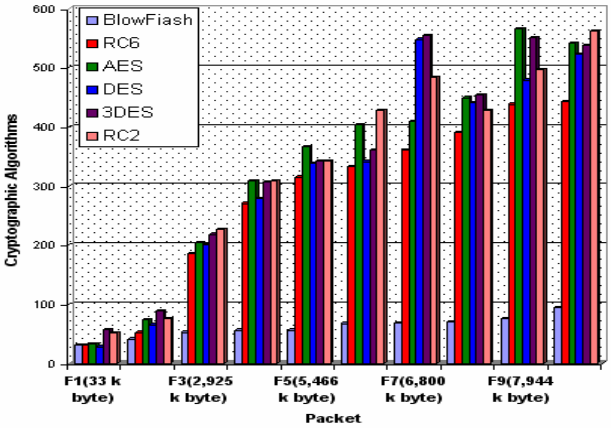


Fig. 12 Time consumption for Decrypt different Audio Files (Millisecond)

.3 Power consumption

Experimental results for this compassion point are shown Fig. 13

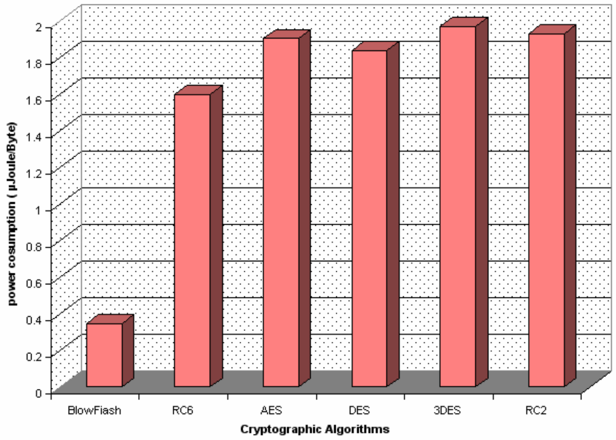


Fig. 13 Power consumption for decrypt different Audio Files

(Micro Joule/Byte)

From the results we found that the result is the same as in encryption process for audio files. When we decrypt the same data by using Blowfish and AES, we found that

Blowfish requires approximately 18% of the power which is consumed for AES. When we decrypt the same data by using RC6 and AES, we found that RC6 requires approximately 84% of the power which is consumed for AES

C. The effect of changing file type (Video files) for cryptographic algorithms on power consumption.

a Encryption of different Video files (different sizes)

1 Encryption throughput

Now we will make a comparison between other types of data (Video files) to check which one can perform better in this case. Experimental results for video data type are shown Fig. 14 at encryption.

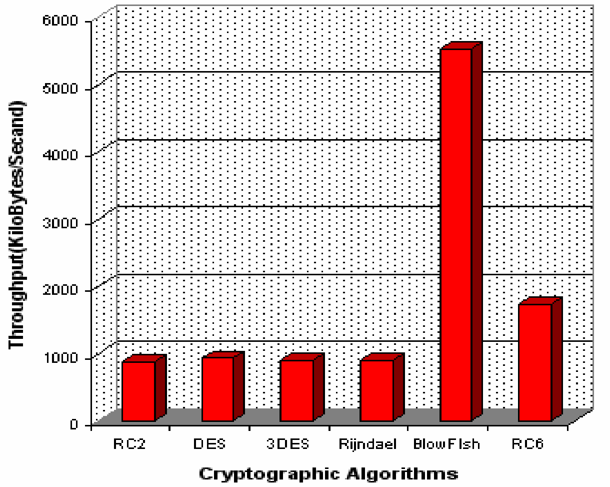


Fig. 14 Throughput of each encryption algorithm (Kilobytes/Second)

2 CPU work load

In Fig. 15, we show the performance of cryptographic algorithms in terms of sharing the CPU load. With a different video block size

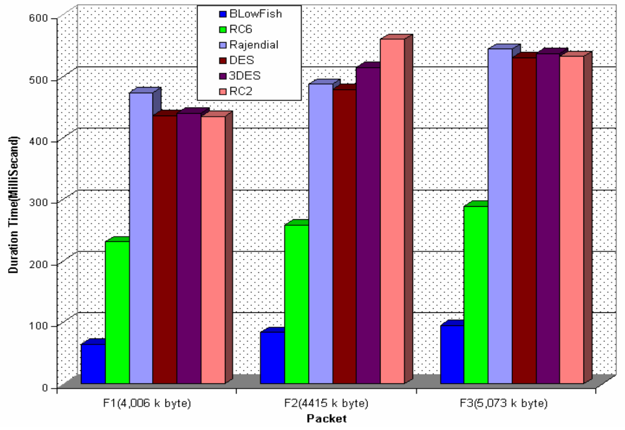


Fig. 15 Time consumption for encrypt different video Files (Millisecond)

.3Power consumption

In Fig.16, we show the performance of cryptographic algorithms in terms of Power consumption for encryption process. With a different video block size

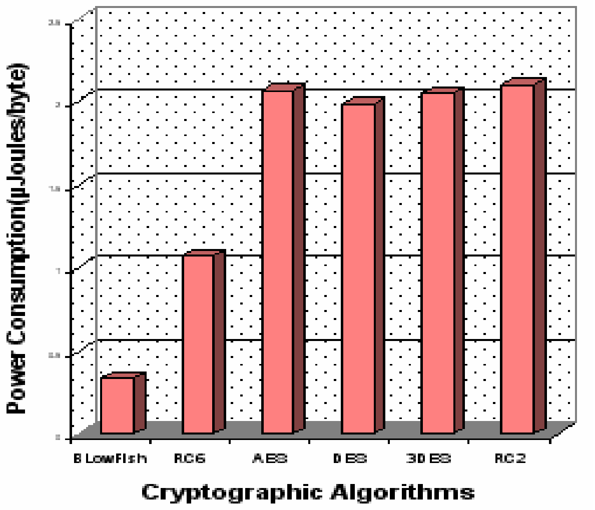


Fig. 16 Power consumption for encrypt different Video Files (micro Joule/Byte)

The result is the same as in text and audio data.The results show the superiority of Blowfish algorithm over other algorithms in terms of the processing time, power consumption, and throughput (when we encrypt the same data by using Blowfish and AES, we found that Blowfish requires approximately 16% of the power which is consumed for AES). Another point that can be noticed here is that RC6 requires less power consumption and less time than all algorithms except Blowfish (when we encrypt the same data by using RC6 and AES, we found that RC6 requires approximately 51% of the power which is consumed for AES). A third point can be noticed here; that 3DES has low performance in terms of power consumption and throughput when compared with DES. It requires always more time than DES. Finally, it is found that RC2 has low performance and low throughput when compared to the other five algorithms

a Decryption of different Video files (different sizes)

1 Decryption throughput

Experimental results for this compassion point are shown Fig. 17

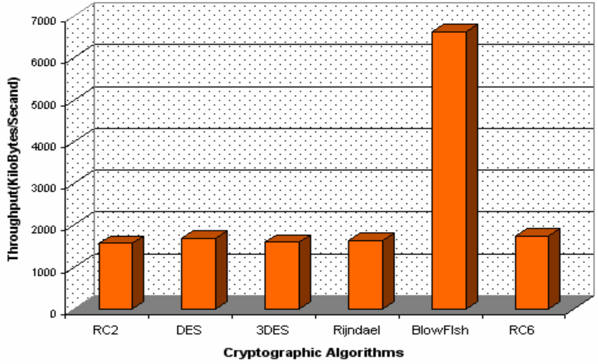


Fig. 17 Throughput of each Decryption algorithm (Kilobytes/Second)

2 CPU work load

Experimental results for this compassion point are shown Fig. 18

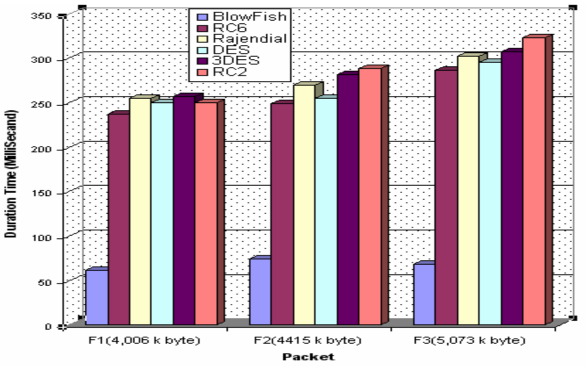


Fig. 18 Time consumption for Decrypt different video Files (millisecond)

3 Power consumption

Experimental results for this compassion point are shown Fig. 19

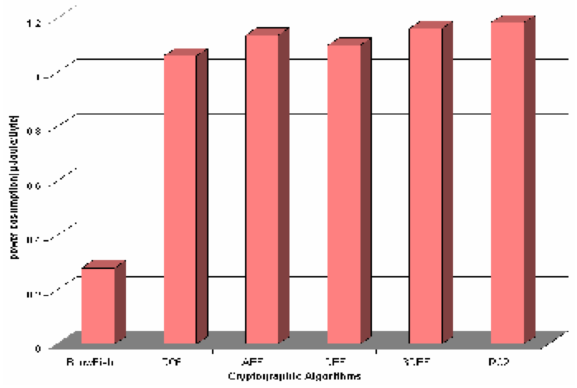


Fig. 19 Power consumption for Decrypt different Video Files (micro Joule/Byte)

From the results we found that the result is the same as in the encryption process for Video, audio files, and text data. When we decrypt the same data by using Blowfish and AES, we found that Blowfish requires approximately 24% of the power which is consumed for AES. When we decrypt the same data by using RC6 and AES, we found that RC6 requires approximately 93% of the power which is consumed for AES.

D. The effect of changing file type (Images) for cryptography algorithm on power consumption.

Experimental results for image data type (JPEG images) are shown Fig. 20 and Fig 21 at encryption and decryption respectively.

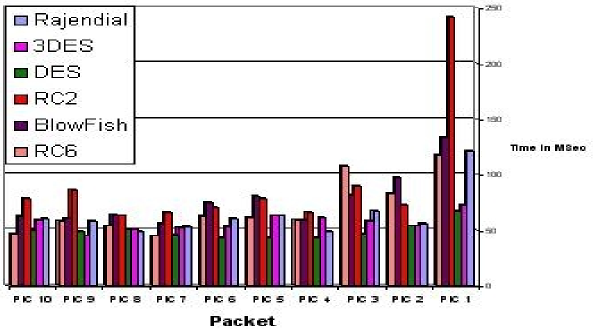


Fig. 20 Time consumption for encrypt different images (Millisecond)

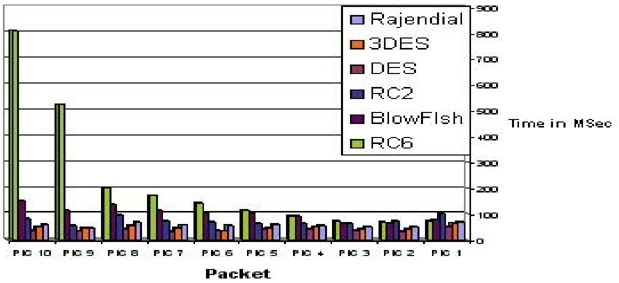


Fig. 21 Time consumption for decrypt different images (Millisecond)

From those results, it is easy to observe that RC2 still has disadvantage in encryption process over other algorithms in terms of time consumption and serially in throughput. On the other hand, it is easy to observe that RC6 and Blowfish have disadvantage in the decryption process over other algorithms in terms of time consumption and serially in throughput. It is found that 3DES still has low performance when compared to DES.

E. The effect of changing key size of AES, and RC6 on power consumption.

The last performance comparison point is changing different key sizes for AES and RC6 algorithm. In case of AES, We consider the three different key sizes possible i.e., 128 bit, 192 bits and 256 bit keys. The simulation results are shown in Fig. 22 and Fig.23.

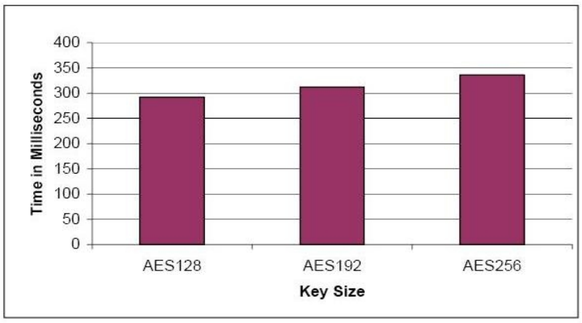


Fig. 22 Time consumption for different key size for AES

In case of AES it can be seen that higher key size leads to clear change in the battery and time consumption. It can be seen that going from 128 bits key to 192 bits causes increase in power and time consumption about 8% and to 256 bit key causes an increase of 16% [9].

Also in case of RC6, We consider the three different key sizes possible i.e., 128 bit, 192 bits and 256 bit keys. The result is close to the one shown in the following Fig.

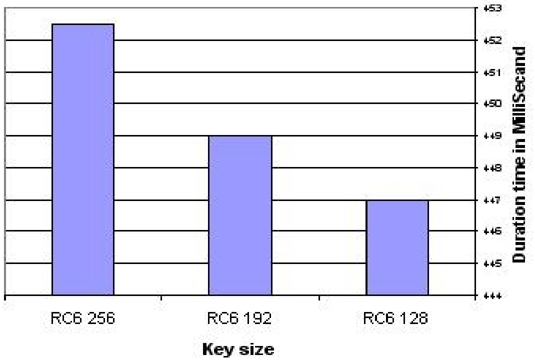


Fig. 23 Time consumption for different key size for RC6

In case of RC6 it can be seen that higher key size leads to clear change in the battery and time consumption.

V. CONCLUSION AND FUTURE WORK

This paper presents a performance evaluation of selected symmetric encryption algorithms. The selected algorithms are AES, DES, and 3DES, RC6, Blowfish and RC2. Several points can be concluded from the simulation results. First, in the case of changing packet size, it was concluded that Blowfish has better performance than other common encryption algorithms used, followed by RC6. Secondly, it is found that 3DES still has low performance compared to algorithm DES. Thirdly, it is found RC2 has disadvantage over all other algorithms in terms of time consumption. Fourthly, it is found AES has better performance than RC2, DES, and 3DES. In the case of audio and video files, it is found that the result is the same as in text and document.Finally -in the case of changing key size – it can be seen that higher key size leads to clear change in the battery and time consumption.

For our future work, we will study the distribution of different packets sizes typically transmitted and received by wireless devices over wireless network. In our future research, we will suggest three approaches to reduce the energy consumption of security protocols and apply them to wireless local area networks (WLANs) to provide an energy efficient security schema for 802.11 WLANs by replacement of standard security protocol primitives that consume high energy while maintaining the same security level. Secondly, modification of standard security protocols appropriately. Finally, a totally new design of security protocol where energy efficiency is the main focus.

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