

**MULTI-OPERATION DATA ENCRYPTION MECHANISM  
USING DYNAMIC DATA BLOCKING AND RANDOMIZED  
SUBSTITUTION**

**IJAZ ALI SHOUKAT**

**UNIVERSITI TEKNOLOGI MALASIA**

MULTI-OPERATION DATA ENCRYPTION MECHANISM USING DYNAMIC  
DATA BLOCKING AND RANDOMIZED SUBSTITUTION

IJAZ ALI SHOUKAT

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*Specially dedicated to Holy Prophet Hazrat Muhammad (P.B.U.H)*

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## ABSTRACT

Existing cryptosystems deal with static design features such as fixed sized data blocks, static substitution and apply identical set of known encryption operations in each encryption round. Fixed sized blocks associate several issues such as ineffective permutations, padding issues, deterministic brute force strength and known-length of bits which support the cracker in formulating of modern cryptanalysis. Existing static substitution policies are either not optimally fit for dynamic sized data blocks or contain known S-box transformation and fixed lookup tables. Moreover, static substitution does not directly correlate with secret key due to which it has not been shown safer especially for Advanced Encryption Standard (AES) and Data Encryption Standard (DES). Presently, entire cryptosystems encrypt each data block with identical set of known operations in each iteration, thereby lacked to offer dynamic selection of encryption operation. These discussed, static design features are fully known to the cracker, therefore caused the practical cracking of DES and undesirable security pitfalls against AES as witnessed in earlier studies. Various studies have reported the mathematical cryptanalysis of AES up to full of its 14 rounds. Thus, this situation completely demands the proposal of dynamic design features in symmetric cryptosystems. Firstly, as a substitute to fixed sized data blocks, the Dynamic Data Blocking Mechanism (DDBM) has been proposed to provide the facility of dynamic sized data blocks. Secondly, as an alternative of static substitution approach, a Randomized Substitution Mechanism (RSM) has been proposed which can randomly modify session-keys and plaintext blocks. Finally, Multi-operation Data Encryption Mechanism (MoDEM) has been proposed to tackle the issue of static and identical set of known encryption operations on each data block in each round. With MoDEM, the encryption operation can dynamically be selected against the desired data block from the list of multiple operations bundled with several sub-operations. The methods or operations such as exclusive-OR, 8-bit permutation, random substitution, cyclic-shift and logical operations are used. Results show that DDBM can provide dynamic sized data blocks comparatively to existing approaches. Both RSM and MoDEM fulfill dynamicity and randomness properties as tested and validated under recommended statistical analysis with standard tool. The proposed method not only contains randomness and avalanche properties but it also has passed recommended statistical tests within five encryption rounds (significant than existing). Moreover, mathematical testing shows that common security attacks are not applicable on MoDEM and brute force attack is significantly resistive.

## ABSTRAK

Sistem kriptografi yang sedia ada berhubung kait dengan ciri-ciri reka bentuk statik seperti sekatan data bersaiz tetap, statik penggantian dan penggunaan set yang sama dalam operasi enkripsi bagi setiap pusingan enkripsi. Sekatan bersaiz tetap dikaitkan dengan beberapa isu seperti permutasi yang tidak berkesan, isu-isu *padding*, ketentuan kekuatan kuasa kasar dan panjang yang dikenali bagi bit yang dapat menyokong penceroboh di dalam menggubal analisis kriptografi moden. Dasar-dasar penggantian statik sedia ada adalah sama ada tidak bersesuaian secara optima untuk blok-blok data bersaiz dinamik atau kandungan yang dikenali sebagai transformasi kotak-S dan jadual carian tetap tanpa berhubung langsung dengan korelasi bersama kunci rahsia. Disebabkan oleh hal yang demikian, dasar-dasar ini menunjukkan tidak selamat terutamanya untuk Piawaian Penyulitan Lanjutan (AES) dan Piawaian Penyulitan Data (DES). Sehingga kini, keseluruhan sistem kriptografi menyulit setiap blok data dengan set yang serupa dalam operasi yang diketahui bagi setiap lelaran, sekali gus kurangnya penawaran pilihan operasi penyulitan yang dinamik. Melalui perbincangan ini, ciri-ciri reka bentuk statik adalah serba diketahui oleh penceroboh, sehingga menyebabkan pencerobohan praktikal oleh DES dan kesulitan keselamatan yang tidak diinginkan terhadap AES seperti yang dibuktikan dalam kajian sebelum ini. Pelbagai kajian telah melaporkan bahawa analisis kriptografi secara pendekatan matematik pada AES sehingga 14 pusingan keseluruhannya. Oleh itu berdasarkan situasi ini cadangan pendekatan reka bentuk dinamik pada sistem kriptografi simetri diperlukan. Pertamanya, Mekanisme Sekatan Data Secara Dinamik (DDBM) telah dicadangkan untuk menyediakan kemudahan blok bersaiz dinamik sebagai pengganti kepada sekatan data bersaiz tetap. Kedua, Mekanisme Penggantian Rawak (RSM) telah dicadangkan sebagai alternatif kepada pendekatan penggantian tetap untuk mengubah kunci-sesi dan blok teks biasa secara rawak. Akhirnya, Mekanisme Pelbagai Operasi Penyulitan Dinamik (MoDEM) telah dicadangkan untuk mengatasi pelaksanaan tetapan set bagi operasi penyulitan di setiap blok data dalam setiap pusingan. Melalui MoDEM, operasi penyulitan boleh memilih blok secara dinamik daripada senarai pelbagai operasi yang digandingkan dengan beberapa sub operasi. Kaedah atau operasi seperti eksklusif-OR, 8-bit pilih atur, penggantian rawak, syif kitaran dan operasi logik telah digunakan. Penilaian eksperimen menunjukkan bahawa DDBM boleh menyediakan blok data bersaiz dinamik jika dibandingkan dengan pendekatan yang sedia ada. Kedua-dua RSM dan MoDEM telah memenuhi sifat kedinamikan dan kerawakan seperti yang diuji dan disahkan mengikut piawaian analisis statistik yang disarankan. Kaedah yang dicadangkan bukan sahaja mempunyai sifat-sifat rawak dan runtunan malah ia telah melepasi ujian statistik yang disarankan dalam tempoh hanya lima pusingan sahaja (ketara berbanding dengan sedia ada). Tambahan pula, ujian matematik menunjukkan bahawa serangan keselamatan biasa tidak berkaitan dengan MoDEM dan serangan kuasa kasar adalah lebih ketara rintangannya.

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**LIST OF ABBREVIATIONS**

AES	–	Advanced Encryption Standard
AVG	–	Average
BFS	–	Brute Force Strength
DBAV	–	Data Block Average Value
DCA	–	Differential Cryptanalysis
DDBM	–	Dynamic Data Blocking Mechanism
DES	–	Data Encryption Standard
DMA	–	Data Modification Algorithm
FDBM	–	Fixed Data Blocking Mechanism
IETF	–	Internet Engineering Task Force
ISO	–	International Standard Organization
KBDV	–	Key Block Decimal Value
LBMA	–	Last Block Management Algorithm
LFSR	–	Linear Feedback Shift Register
MoDEM	–	Multi-operation Data Encryption Mechanism
NIST	–	National Institution of Standard and Technology
OP CODE	–	Operation Code
RSM	–	Randomized Substitution Mechanism
RXOR	–	Reverse Exclusive OR
SKGMA	–	Session Key Generation and Mixing Algorithm
SPN	–	Substitution-Permutation Network
STS	–	Statistical Testing Suite
TDES	–	Triple Data Encryption Standard
XOR	–	Exclusive OR



## LIST OF SYMBOLS

$DB$	–	Data Blocks
$B$	–	Bits
$\mu$	–	Number of bits of each block
$\beta$	–	Number of data blocks
$\mathcal{B}_x$	–	block length
$K$	–	Initial Master Secret Key
$\Delta K$	–	Session Key
$D$	–	Plaintext
$\acute{C}$	–	Cipher Text
$\mu$	–	Number of block bits
$\mathbb{P}$	–	Probabilistic Randomness
$\exists DB$	–	Encrypted Data Block
$D\mathcal{B}^{av}$	–	Data block Average Value
$K_\beta^{DV}$	–	Key Block Decimal Value
$\in$	–	Belongs to
$\neq$	–	Not equal to
$\Rightarrow$	–	Implies that
$\Delta D$	–	Chosen Plain Text
$\Delta \acute{C}$	–	Chosen Cipher Text
$\beta D$	–	Known Plain Text
$\oplus$	–	Exclusive XOR
$\ominus$	–	Reverse (RXOR)

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Overview

Security is the major driving force for remote communication. Security against confidential transactions cannot be compromised over insecure communication channels. Variety of cryptosystems persist to offer encryption heuristics for such kind of transactions but the question of security strength of underlying algorithm matters against cryptanalysis attacks. Cryptanalysis is a way of breaking cryptographic algorithms using analytical reasoning, pattern locating, guessing and statistical analysis approaches as discussed in (Ayushi, 2010). Exhaustive key searching is commonly used, efficient and successful attack to defeat the security strength of any cryptographic algorithm discussed by Jarvinen (2008). Therefore, differential cryptanalysis, exhaustive key searching, shortcut attacks and side channel attacks are creating anxious and perilous scenario for remote communication. It is too critical to remain competitive in forgoing market with data privacy and security without the science of cryptography. Currently, symmetric cryptosystems are prime heuristics in designing of secure cryptosystems (Yadav, 2010) with several benefits such as short key length, computational efficiency and less memory consumption as compare to asymmetric cryptosystems (Rejani and Krishnan, 2015). Symmetric cryptosystems associate several noteworthy parameters such as fixed data blocking (FIPS Pub 46; Jain *et al.*, 2015), static substitution and fixed set of identical enciphering operations on each data block (Saini, 2014; Abdulgader *et al.*, 2015), which trigger actual security vulnerabilities (Biryukov *et al.*, 2014) for cryptosystems and play the vital role in the successfulness of modern

attacks as reflected through many studies against advanced encryption standard (Alex and Johann, 2012; Derbez *et al.*, 2013; Bogdanov *et al.*, 2014; Chang *et al.*, 2015; Gangadari *et al.*, 2015).

Existing well-known encryption algorithms such as Advanced Encryption Standard (AES) and Data Encryption Standard (DES) are reliant on a reality of fixed data blocking (FIPS Pub 46; Chavan and Annadate, 2015) which means the block size (bit length) is not dynamic, fully known and total number of blocks against a plain text are also known before initiating encryption phase. AES deals with 8 bit static substitution and 128 bit fixed data blocking (Senthilkumar and Rajamani, 2014; Abdulgader *et al.*, 2015). Similarly, DES contains 64 bit fixed block size (Jain *et al.*, 2015). In existing algorithms (e.g. AES), each time fixed set of known and identical encryption operation are applied to encrypt data (Srinivas *et al.*, 2014; Kaur and Madaan, 2014; Dara and Manochehri, 2014; Saini, 2014) which means there is no multi-operation based dynamic enciphering. Existing dynamic substitutions approaches have been designed to work with fixed-sized data blocking approaches (See Chapter 2, Section 2.7) due to which it cannot fit with dynamic natured ciphers which contains dynamic features such as dynamic data blocking, randomized substitution, dynamic selection of encryption operations. The knowledge of block sets and fixed sizes are increasingly beneficial for any cryptanalyst to possibly crack any symmetric encryption algorithm (Biryukov *et al.*, 2014; Gangadari *et al.*, 2015). Static substitution causes less random permutation and is the primary weakness of existing block ciphers (Ritter, 1998; Mehla and Kaur, 2014) which means just to increase processing computational ability that can easily be defeated in current era's based high computing processors. In this situation, the practical cracking of DES (Biryukov *et al.*, 2010) and academic (theoretical) cracking of all AES versions are noteworthy (Biryukov *et al.*, 2009; Biryukov and Großschäd, 2012; Chang *et al.*, 2015).

Moreover, the AES security strength is not as stronger as it is believed or conveyed (Biryukov *et al.*, 2010). The 4 rounds of AES-128 requires  $2^{17}$  time with  $2^{16}$  data complexities and 5 rounds takes  $2^{38}$  time and  $2^{40}$  data complexities which become  $2^{90}$  time with  $2^{64}$  data complexities against 6 round of AES-128 (Tiessen *et*

*al.*, 2015). On 8 rounds of AES-192 and AES-256, the key recovery attack takes  $2^{172}$  and  $2^{196}$  time complexities respectively which give overall  $2^{107}$  chosen plaintext complexity with  $2^{96}$  memory lookup trails as well as 9-rounds based key recovery attack requires  $2^{120}$  chosen plaintext complexity with  $2^{203}$  memory lookup trails on AES-256 (Derbez *et al.* 2013). The 10, 11 and full 14 rounds of AES-256 are also vulnerable against modern attacks (Biryukov *et al.*, 2009a; Biryukov *et al.*, 2010; Lu, 2010; Bogdanov *et al.*, 2011; Bogdanov *et al.*, 2014; Chang *et al.*, 2015). Lu (2010) claimed, AES has lowest impossible-boomerang-attack computational complexity ( $2^{56}$ ) and according to Biryukov the quasi-practical attack takes only  $2^{70}$  time traces to recover 11 rounds of AES-256 with  $2^{45}$  time complexity having  $2^{33}$  memory lookups and  $2^{44}$  data complexity trials. This gives almost practical cracking complexity of ( $q \cdot 2^{67}$ ) queries against full rounds of AES-256. Furthermore in year 2014 and 2015 the cryptanalysis of full rounds of AES remained carry on with further improvements. For full rounds of all AES versions (AES-128, AES-192 and AES-256), the latest and outperformed attack complexities ( $2^{125.56}$ ,  $2^{189.51}$  and  $2^{253.87}$ ) have been found respectively (Bogdanov *et al.*, 2014). The large scale machine (hardware) based attacks are also feasible on AES-128 and AES-256 which can be applied with time complexity of  $2^{100}$  search trails (Biryukov and Großschäd, 2012). The hashing based biclique-cryptanalysis of AES-128 was conducted by change *et al.*, (2015) and he observed that attack complexities lie between  $2^{126.3}$  up to  $2^{127.4}$  search trails. Thus, the critical literature findings show that full rounds of all AES versions are vulnerable to modern cryptanalysis attacks and overall discussion made in this section triggers the need of significant design parameters such as dynamic data blocking rather to fixed data blocking, randomized substitution rather to static substitution and dynamic selection of encryption operations as compare to static and identical selection of encryption operations in symmetric cryptosystems to encrypt data.

## 1.2 Problem Background

This section discusses the problem background which has been divided to three sub-sections. Each sub section highlights and discusses the related issues.

### 1.2.1 Fixed Data Blocking

Existing well-known symmetric cryptosystems (AES, DES, TDES) use fixed sized data blocks (FIPS Pub 46; Mehla and Kaur, 2014; Jain *et al.*, 2015) with Substitution-Permutation Network (SPN) or Feistel cipher structure (Tu *et al.*, 2015) which means they did not create dynamic sized blocks. Due to the lack of dynamicity in data blocking, the fixed sized block parameters help the cracker in cryptanalysis inspection as discussed by Biryukov *et al.*, (2014), in case of Feistel based block ciphers (SIMON and SPECK), he considered four differential ( $d_1, d_2, \dots, d_4$ ) to recover key of SIMON32 through constructing of one set of  $2^{23}$  fixed plaintext blocks (each with 9 bits) and he was succeeded to locate several plaintext pairs  $2^{25}$  for each differential ( $d_i$ ). In case of 4 key guess approach upon 2 ciphered rounds, to locate  $2^{30.5}$  plaintext pairs, the achieved complexity was  $\{2^{33.5} * 4 * (2/29)\} \approx 2^{32}$  which gives ultimate  $2^{34}$  computational complexity to apply full key recovery attack. Moreover as compare to the random permutation on fixed or same sized (length) blocks, the differential attacks always provide larger differential probability for cryptanalysis (Lu, 2008; Lu, 2010) which has reflected the full cracking of all AES versions (128, 192, 256) with computational complexities trails  $2^{125.56}$ ,  $2^{189.51}$  and  $2^{253.87}$  respectively (Bogdanov *et al.*, 2014) because AES also uses fixed sized data blocking. Several other studies about the cryptanalysis of AES are the part of literature (Une and Kanda, 2007; Biryukov *et al.*, 2009; Alex and Johann, 2012; Derbez *et al.*, 2013; Chang *et al.*, 2015).

Other significant issue is that, the secret sub-keys of fixed sized block based SPN structure can be recovered (Guo *et al.*, 2014) and SPN also associates the discrepancy in linear cryptanalysis and its secret design can be re-produced by matching of cipher and plaintext values each with 16 bits as discussed in (Brown *et al.*, 2009; Rivain and Roche, 2013). Thus, it truly reflects the literature that the fixed length blocks support the cracker in matching of supposed decrypted string (block) with the targeted chosen plaintext string to get accurate final results. Another noteworthy problem with fixed (known) length block is the brute force attacking because any chosen fixed sized block means that same sized key is implemented due

to which the brute force attack is more likely and effectively to be applicable as explained in Table 1.1.

**Table 1.1:** Randomness Comparison between Dynamic and Static Data Blocking

Factors	With Prior Fixed Data Blocking Mechanism of (DES, AES-128)	With Proposed Dynamic Data Blocking Mechanism
<b>Probabilistic Randomness Calculation</b>	Suppose, Plaintext (D) = 2048 bits.	Suppose Plaintext (D) = 2048 bits
	Blocking with AES-128= 2048/128= <b>16</b> blocks, So Number of Data Blocks ( $\beta$ ) = 16	Number of Data Blocks are based on Random (dynamic) parameter (say) = $\mathbb{P}(\beta)$
	Number of bits of each block( $\mu$ ) : 128 bits	Number of bits of each block are based on Random (dynamic) parameter (say) = $\mathbb{P}(\mu)$ bits
	Probabilistic Randomness Calculation Formula: $\beta * 2^{\mu \text{ bits}}$ where For each single block= $1 * 2^{\mu \text{ bits}}$ $\beta$ is fixed = 16 in supposed case $\mu$ is fixed = 128 in supposed case So, $16 * 2^{128 \text{ bits}}$	Probabilistic Randomness Calculation Formula: $\mathbb{P}(\beta) * 2^{\mathbb{P}(\mu) \text{ bits}}$ Where $\mathbb{P}(\beta)$ is random $\mathbb{P}(\mu)$ is random As these are unknown to the cracker. So it is quite hard for the cracker to guess it. So (P $\neq$ NP) is effectively satisfied because both parameters ( $\beta, \mu$ ) are un-known and random.
<b>Result of guessing of block partitioning</b>	Weak and guessable	hard to guess

Research Gap: Furthermore, in existing literature there is gap of dynamic block ciphers because AES, DES are fixed-natured ciphers having fixed data blocking (Jain *et al.*, 2015), fixed substitution (Dara and Manochchri, 2014) and fixed selection of encryption operation for each encryption round (Shyamala-Bai, *et al.*, 2011; Srinivas *et al.*, 2014). Rather to dynamic-natured ciphers, either fixed-natured or few variable-natured block ciphers exist which did not deal with dynamic data blocking approach, neither with effective randomized substitution nor with dynamic selection of encryption operations for each round such as RC5 (Rivest, 1995) which utilizes three fixed and known variable block sizes (32, 64, 128 bits)

and similarly the Rijndael (Daemen and Rijmen, 2002) has also three fixed and known block sizes (128,192,256 bits). User can select any of block size from the 3 available options. These block sizes are publically known, variable in nature but not dynamic in nature. The Modified Symmetric Encryption Algorithm (MSEA) (Kumar *et al.*, 2014) provides large block size selection list (128, 192, 216, 256...728, 936, 1024, 1384, 1712, 2048 bits) these are also fixed and publically known. Therefore, MSEA also provides fixed and known variable block sizes which are not dynamic in nature. In case of MSEA the many block size options (728, 936, 1024, 1384, 1712, 2048 bits) are inadequate because the block size range that has been used in recent well-known algorithms (DES, AES) lies among (64, 128, 256 bits) which means the block size larger to 256 bit is not a recommended approach. Many other ideas of dynamic encryptions are either based on dynamic Steganography approach with fixed block size (Sawant *et al.*, 2015) or variable blocking using dynamic key (Shyamala-Bai *et al.*, 2011) or pair of keys (static and dynamic) with fixed block size (Harmouch and Kouch, 2015) which means their data blocking approach is not dynamic.

The variable block partitioning policy of Message Based Random Variable Length Key Encryption Algorithm (MRVLK) (Mirvaziri *et al.*, 2009; Davahli *et al.*, 2014) is based on a secret number ranged from ( $R_{nd}$ : 7 to 61) in which initial (very first) block size is decided in between 7 to 61 and other block sizes become arbitrary longer in such a way: ( $R_{nd}, 2R_{nd}, 4R_{nd}, 6R_{nd} \dots$ ). But, MRVLK has several discrepancies such as, it's very first *small-sized* block (Mirvaziri *et al.*, 2009) for which DES like weak block attacks are permissible (Minematsu, 2008; Paar and Pelzl, 2010) or arbitrary longer blocks even greater to 720 bits (un-recommended), fixed padding, and its non multiple of 8 bit block size is not feasible for disk encryption (Zhang, 2012) as well as its non-secure enciphering and randomness limitations (Davahli *et al.*, 2014). Thus, the critical literature analysis shows that, the variable data blocking solution of MRVLK has been found deficient in block length, disk encryption, enciphering strength, padding, cryptanalysis *etc.* and all other prior variable solutions contain fixed block sizes which is also known to the cracker.



Concussively, fixed sized blocking (AES, DES) and fixed padding are more helpful (Biryukov *et al.*, 2014) for cracker in succeeding of exhaustive key searching attack (brute-force attack) (Du and Atallah, 2001), reaction attack (Bellare *et al.*, 2004), biclique attack (Chang *et al.*, 2015) as well as other cryptanalysis attacks on AES (Bogdanov *et al.*, 2014; Guo *et al.*, 2014). Random padding is fine but not always especially in case if block size is fixed or known (e.g. 128 bit in AES) because if the random padding (e.g. 16 bits) has been used with 128 bits fixed block size which simply meaning that  $(128-16 = 112 \text{ bits})$  resulting many bits (112 bits) as a “waste bits” in cipher-text ( $C$ ) due to which attacker can recover secret key bits through matching all possible keys ( $K \in K'$ ) until block cipher ( $E^{-1}_K(C)$ ) starts with 112 zeros (Black and Rogaway, 2002), thus random-padding also provides trapdoor to render the algorithms vulnerable through back-door of an encryption key (Russell *et al.*, 2015). Variable-input-length (VIL) based cipher designs associate several issues such as infeasibility of encrypting disk sectors, weak security strength with smaller sized message, fixed padding, known-bit and weak block attacks (Bellare and Rogaway, 1999; Patel *et al.*, 2005; Zhang, 2012; Nandi, 2014) that demand the improvement in data blocking approach with dynamic features such as block size should be dynamic rather to fixed or variable, must be multiple of 8 without fixed padding, not greater than 256 bits, and must not be known to the cracker.

### 1.2.2 Static Substitution

The existing S-box design of AES is static (fixed) and un-changeable (Dara and Manochehri, 2014). Therefore, the static substitution policy of AES is its weak point (Mehla and Kaur, 2014; Abdulgader *et al.*, 2015) because of happening of static connection with input and output bits due to which AES has no direct association with secret key that is the only changeable parameter (Senthilkumar and Rajamani, 2014). The modern attacks (linear and differential) ideally require known transformation of lookup tables (i.e. S-box) as agreed by Kazlauskas *et al.*, (2015). Moreover, Senthilkumar and Rajamani discussed that differential attacks are more applicable on static s-boxes because these attacks are based on the information of  $XOR$  tables produced against S-Boxes. The  $XOR$  table contains columns and rows starting with indexes  $(0, 1, 2 \dots \dots 2^{m-1})$  against the related  $(m \times m)$ S-box which can

further mapped with *XOR* table entries  $q, f \in (0, 1, 2, \dots, 2^{m-1})$  deal with position  $q, f$  having  $\{value | (Z \in \{0, 1\}^m : S(Z) \oplus S(Z \oplus q) = f)\}$ . Thus, modern cryptanalysis attacks ideally demand fixed (static) relationship of input and output bits with S-boxes that prompt the need of key dependent randomized substitution policy (Senthilkumar and Rajamani, 2014). Furthermore, the substitution policy of AES is based on static numerical search tables which lead the AES to vulnerable against modern security attacks and have not been shown safe in terms of designing various cryptanalysis methods (Moreno-Diaz and Pichler, 2011; Gangadari *et al.*, 2015).

The linearity in static substitution is significant weakness of AES (Shyamala-Bai *et al.*, 2011; Sikdar, 2014) due which permutation produces only bit redistribution which does not satisfies the sufficient diffusion properties (Ritter, 1998) because strength of algorithm and hindrance of cryptanalysis significantly relies on S-Box parameters (Jithendra and Shahana, 2015). The internal Substitution components of DES and AES (Sub-Bytes, Shift Column, ShiftRow) are insecure because they do not contain any correlation with secret key (Ramly *et al.*, 2001; Sreedharan, 2014) by itself and key is the only changing parameter (Senthilkumar and Rajamani, 2014). Moreover, the prior symmetric block ciphers implement substitution through look-up tables and look-up substitution tables (fixed S-Boxes) help the cracker (Saini, 2014; Kazlauskas *et al.*, 2015) and are more vulnerable upon timing attacks (Smith, 2007; Sahnoud *et al.*, 2013) therefore as a result, static substitution boxes should be eliminated from prior algorithms. Kocher *et al.* (2011) have claimed that the secret parts in symmetric cryptographic algorithms can be changed or masked under fresh randomness and if key state is updated on some random bases dynamically then it can be resulted as reasonably hard for adversary (attacker) to get useful secret information. Also, the dynamic substitution is significant area of improvement (Flamm, 2014) better to static s-box (ReddyK and Vishnuvardhan, 2014) and can enhance confusion (strength) properties (Kazlauskas *et al.*, 2015) of encryption algorithms which make them more difficult in cryptanalysis (Mirvaziri *et al.*, 2009; Hosseinkhani and Javadi, 2012; Saini, 2014; Velayutham *et al.*, 2015). Furthermore, the related (existing) substitution methods are deficient in many aspects (e.g. design, known parameters, feasibility *etc.*) as it has been discussed in Chapter 2. Thus, substitution should not be fixed and it should

be done against the probabilistic random values achieved from key. All these evidences negate the utilization of static (fixed) substitution in future cryptosystems.

### 1.2.3 Static and Identical Enciphering Operations

Each AES version has fixed number of multiple encryption rounds with repetition of identical (similar) operations having known strategies (Saini, 2014; Srinivas *et al.*, 2014; Kaur and Madaan, 2014) and last-round-attack can be applied on the final round of AES because this round does not apply mix-column operation (Tange and Andersen, 2014). AES encryption operations are publically well-known which is more serious aspect towards AES because the linear and differential attack always require known S-box transformation (Kazlauskas *et al.*, 2015) but on the other hand, the dynamic transformation which is not known to the cracker makes the algorithm more resistive against modern attacks (Al-Wattar *et al.*, 2015; Velayutham *et al.*, 2015). Moreover, each round in AES is identical and computationally feeble (Mirvaziri *et al.*, 2009) which are unclear to predict whether large number of rounds with fixed operations are really feasible to create strong enciphering as agreed by Ritter, (1998) in US Patent No. 5727062. Furthermore, existing enciphering designs (Feistel, SPN) are not reliably secure or suspected against various cryptanalysis attacks (Brown *et al.*, 2009; Isobe and Shibutani, 2013; Biryukov and Nikolic, 2014; Guo *et al.*, 2014). The other more surprising fact that reflecting the weakness of current enciphering mechanism is the cracking of DES (Franke *et al.*, 2005; Batina *et al.*, 2005; Zaidan *et al.*, 2010) and the cryptanalysis of AES (Biryukov *et al.*, 2009; Biryukov *et al.*, 2010; Biryukov and Großschäd, 2012; Derbez *et al.*, 2013; Chang *et al.*, 2015) which has been discussed in Chapter 2.

Security of any cryptographic algorithm is essentially reliant on randomness that can be achieved through probabilistic process (dynamicity) (Duta *et al.*, 2014). The term operational dynamicity means to select encryption operation run time on dynamic bases so that, it should not be aware to the cracker, which encryption operation has applied on which data block. This sort of operational dynamicity creates sufficient operational randomness because unpredictable information directly co-relates with pseudo-randomness (Sanjeev and Barak, 2008; Alimomeni, 2014).

Enhancing the randomness means enhancing the security of encryption algorithm (Al-Shakarchi, 2014). Poor, predictable and repeated randomness can be resulted as full security breakdown of cryptosystems (Ristenpart and Yilek, 2010; Alimomeni, 2014). Thus, for designing secure algorithms, randomness and dynamicity are the needy constraints because randomness enhances confusion to resist modern and common attacks (Cook, 2006; Mishra and Mankar, 2012). All these evidences prompt that the cryptographic algorithm is always as secure as it contains randomness and operational dynamicity. The solution to cope the issue of constant and static selection of encryption operations in prior algorithms (DES, AES) requires the need of dynamic selection of encryption operations by developing multi set of operations having sub-operations inside. This type of multiple operation development approach is known as design diversity approach and it can be achieved through joint committee of different sub-operations under a master encryption operation (Schneier, 1994). Currently, multi-encryption is the most focused area of development for symmetric cryptosystems (Harmouch and Kouch, 2015). Currently, there is a significant gap of this type of particular feature (i.e. dynamic selection of encryption operation for each data block) in existing literature.

### **1.3 Problem Statement**

Fixed data blocking approach is inadequate to create effective dynamicity and larger computational probability due to which it helps the cracker in succeeding of modern attacks as witnessed in the literature. Static substitution approaches do not create sufficient diffusion (distribution of output bits) which depends on the input bits, but only within the scope of substituted number of bits and in this way the permutation is just bit re-distribution. Moreover, existing substitution approaches are either infeasible for dynamic sized data blocks or deal with known S-box formulations or lacked of direct association with encryption key or behaves as a trapdoor for building and succeeding of cryptanalysis attacks due the fixed relation of input and output bits. Similarly, the known selection of identical operations on each data block is not an optimal way of creating effective operational randomness under least number of encryption rounds. Thus, fixed data blocking, static

substitution and constant implementation of fixed set of known enciphering operations are the critical factors limiting the dynamicity and randomness in cryptosystems as reflected through mathematical cracking of AES-256 up to full of its 14 rounds.

#### 1.4 Research Questions

Prominent literature problems prompt the need to answer these several research questions.

- i. How to improve fixed data blocking approach in symmetric cryptosystems with dynamic data blocking:-
  - (a) How to achieve effective and dynamic sized data blocks?
  - (b) How to avoid fixed padding and weak sized dynamic block even by fulfilling the condition of multiple of 8 bits?
- ii. How effectively to enhance static substitution policy in symmetric cryptosystems with randomized substitution approach:-
  - (a) How to achieve key-dependent randomized substitution?
  - (b) How to enhance pseudo-randomness and dynamicity with randomized modifications in key and data?
- iii. How to achieve effective and secure encryption in symmetric cryptosystems:-
  - (a) How to use multi-encryption operations dynamically for each data block?
  - (b) How to achieve effective data encryption (security) with least number of encryption rounds?

## **1.5 Research Aim**

The aim of this research is to develop dynamic multi-encryption method by ‘improving’ fixed data blocking with dynamic data blocking, static substitution with randomized substitution and known operation based identical encryption approach with dynamic multi-encryption method to improve data encryption effectively.

## **1.6 Research Objectives**

To answer the projected research questions, this study includes several objectives which potentially required to be accomplished as an optimal solution for the said problem.

- i. To develop dynamic data blocking mechanism for converting the data to dynamic sized blocks in order to achieve effective dynamicity and larger computational probability.
- ii. To develop a randomized substitution mechanism for mixing (key and Data) through dynamic modifications in order to achieve effective dynamicity and probabilistic randomness.
- iii. To develop a multi-operation data encryption mechanism to select enciphering operation dynamically in order to achieve effective data encryption (security) with less number of encryption rounds.

## **1.7 Significance of the Study**

Data security and privacy against confidential information are increasingly important in remote transactions over insecure communication channels. The encryption practices are actively employed in banking sectors, exchange of confidential data in academic organizations, medical sectors, storage of data in forensic and scientific laborites and securing of network communications. This study

is enriched with great significance of data encryption with optimal security. It provides an encryption method with dynamic design features such as dynamic data blocking, randomized substitution and multi-operation based dynamic enciphering mechanism. These features are an optimal way to enhance the security of data encryption method. Earlier encryption algorithms (DES, AES) possesses static design features in various stages such as data blocking, substitution and selection of enciphering operations which are seriously effecting the overall security of already deployed design ciphers (Feistel, SPN) as discussed in problem background section. These static features are not effectively sufficient to create dynamicity, larger probability and optimal randomness due to which the past cryptanalysis of DES and present academic cracking of AES are being more critical day by day. Thus, the proposed study is timely significant to improve the static design features with dynamic design features through development of dynamic data blocking, randomized substitution and multi-operation data encryption mechanism. The proposed idea is essentially important to boost the security of symmetric cryptosystems. Furthermore, the proposed idea is effectively innovative for the researchers to design future cryptosystems and highly beneficial for the academic researchers to evolve the cryptography research.

## **1.8 Research Scope**

This study focuses on symmetric data encryption method for providing both data privacy and security upon confidential data. The proposed idea mainly covers the design and development of proposed encryption method which includes dynamic data blocking, randomized substitution and multi-operation data encryption mechanism. Furthermore the scope of this study covers:-

- i. The different natured plaintext (alphabets, numerical data, special characters or their combination) have been used to make user input samples for testing the system.
- ii. Development has been done by using Visual Studio.Net tool.

- iii. Evaluation is done using standard tool - Statistical Testing Suite(STS) recommended by National Institute of Standard and Technology (NIST).
- iv. In statistical evaluation, some tests require large sized input sample ( $10^6$  bit longer sequence) which is recommended by NIST. Therefore, large sequence size has been used for some tests (Serial test, Lempel-Ziv, overlapping and non-overlapping tests).
- v. The longer sequence size (1268784 bits) is used for evaluating the Randomized Substitution Mechanism (RSM) during the statistical randomness testing, because the longer parameter length in STS, must be greater than or equal to  $10^6$ .
- vi. The larger sequence (1153440 bits) is used to test the Multi-operation Data Encryption Mechanism (MoDEM) because it is recommended parameter length ( $\geq 10^6$ ) for STS tool.

## 1.9 Thesis Structure

The rest of this thesis is structured as:-

In Chapter 1, overview, problem background related to fixed data blocking, static substitution including static and constant enciphering operations have been discussed to generate problem statement. Furthermore, the study aim, research questions, objectives, significance and research scope have been highlighted.

Chapter 2, provides the extensive literature review of most related research topics (Issues in symmetric cryptosystems, Feistel structure limitations, SPN design deficiencies, other potential security issues, need of proposed design and discussion of latest attacks on AES and DES).

Chapter 3, outlines the research methodology and flow used in this research. It discusses the research plan, design and procedures followed against the development of proposed method. Furthermore, it elaborates the research scope and



evaluation metrics through which the proposed method can be evaluated. Detail about the recommend statistical tests and tool with experimental setup has also been discussed in this chapter.

Chapter 4, contributes the design, development and evaluation of proposed Dynamic Data Blocking Mechanism (DDBM) which is the first objective of this study. The DDBM has been developed in Visual Studio.Net and its evaluation has been done through practical experimentations.

Chapter 5, provides the design, development and evaluation of proposed Randomized Substitution Mechanism (RSM) by discussing all interrelated steps. The RSM is the second objective of this study which firstly developed through utilizing the Visual Studio. Net tool and after that it has been evaluated and validated by executing several statistical randomness tests (discussed in Chapter 3) by using Statistical Testing Suite (STS) tool recommended by National Institute of Standard and Technolgoy (NIST).

Chapter 6, discusses the design, development and evaluation of Multi-Operation Data Encryption Mechanism (MoDEM) which is the third objective of this study. The proposed MDEM has been developed in Visual Studio. Net and subsequently, it has been evaluated and validated through experimental testing of NIST's recommend statistical tests conducted through STS Tool. Mathematical testing of common attacks against proposed method including brute force strength attack have also been provided in Chapter 6.

Chapter 7, comprehensively summarizes the achievements and contributions against each study objective in addition with the concluding remarks. Moreover, this chapter directs the researchers how to continue this research work toward more revolutionary enhancements about cryptosystems in near future.

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