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Improved Image Security in Internet of Thing (IOT) Using Multiple Key AES

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Abstract:

Image is an important digital information that used in many internet of things (IoT) applications such as transport, healthcare, agriculture, military, vehicles and wildlife. etc. Also, any image has very important characteristic such as large size, strong correlation and huge redundancy, therefore, encrypting it by using single key Advanced Encryption Standard (AES) through IoT communication technologies makes it vulnerable to many threats, thus, the pixels that have the same values will be encrypted to another pixels that have same values when they use the same key. The contribution of this work is to increase the security of transferred image. This paper proposed multiple key AES algorithm (MECCAES) to improve the security of the transmitted image through IoT. This approach is evaluated via applying it on RGB bmp images and analyzing the results using standard metrics such as entropy, histogram, correlation, Peak Signal-to-Noise Ratio (PSNR) and Mean Square Error (MES) metrics. Also, the time for encryption and decryption for the proposed MECCAES is the same time consumed by original single key AES is 12 second(the used image size is 12.1MB therefore time is long). The performance experiments show that this scheme achieves confidentiality also it encourages to use effectively in a wide IoTs fields to secure transmitted image.

Key words: AES, Asymmetric, Cryptography, IoT, MECC, RGB Color Image, Symmetric, Security, WiFi, WiMAX.

Introduction:

The IoT involves diverse link layer technologies and an enormous collection of devices (1). The number of IoT applications is growing. The applications comprise smart home, smart city, smart agriculture, utilities, healthcare monitoring, and animal farming, smart water, security and emergencies, industrial control, smart transportation, environment monitoring (2). It tackles the highly sensitive information about people and companies, which must not be revealed to those unauthorized persons and attackers.

Security is a very important issue that could confront the IoT development and providing security for IoT technology is a great real challenge. As the IoT technology has a wide spread scope, there are many variables areas of research that focuses on security challenges. Security requirements in the IoT environment are confidentiality, integrity, authentication, authorization, access control, and availability.

One of the most important methods to provide data security, especially to protect end-to-end data sent over networks is Cryptography. Cryptography is the system in which text or any type of data is converted from readable data to unreadable (encrypted) data that can only be decrypted by someone who has the decryption key therefore, the purpose of the encryption is to ensure that the privacy of the data is not allowed to tamper with or view it, because it is either confidential or private and very important. Symmetric (the key used to encrypt and decrypt is the same) and asymmetric (the key used to encrypt is differed from the key used to decrypt) are basic types in cryptography and lightweight appear as modern type which is focused on the lower end devices.

A few lightweight security mechanisms currently in use are based on number of security techniques and cryptographic algorithms. They include hash functions like access control, XOR encryption, lightweight public-key cryptographic schemes based on ECC(Elliptic Curve Cryptography) (3) and symmetric AES 128 algorithm (that used as default in Wireless Fidelity

(Wi-Fi), Worldwide Interoperability for Microwave Access X (WiMAX) and Bluetooth(4)(5) .

Elliptic Curve Cryptography (ECC) is the more secure public key cryptography algorithm because it uses fully exponential computations to solve the problems. It is used to generate smaller, faster, and more efficient cryptographic keys. ECC generates the keys through the properties of an elliptic curve equation instead of the conventional generation method as a result of very large initial numbers. Because ECC helps create equivalent security with less power to use the computer and use battery resources.

The Advanced Encryption Standard (AES) is one of the most symmetric block cipher algorithm that is used commonly in ciphering. When encrypting data by AES algorithm it is very difficult for hackers to get the original data. There are three key sizes allowed for the AES algorithm: 128, 192, and 256 bit; but the block size of the message allowed is fixed which is 128 bit

Security in transmission of the digital images has its importance in the present image communications due to the increasing use of image throughout the industrial process, transport, healthcare like Connected MRI(Magnetic Resonance Imaging) scanner (6), industrial (7) agriculture(8), military, vehicles and wildlife .. etc. It is necessary to protect the confidentiality of image data from unauthorized access, therefore image security is a critical issue and that is obvious from researchers who tried in many papers to enhance image security by use different encryption schemes.

The previous studies that attempted to enhance image security by using symmetric single key AES are many. Alireza etal. suggested chaos system to generate key rounds and make modifications on standard AES(9). Also, Ahmed et.al suggested mixing of a shifting technique and AES scheme (10), and Jha suggested image encryption approach corresponding to AES and 2-D logistic map (11). All (9)(10)(11) attempted to enhance the weakness of single key standard AES by increasing the randomness of key or make some modifications on original AES. On other hand, Mohsen and khizrai used multiple keys schemes (12) (13) to increase security level. The contribution of this work is to increase the security of transferred image by combining the good randomness of key with using AES multiple keys.

This study tries to enhance the security of transmitted image through IOT which is secured by using AES 128 single key. The proposed **MECC - AES** (Multiple key Elliptic Curve Cryptography) achieves high levels of security and integrity according to statistical metrics such as Entropy, PSNR, MSE and correlation.

The Proposed Scheme:

The main objectives of this work are improving the security and the accuracy of the transmitted image through IOT. The work suggested a multiple key symmetric scheme. At the first use MECC technique to generate multiple secret keys which is used with AES for improving the security and accuracy of image of IOT.

MECC Technique

The proposed MECC (14) technique can generate N keys by using multiple ECC public keys. The proposed MECC is two sets key generator. In this model, a different number of initial sequences and different ECC public keys are used, two initial random key seeds r0 and s0 are used to generate two sets of keys: r1, r2 ... rn; s1, s2 ... sn, where the sets are generated according to the Equations (1 and 2).

Then, the xor function f equation (3) is used to obtain the final keys, which are used in the encryption and decryption process.

$$r_i = \text{ECCen}(\text{TCK1}, r_{i-1}) \quad 0 < i \leq n \quad (1)$$

$$s_i = \text{ECCen}(\text{TCK2}, s_{i-1}) \quad 0 < i \leq n \quad (2)$$

Where:

ECCen is an elliptic curve ciphering (ECC algorithm).

TCK1and TCK2: are trust center public keys which are different keys.

The trust center must satisfy the values of r0 and s0 in the sender and receiver sides.

$$\text{Key}i = f\,(\text{k}i, \text{rn-}i\text{+1}) \quad 1 \leq i \leq n \quad (3)$$

The diagram of the proposed MECC technique with two sets key generator model is demonstrated in Fig.1. Algorithm 1 shows the proposed MECC technique with two sets key generator model.

Algorithm (1):MECC Algorithm (Two Sets)

Input: s0, r0; *key sets PK1, PK2; generated public keys*
Output: *K1; proposed generated keys*

```
Begin
    For i= 1 to n (Where n: is number of the secret keys)
        $s_i$ = ECC ($s_{i-1}$, PK1)
        $r_i$= ECC ($r_{i-1}$, PK2)
    End for
    For i= 1 to n
        $K1_i$= f ($s_i$, $r_{n-i+1}$)
    End for
End
```

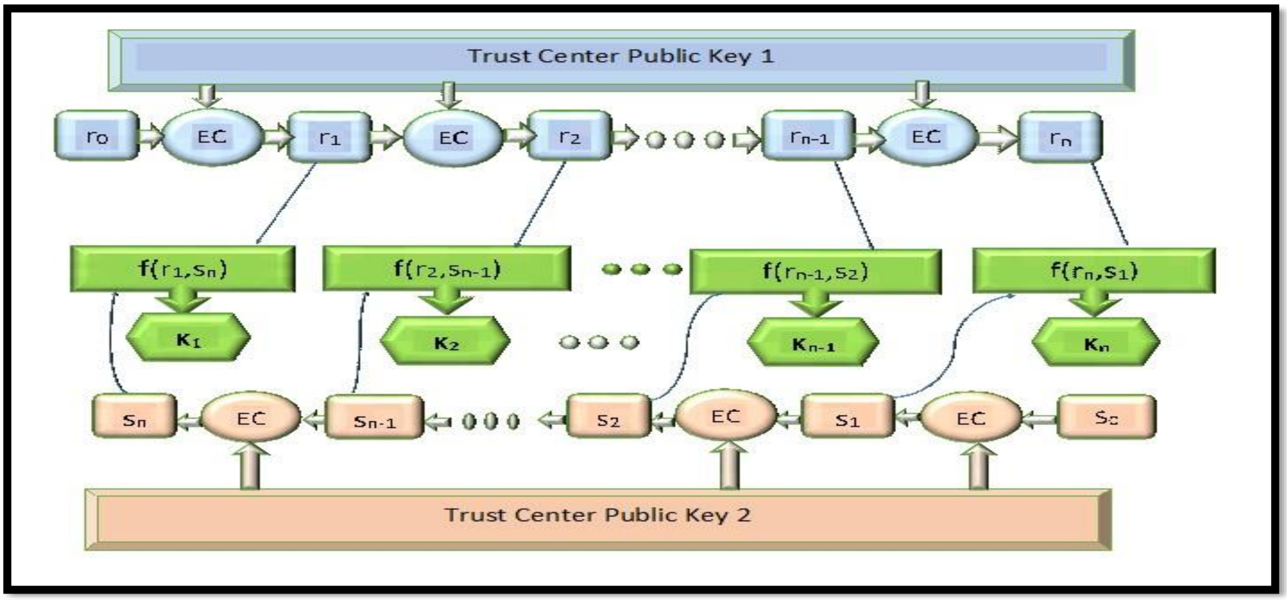


Figure 1. The Proposed MECC Technique with Two Sets Key generator model

MECC -AES Scheme

The MECC -AES technique is suggested to improve the strength of the security system that is available when using keys generated by the MECC technique. The MECC -AES technique consists of a MECC technique that generates secret keys and the AES algorithm which uses these secret keys in the encryption and decryption operations .In order to encrypt the plain image by the MECC -AES technique after separating the plain image into three matrix of R,G,B colors, each matrix must be divided into the same number of n blocks, as demonstrated in Equation(4). If the number of secret keys equals the number of image blocks then encrypting each block directly with the corresponding key. But if the number of keys is less than the number of blocks. Then these blocks are distributed into groups. The number of these groups is equal to the number of secret keys. All blocks belonging to the same group i are encrypted by the secret key Keyi. The encryption operation using AES algorithm is demonstrated in Equation (5). The decryption operation is in reverse way.

$$I_R=\sum_i^n B_i\,,\ I_G=\sum_i^n B_i\,,\ I_{,B}=\sum_i^n B_i \qquad (4)$$

IR:red color matrix of image .
IG:green color matrix of image .
IB:blue color matrix of image .
B_i:Block of image.

$$\begin{aligned} CiR &= AES\,(BiR)\\ CiG &= AES\,(BiG)\\ CiB &= AES\,(BiB) \end{aligned} \qquad (5)$$

Where:

C_R: red color matrix of encrypted image.
C_G: green color matrix of encrypted image.
C_B: blue color matrix of encrypted image.
AES: AES algorithm.
Key: Secret key which is generated by the MECC technique.

Figure 2 shows a general view of the proposed MECC-AES encryption and decryption technique.

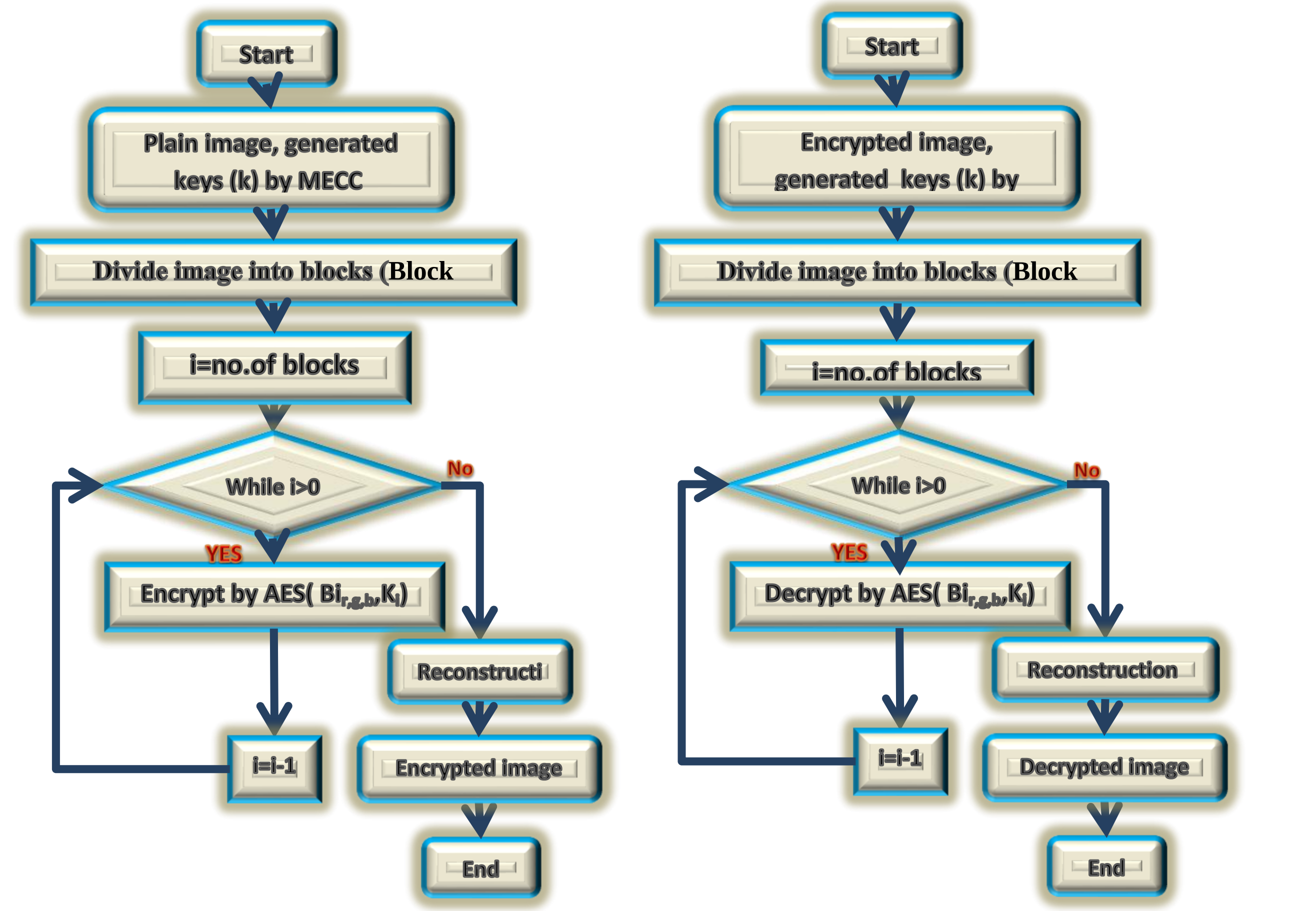
Algorithms 2 and 3 demonstrates the encryption of the proposed MKE-AES technique .

Algorithm (2):M ECC-AES Encryption

```
Input :RGB Image(separate RGB color image into three matrix Red, Green,  Blue);
        Fifty(50) keys; secret keys
Output: C1 ,C10,C20,C30,C40,C50; the cipherd image(depending on the number of  secret keys)
Begin
        Block-size = 16 byte
        No-of-Blocks(R,G,B)= (Height*width) / block-size
        No-of-Blocks-in-Group= No-of-Blocks / n ;(Where n: is number of the secret keys)
        i=1
    For j= 1 to No-of-Blocks(R,G,B)
            CRj= AES (Bj, Keyi)
            CGj= AES (Bj, Keyi)
            CBj= AES (Bj, Keyi)
            If (j mod (No-of-Blocks-in-Group) = 0)
            i=i+1
        End If
        Reconstruct image
        End For
End
```

Algorithm (3): MECC-AES Decryption

```
Input: RGB Ciphered Image(separate RGB color image into three matrix Red, Green, Blue));
        Fifty(50) keys; secret keys
Output:   DC1,DC10,DC20,DC30,DC40,DC50;   the Deciphered image(depending on the number of  secret keys)
Begin
Block-size = 16 byte
No-of-Blocks(R,G,B)= (Height*width) / block-size
No-of-Blocks-in-Group=  No-of-Blocks  /  n ;(Where n: is number of the secret keys)
i=1
For j= 1 to No-of-Blocks(R,G,B)
DCRj= AES (Bj, Keyi)
DCGj= AES (Bj, Keyi)
DCBj= AES (Bj, Keyi)
If (j mod (No-of-Blocks-in-Group) = 0)
i=i+1
End If
Reconstruct image
End For
End
```


Start
Plain image, generated keys (k) by MECC
Divide image into blocks (Block
i=no.of blocks
While i>0
No
YES
Encrypt by AES($Bi_{r,g,b}$,K_i)
Reconstructi
i=i-1
Encrypted image
End
Start
Encrypted image, generated keys (k) by
Divide image into blocks (Block
i=no.of blocks
While i>0
No
YES
Decrypt by AES($Bi_{r,g,b}$,K_i)
Reconstruction
i=i-1
Decrypted image
End

(A) (B)

Figure 2. The Proposed MECC-AES Technique (A) Encryption (B) Decryption

Result and Discussion:

Based on the algorithms discussed in the previous section, an encryption quality is evaluated by using Sun image shown in Fig.3 which has high redundancy and it is taken from website (https://www.hlevkin.com/06testimages.htm) (15). The proposed scheme is implemented on configuration such as OS : Windows 7 ultimate 32 bit ,Processor : Intel Celeron ,Memory : 4 GB ,Software used : Java , Matlab 2008a , Excel and Input image: RGB image with **Dimensions 2096*2030** and size **12.1 MB Bit depth 24 bit** . After applying the proposed scheme, Fig.4 shows the ciphered images that belongs to the original RGB Sun image.

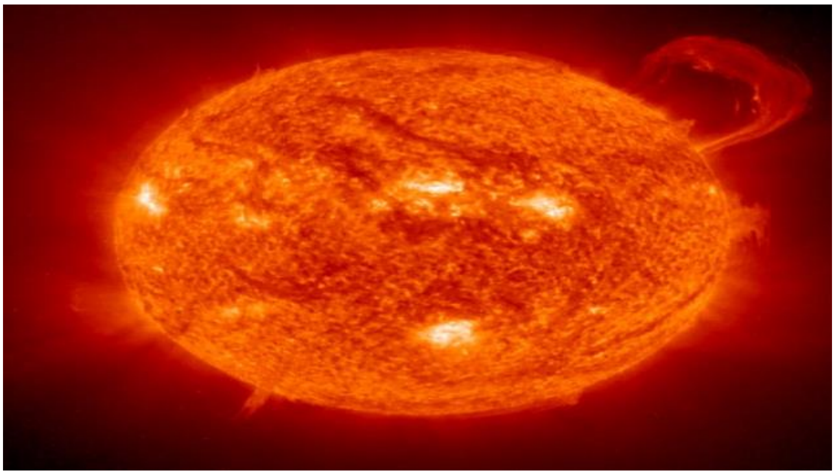
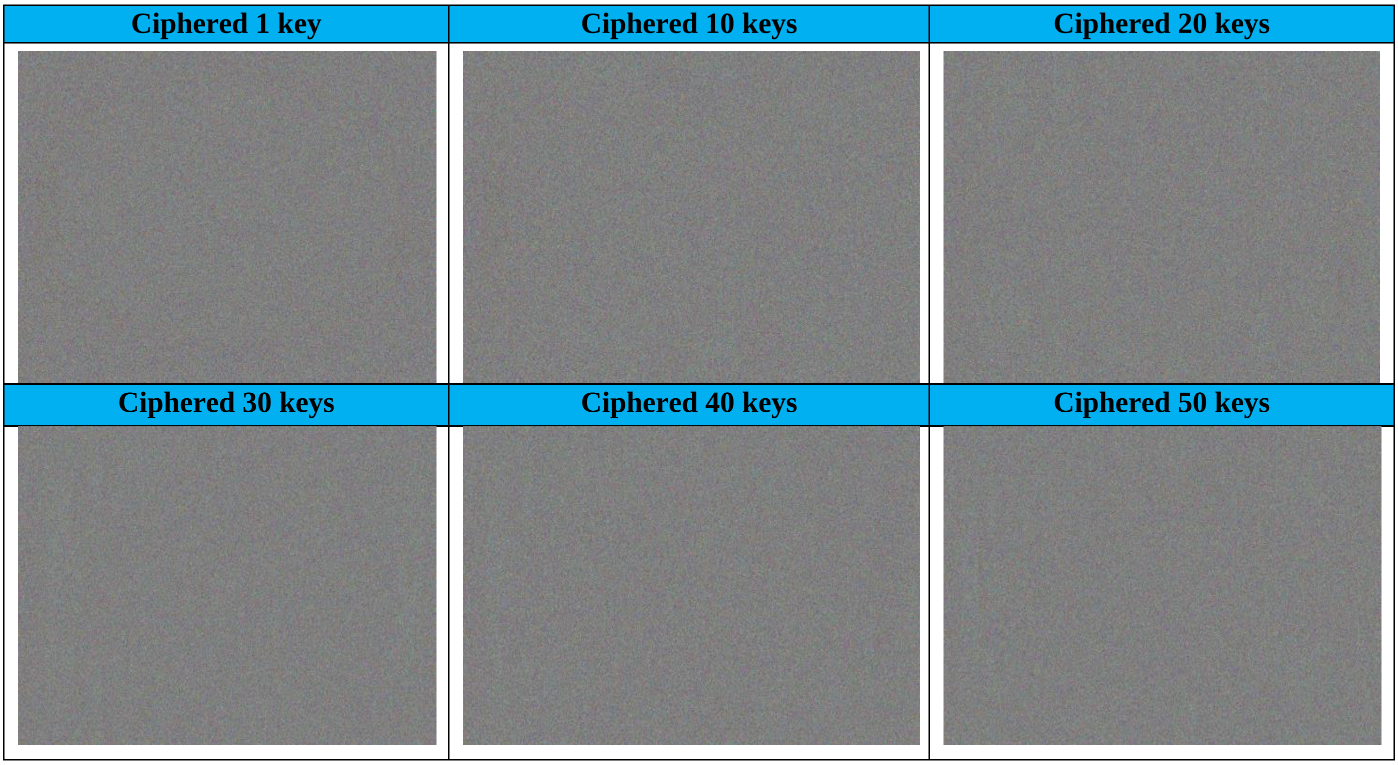


Figure 3.original Sun image.



Also, in this section the results of the proposed MKE-AES method are discussed as follows:

Figure 4. The ciphered images with different number of secret keys corresponding to plain Sun image.

Entropy

Entropy (H) is a statistical measure of uncertainty (randomness) in communication theory (16). Information theory (Entropy) is concerned with network security, cryptography, data compression, communication systems, error correlation and other related topics. The Eq. (6) is used to calculate the entropy as follows:

$H=-\sum p(xi)\log2\ p(xi)$……………. (6)

Where p(xi) is the probability density function of the occurrence of the symbol xi. Entropy of an

image indicates how grey level values are distributed. When an image has equal probabilities, the entropy will be calculated to 8 which is an ideal result. If the entropy is less than eight (8) this means there is a certain degree of predictability (17)
For a cryptosystem to resist the entropy attacks.

Table 1 for Sun image illustrates how the entropy is increased when number of keys is increased. The entropy values in each ciphered image is increased and be more close to ideal value(8) which mean highly randomness. As a result all entropy values are better than entropy for ciphered image with one key.

Table 1. Evaluation of entropy to Sun image

Entropy	Red	Green	Blue	AVG(RGB)
Original Sun	7.350198419	4.706794447	1.5760462	4.5443464
Ciphered 1 key	7.999960541	7.9949104	7.9981814	7.9976841
Ciphered 10 keys	7.999953581	7.999339879	7.9997501	7.9996812
Ciphered 20 keys	7.999959587	7.999637732	7.9998085	7.9998019
Ciphered 30 keys	7.999958022	7.999772259	7.9998683	7.9998662
Ciphered 40 keys	7.999960651	7.999807619	7.9999037	7.9998906
Ciphered 50 keys	7.99995235	7.999836309	7.9999058	7.9998982

PSNR & MSE

PSNR is abbreviation to Peak Signal-to-Noise Ratio that reveals the encryption quality and displays the changes in the pixel values between the plain image and the ciphered image (18). The result of PSNR is a single number in decibels (dB) and if this number is smaller than 30dB that mean the encrypted image is dissimilar to the original. Mathematically PSNR is founded by putting the Mean Squared Error (MSE) in relation to the maximum possible value of luminance (for a typical 8-bit value this is 2^8 -1 = 255) as follows:

$$\mathrm{MSE}=\frac{1}{\mathrm{mn}}\sum_{\mathrm{i}=0}^{\mathrm{m}-1}\sum_{\mathrm{j}=0}^{\mathrm{n}-1}(\mathrm{f}(\mathrm{i},\mathrm{j})-\mathrm{F}(\mathrm{i},\mathrm{j}))^2 \ldots\ldots\ (7)$$

$$PSNR = 10\cdot log10\left(\frac{\mathrm{MAX}^2}{\mathrm{MSE}}\right)\mathrm{dB}\ \text{(formula no)}\ldots...(8)$$

Where f(i,j) represent the original pixel (i, j), while F(i, j) is the ciphered pixel, and M × N refer to the picture size. MSE as part of equation 6, provides a quantitative score to describe the degree of similarity between two signals (19).

Table 2 show the values of PSNR is highly below 30dB and that prove the encrypted image is highly secure and MSE values is very high and far from 0 with significant value. Therefore PSNR and MSE proved that the ciphered image is completely different from original one. At the same time the values of PSNR & MSE are Inf and 0 successively prove that the deciphered image is identical to the original image ,by which this scheme is lossless way.

Table 2. Evaluation of PSNR and MSE to Sun image.

Image	Avg.MSE	Avg.PSNR
Original Sun with decrypted image	0	Inf dB
Ciphered 1 key	16262.76	6.1761 dB
Ciphered 10 keys	16329.59	6.1598 dB
Ciphered 20 keys	16335.59	6.1586 dB
Ciphered 30 keys	16365.47	6.1511 dB
Ciphered 40 keys	16341.59	6.1571 dB
Ciphered 50 keys	16347.52	6.1551 dB

Histogram

Histogram is one of the significant statistical characteristics that illustrates how many times the pixel intensity value occurs inside an image. A respectable encryption scheme provides a uniform histogram of ciphered image contrasting to the original image histogram. (20)

The below Fig.5 shows the histogram of original and ciphered images. Histogram of ciphered image in contrast to the original image histogram is uniform in RGB channels and when number of keys is increased histogram is more uniform and this proves the encryption with multiple keys increases defense toward statistical attacks.

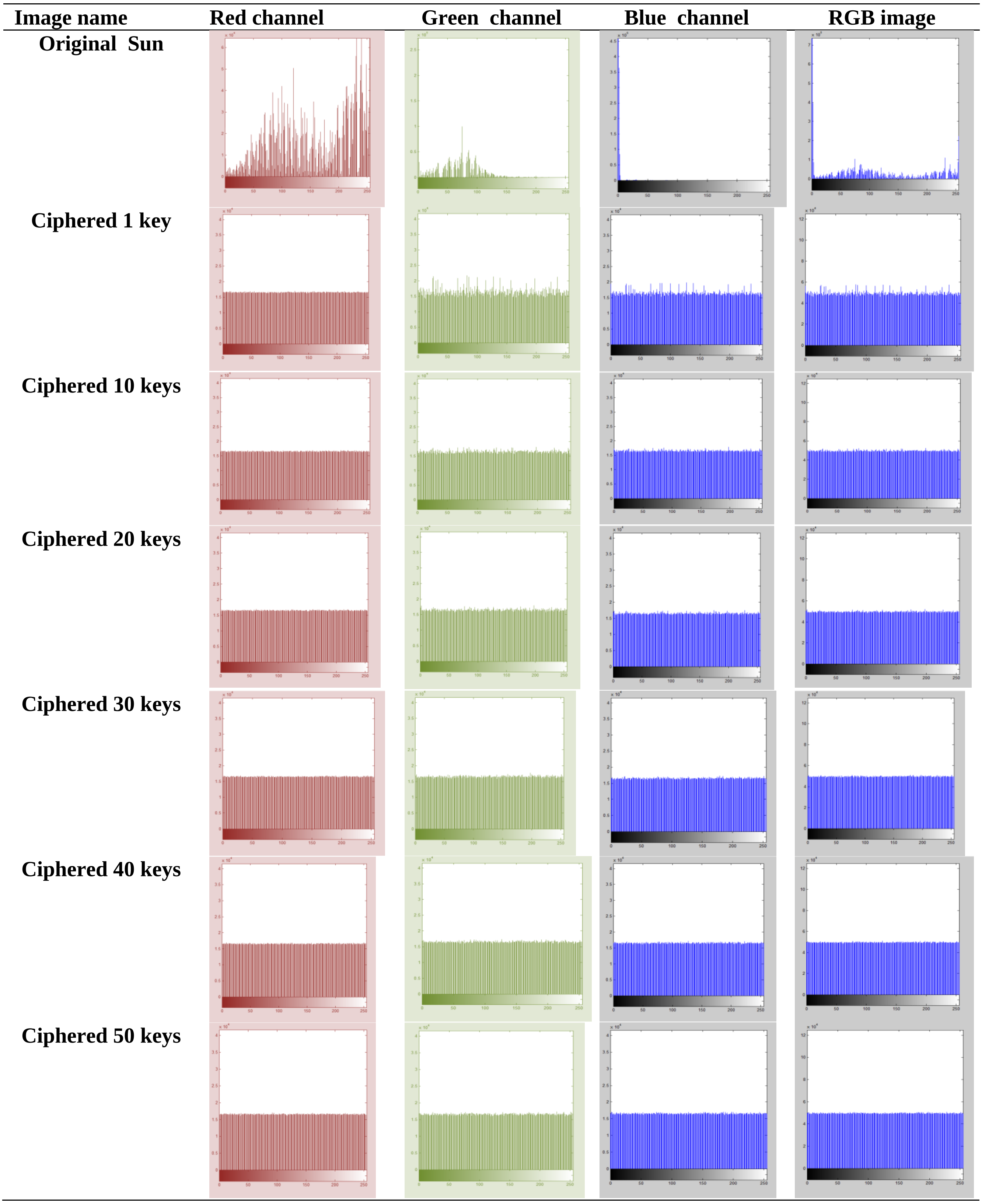


Figure 5. Histogram of original and encrypted Sun image with different number keys

Correlation

Highly correlation inherently is guaranteed in plain image data between pixels (close to one) in horizontal, vertical or diagonal directions. The encryption aim is to destroy the strong correlation between neighboring pixels of the ciphered image (near to zero). It is strongly related if |rxy |> 0.8, otherwise weakly related if |rxy |< 0.3. In image, the correlation coefficient between each pair of pixels uses equation (9) to be calculated as follow:

$$D(x) = \frac{1}{N}\sum_{i=1}^{N}(x\,i - E(x))^2$$

Where,

$$Cov\,(x,y) = \frac{1}{N}\sum_{i=1}^{N}(x\,i - E(x))(y\,i - E(y))$$

$$E(x) = \frac{1}{N}\sum_{i=1}^{N} x\,i$$

$$r\,\{x,y\} = \frac{Cov\,(x,y)}{\sqrt{D(x)}\sqrt{D(y)}}$$

……………(9)

Where cov(x:y), D(x) and D(y) are covariance and variances of variable x and y respectively. E(x) and E(y) are the expected values of the variables x and y. Where N is the whole pels of an image, N=rows × cols, x is a vector of length N and xi is the intensity values of original image (20,21).

Tables 3,4,5 and Figs. 6,7,8 show correlation between pixel pairs adjacent. Original Sun image show strong correlation while encrypted images show low correlation in three directions horizontal, vertical and diagonal for selected 3000 pixel pairs in a random way. The low values of correlation nearly to zero and less than 0.3 between pixels in ciphered image proved the power of MECC-AES scheme.

Table 3. Evaluation of correlation metric in horizontal, vertical and diagonal for Sun image in Red channel.

Red	horizontal	vertical	diagonal
Original Sun	0.997	0.9969	0.9953
Ciphered 1 key	0.0005	-0.0234	-0.0152
Ciphered 10 keys	0.0049	0.0583	-0.0022
Ciphered 20 keys	0.0089	-0.0066	0.004
Ciphered 30 keys	-0.0098	-0.0409	-0.0492
Ciphered 40 keys	0.0057	0.0038	0.01
Ciphered 50 keys	0.0152	0.0101	-0.0138

Table 4. Evaluation of correlation metric in horizontal, vertical and diagonal for Sun image in Green channel.

Green	horizontal	Vertical	diagonal
Original Sun	0.9937	0.994	0.9892
Ciphered 1 key	-0.0168	0.0224	0.0066
Ciphered 10 keys	-0.0302	-0.0072	-0.0256
Ciphered 20 keys	0.04	0.007	0.0017
Ciphered 30 keys	0.0078	-0.005	-0.0172
Ciphered 40 keys	-0.0231	-0.0083	-0.012
Ciphered 50 keys	0.0034	0.0149	0.0375

Table 5. Evaluation of correlation metric in horizontal, vertical and diagonal for Sun image in Blue channel.

Blue	Horizontal	Vertical	diagonal
Original Sun	0.9754	0.9857	0.9551
Ciphered 1 key	0.0187	-0.0038	0.0027
Ciphered 10 keys	-0.00005	0.0074	-0.0153
Ciphered 20 keys	-0.018	0.0241	-0.0095
Ciphered 30 keys	0.0084	-0.0284	-0.0367
Ciphered 40 keys	0.0112	0.0034	0.0178
Ciphered 50 keys	0.018	-0.0031	0.0029

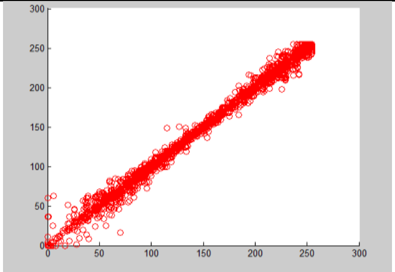
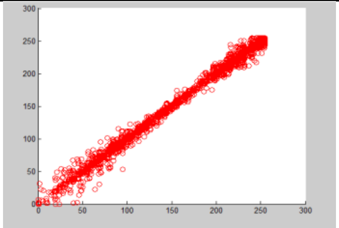
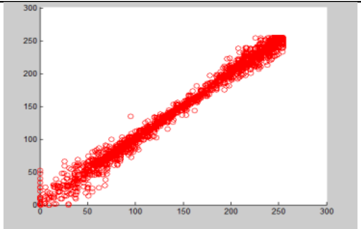
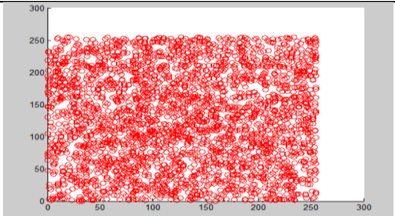
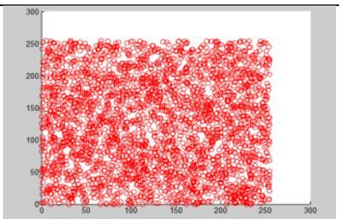
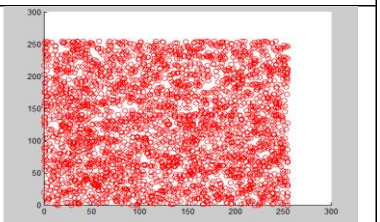
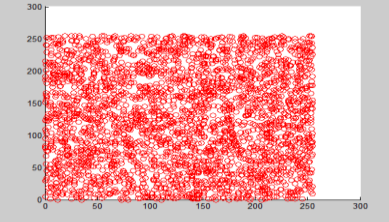
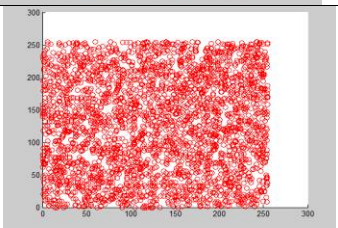
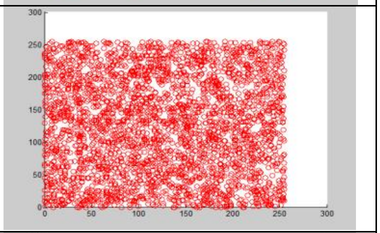
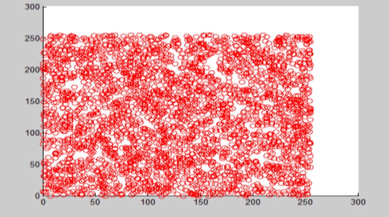
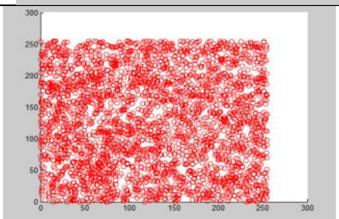
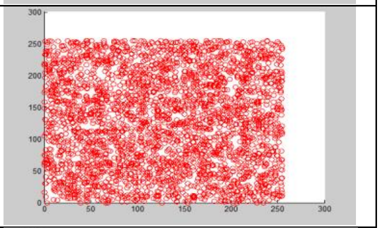
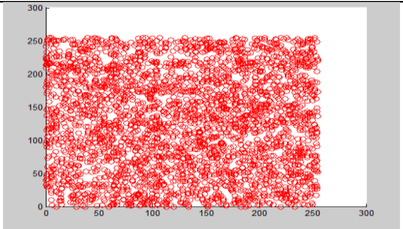
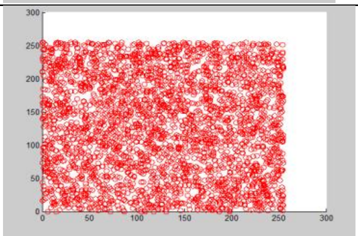
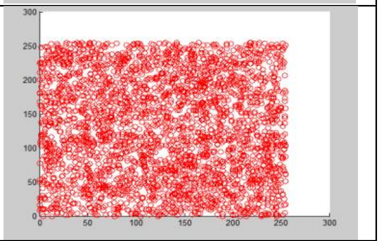
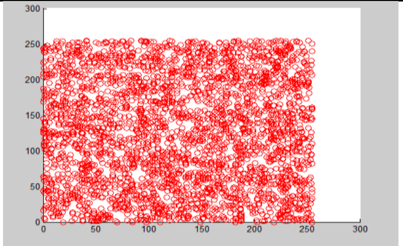
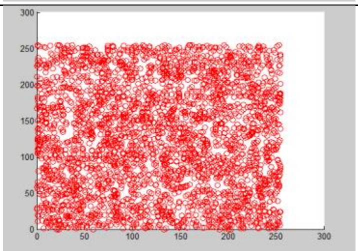
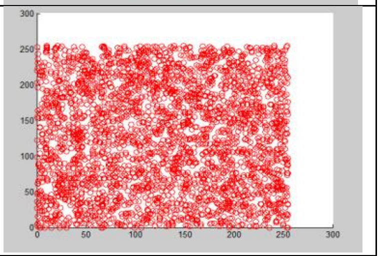
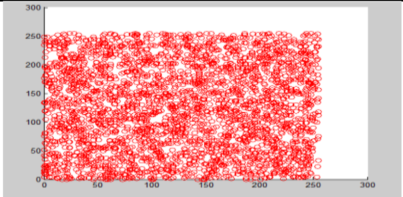
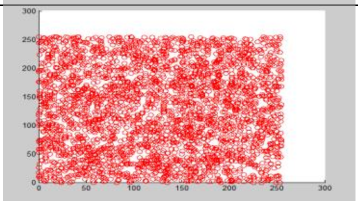
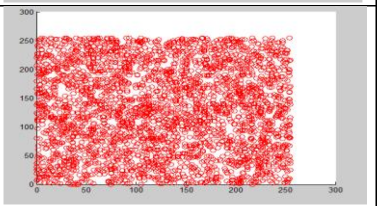
Image name	Red _horizontal	Red _vertical	Red _diagonal
Original Sun			
Ciphered 1 key			
Ciphered 10 keys			
Ciphered 20 keys			
Ciphered 30 keys			
Ciphered 40 keys			
Ciphered 50 keys			

Figure 6. Correlation in Red channel of original and encrypted(Sun) image with different number keys

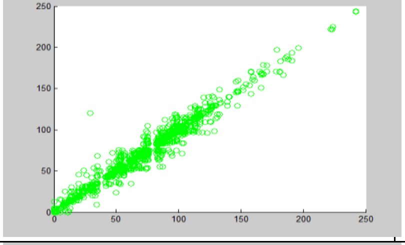
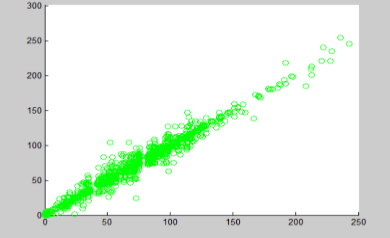
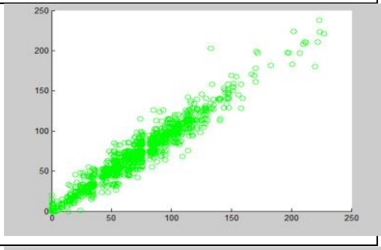
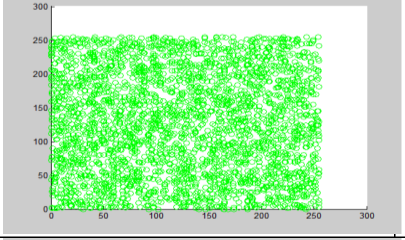
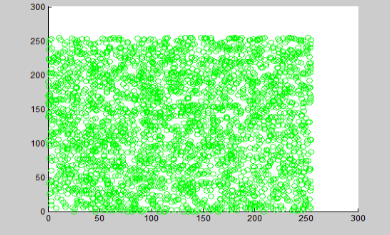
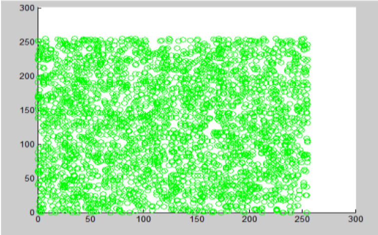
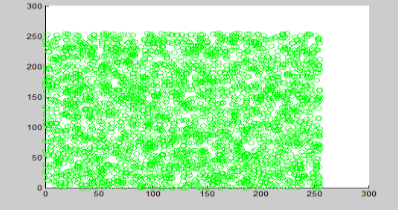
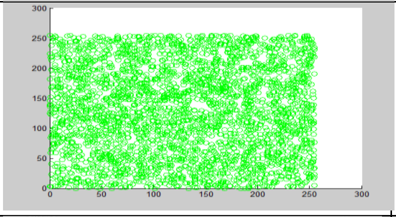
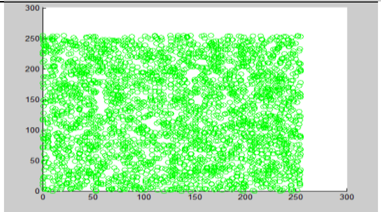
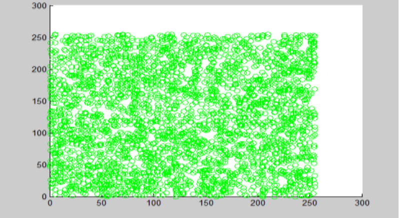
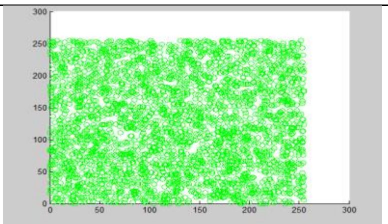
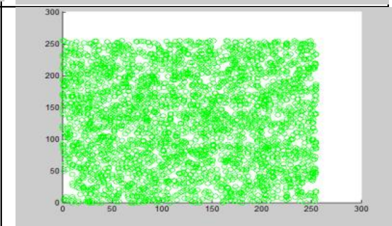
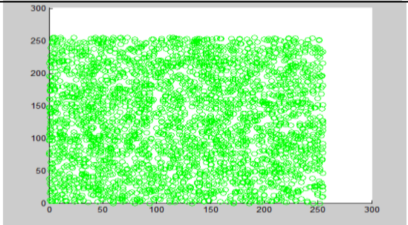
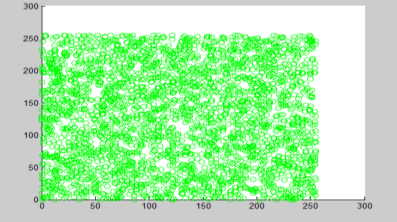
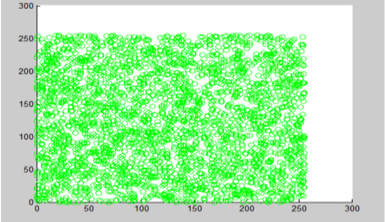
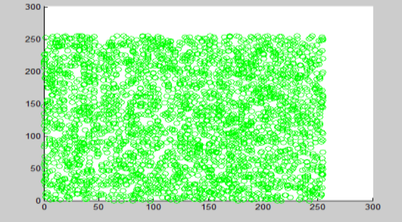
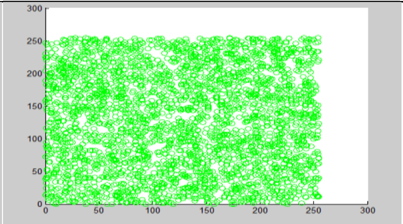
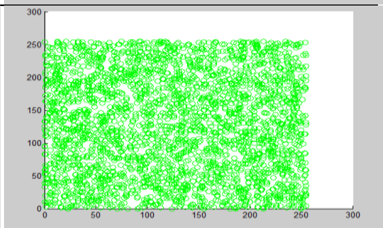
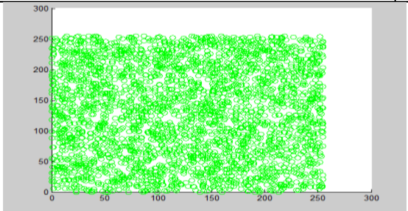
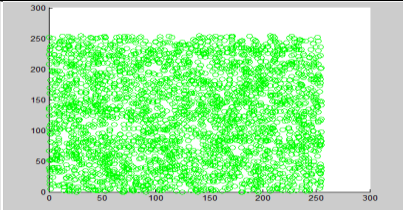
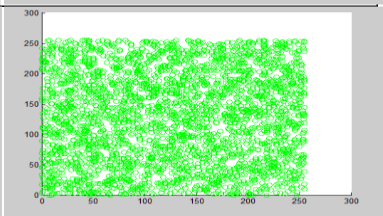
Image name	**Green_ horizontal**	**Green _vertical**	**Green _diagonal**
Original Sun			
Ciphered 1 key			
Ciphered 10 keys			
Ciphered 20 keys			
Ciphered 30 keys			
Ciphered 40 keys			
Ciphered 50 keys			

Figure 7. Correlation in Green channel of original and encrypted (Sun) image with different number keys

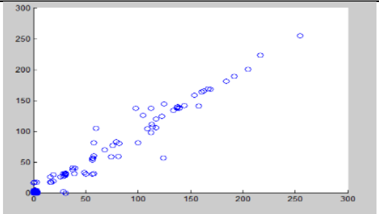
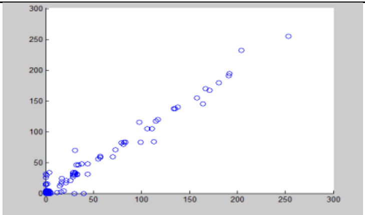
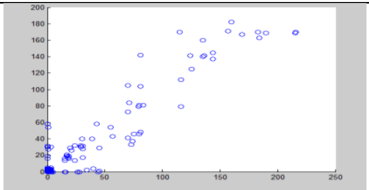
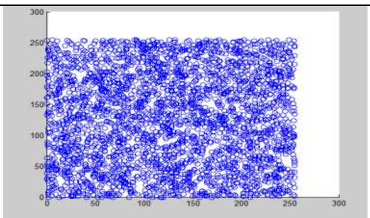
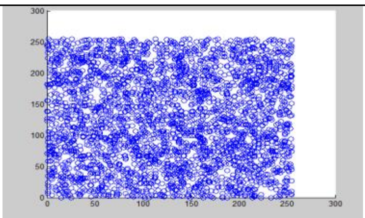
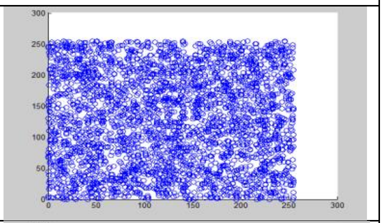
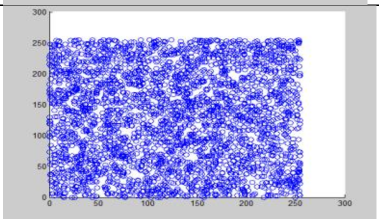
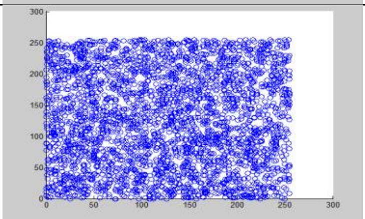
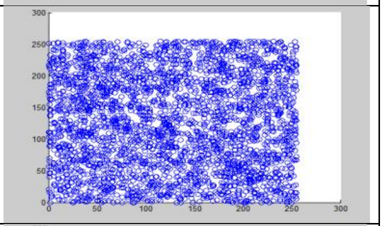
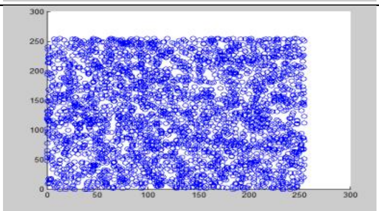
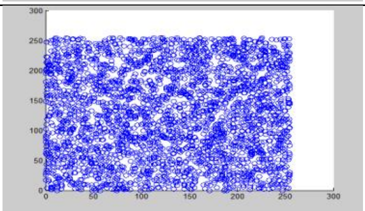
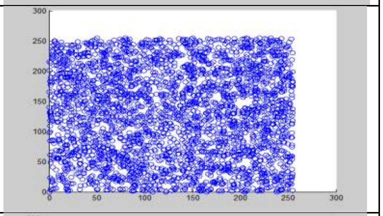
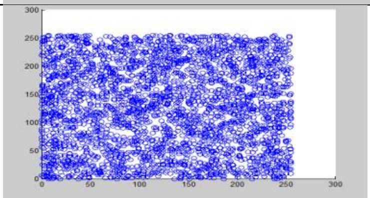
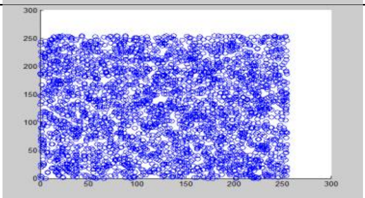
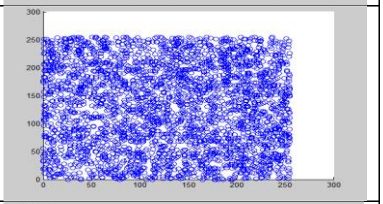
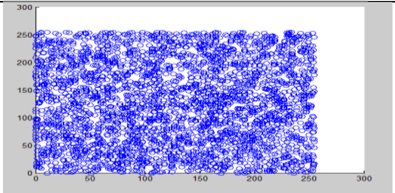
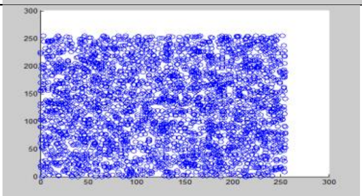
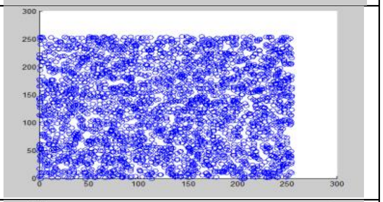
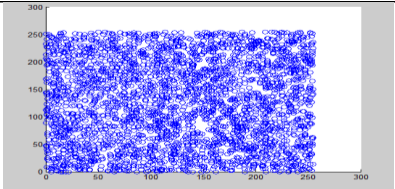
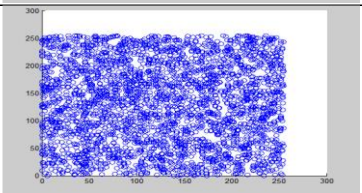
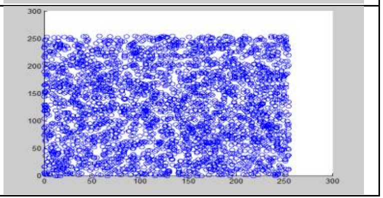
Image name	**Blue_ horizontal**	**Blue _vertical**	**Blue _diagonal**
Original Sun			
Ciphered 1 key			
Ciphered 10 keys			
Ciphered 20 keys			
Ciphered 30 keys			
Ciphered 40 keys			
Ciphered 50 keys			

Figure 8. Correlation in Blue channel of original and encrypted (Sun) image with different number keys

Conclusion:

It is concluded that the standard encryption method which has been proposed to enhance image security and integrity which uses multiple keys proved that security is increased throughout using entropy, MSE, PSNR and correlation. Also it is concluded that the accuracy of transmitted image increases by using this approach which is lossless thus the decrypted image is the identical to the original image. At the end, the suggested MECC_AES will be perfect and appropriate to be used for securing image in a widespread range of visual applications in IoT.

As mentioned above, the limitation of this work is that it will be used in IoT technologies that use or have the ability to use AES algorithm for security, thus, there are IoT technologies that need lightweight security scheme. The future work is using MECC-AES technique in parallel mode to enhance power consumption and using MECC with lightweight encryption algorithms.

Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Babylon.

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تحسين امنية الصورة في انترنت الاشياء(IoT) باستخدام AES متعددة المفاتيح

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الخلاصة:

الصورة هي معلومات رقمية مهمة تستخدم في العديد من تطبيقات إنترنت الأشياء (IoT) مثل النقل والرعاية الصحية والزراعة والتطبيقات العسكرية والمركبات والحياة البرية .. إلخ. كذلك تتميز الصورة بسمات مهمة جدًا مثل الحجم الكبير والارتباط القوي والتكرار الهائل وبالتالي تشفيرها باستخدام معيار التشفير المتقدم (AES) بمفتاح واحد من خلال تقنيات اتصالات إنترنت الأشياء تجعله عرضة للعديد من التهديدات. مساهمة هذا العمل هي لزيادة أمن الصورة المنقولة. لذلك اقترحت هذه الورقة خوارزمية AES متعددةالمفاتيح (MECCAES) لتحسين الأمان للصورة المرسلة من خلال إنترنت الأشياء. يتم تقييم هذا النهج من خلال تطبيقه على صور RGB bmp وتحليل النتائج باستخدام المقاييس القياسية مثل الإنتروبيا(Entropy) ،المدرج التكراري (histogram)، الارتباط(correlation) ، مقاييس نسبة الذروة للأشارة إلى الضوضاء (PSNR) ومتوسط مربع خطأ (MES). تظهر نتائج التجارب أن الطريقة المقترحة تحقق مستوى عالي من السرية كما أنها واعدة باستخدامها بشكل فعال في مجالات واسعة من تشفير الصور في إنترنت الأشياء.

الكلمات المفتاحية :معيار التشفير المتقدم ،غير متماثل، التشفير ، انترنت الاشياء، تشفير منحني الاهليجي المتعدد، الصور الملونة(RGB)، متماثل، الأمنية,WiFi, WiMAX.