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Chaos Encryption and Coding for Image Transmission over Noisy Channels

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Abstract: *The security and reliability of image transmission over wireless noisy channels are a big challenge. Ciphering techniques achieve security, but don't consider the effect of errors occurring during wireless transmission. Error correction coding techniques must be used with ciphering to improve reliability and throughput. We propose a combined ciphering and coding scheme based on the modified chaotic Logistic map with Low Density Parity-check Coding (LDPC) as an error correction coding technique to overcome the limitations of wireless channels due to the factors that affect transmission such as noise and multipath propagation. The experimental results show that this combined scheme enhances the performance parameters such as Peak Signal-to-Noise Ratio (PSNR) and Bit Error Rate (BER)and achieves both security and reliability in image transmission through the wireless channel*

Keywords: *Chaos, Filter, Image, LDPC, Logistic map*

I. Introduction

Two important issues are needed for the unbounded nature of the wireless communication channel. The first issue is the security of data transmission, where the unconstrained environment of wireless channel increases the illegal data access. So, a robust ciphering technique is essential to protect data from attackers. In the case of traditional image encryption schemes such as Data Encryption Standard (DES) [1] and Advanced Encryption Standards (AES) [2], wireless communication becomes prohibited due to the long processing time. Chaos image encryption algorithms have shown better performance in image than the traditional encryption schemes [3]. Chaotic systems meet the main encryption requirements such as diffusion and confusion [4]. Many chaotic maps are used for image encryption, such as Logistic and Henon maps [5]. The old Logistic map is one of the simplest functions of the chaotic system. Mathematically, a Logistic map has the form [6]:

$$x_{n}=rx_{n-1}(1-x_{n-1}) \qquad (1)$$

Where xn is a number between zero and one, n is the iteration number, r is the chaotic range, $r\in[0, 4]$, and x0 is the initial value.

The second issue of wireless transmission is the reliability. In addition to security considerations, data must be transmitted correctly without errors. There are many factors that cause errors such as attenuation, nonlinearities, bandwidth limitations, multipath propagation, and noise [7]. To improve the throughput in noisy environments, channel coding is performed after ciphering techniques. The basic block diagram of image transmission is shown in Fig. 1

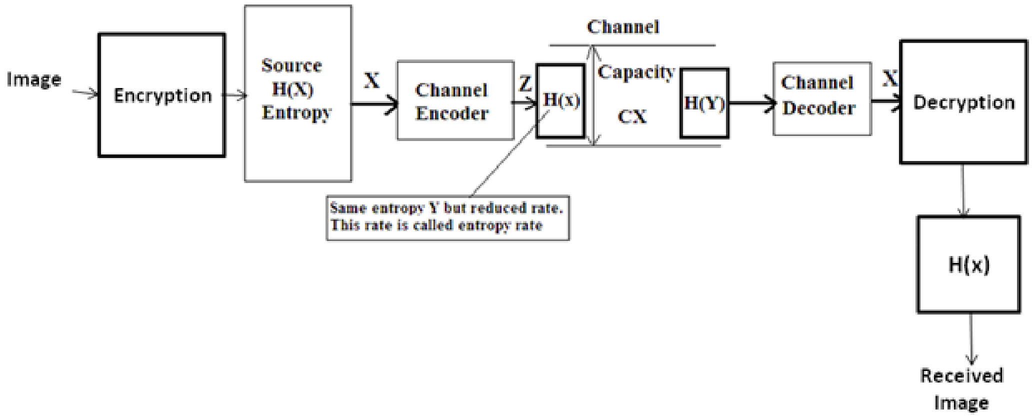


Fig. 1 The basic block diagram for image transmission

The Entropy is the expected value of the information contained in a message measured in bits and the channel capacity is the maximum average amount of information that can be sent per channel. According to Shannon theory, it is possible to transmit information over the channel reliably (with probability of error $\rightarrow 0$) if and only if the entropy rate (R) is less than or equal to channel capacity $R \leq CX$[8]. We can reduce the entropy of data by adding redundant symbols. This is the key idea of channel coding. We added redundant bits using a coding algorithm so that we reduce the information of the source and make it able to pass the channel with very low probability of lost information.

Channel codes are generally divided into block codes such as LDPC codes [9] and convolutional codes such as Turbo codes [10]. In block codes, the information sequence is broken into blocks of length k and each block is mapped into channel inputs of length n. This mapping is independent of the previous blocks. In convolutional codes, there exists a shift register. The information bits enter the shift register at a time and then the output bits, which are linear combinations of various shift register bits are transmitted over the channel [11]. In our case, we will concentrate on the block codes.

The proposed combined ciphering and coding scheme for image transmission is based on the modified Logistic map as a ciphering technique for security and LDPC code as a coding technique for reliability.

II. Related Work

In order to achieve information security with a ciphering scheme, an errorless input to the decryption process is necessary. Error correction codes are necessary to handle a certain amount of errors in the input data, but these codes are not designed to provide any security of the data. However, there are many cases, in which both information security and error-correction are needed. Some researchers have studied the combination of security and the error correction codes in one algorithm to secure transmission of images over wireless networks [12-14].

In [12], a modified wireless image transmission scheme that combines chaotic encryption based on a two-dimensional chaotic map and turbo coding technique into one processing step is introduced. In [13],a joint optimization framework of Rijndael cipher and modulation with the use of Forward Error Correcting (FEC) codes to protect encrypted packets from bit errors is proposed. In [14], a combination of cryptographic algorithms and an error correction code is evaluated over an Additive White Gaussian Noise (AWGN) channel. It is realized by AES-Turbo. AES was chosen for the encryption and decryption process, and turbo codes for encoding and decoding. According to the general perspective of the system, the turbo encoder block is embedded in the AES encryption block in the first round after the subbytes block. The remaining steps of the AES encryption are normal. In the decryption phase, the turbo decoder block is embedded in the AES decryption block in the last round before subbytes block.

In the proposed combined ciphering and coding scheme, we will use LDPC codes for error correction. The question now is, Why LDPC? Since 1993, with the invention of turbo codes, researchers have switched their focus to finding low complexity codes that can approach Shannon channel capacity. Unlike many other classes of codes, LDPC codes are already equipped with very fast (probabilistic) encoding and decoding algorithms. New analytic and combinatorial tools make it possible to solve the design problem. This makes LDPC codes not only attractive from a theoretical point of view, but also perfect for practical applications [15]. The feature of LDPC codes to perform near the Shannon limit of a channel exists only for large block lengths [16]. For example, there have been simulations that perform within 0.04 dB of the Shannon limit at a Bit Error Rate (BER) of $10{-}6$ within Shannon limit block length of 107, see Fig. 2 [17].

In addition, LDPC codes have certain advantages over some of the best known codes like turbo codes. Some of the advantages of LDPC codes may be summarized as follows [18]:

1. They do not have low-weight codewords.
2. They are iteratively decoded with lower complexity.
3. Their error floor occurs at a much lower BER.
4. Their decoding is not trellis based, so they have small delay.
5. They can have very high rates, maximizing information rate (channel usage).

6. They have an excellent error performance; LDPC codes can operate within 0.0045dB away from the Shannon limit [19], whereas the recently discovered turbo codes can operate within 0.25–0.5 dB away from the Shannon limit.

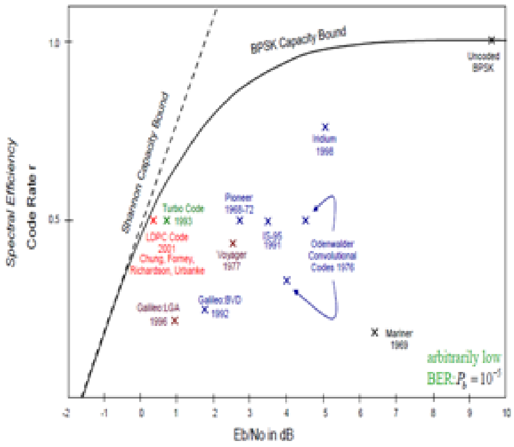


Fig. 2 Power efficiency of standard binary channel codes [17].

III. Comparison Between LDPC And Turbo Codes

Now, we will compare between the performance of LDPC and turbo codes in BER to determine the best for use in the proposed algorithm. We will use the two codes with the parameters shown in Table1.

Table 1. Simulation parameters of the comparison between LDPC and Turbo codes.

Code Rate	½
Block length	512 bits
Modulation	Binary Phase Shift Keying (BPSK)
Channel	Additive White Gaussian Noise (AWGN)
Signal-to-Noise Ratio (SNR) dB	From 0 to 4

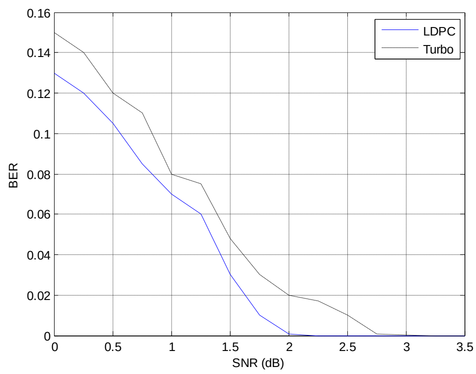


Fig. 3 BER versus SNR of the received Cameraman image with Turbo and LDPC codes.

From the simulation results shown in Fig. 3, it is clear that, theLDPC code achieves a smaller BER than the turbo codeat the same values of SNR.So that,it is preferable to use the LDPC as an error correction code in the proposed scheme.

IV. Pefrormance Evaluation Parameters

First, to measure the image quality, we must study some performance evaluation parameters such as the Peak Signal-to-Noise Ratio (PSNR). PSNR is used as a quality measure between the original and the reconstructed images. The greater the value of the PSNR, the better the quality of the proposed scheme. The PSNR for an m x n gray-scale image is defined via the Mean Square Error (MSE) as:

$$PSNR = 10log_{10}\frac{255^2}{MSE} \qquad (2)$$

$$MSE = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M \times N} \quad (3)$$

where I1represents the original image matrix and I2 represents the image matrix of the reconstructed image.

Bit Error Rate (BER) is another parameter to quantify the reliability. BER determines the reliability of the entire radio system from “bits in” to “bits out”, including the electronics, antennas and signal path in between. The BER can be defined as [20]:

$$\text{BER} = \frac{\text{Number of bits in Errors}}{\text{Total Number of Bits}} \quad (4)$$

V. The Ciphering Scheme

The proposed ciphering scheme is based on the modified chaotic Logistic map developed to increase the range of r to be from 0 to 13.8. The modified chaotic function is [21]:

$$x_n = r x_{n-1}(1 - x_{n-1})(1 - x_{n-1})(1.2 - 2x_{n-1})(1.2 - 2x_{n-1}) \quad (5)$$

The bifurcation diagram of the modified Logistic map illustrates xn versus the parameter r and determines the chaotic range of the map. It is found that when $r \in [6.1, 13.8]$, the modified Logistic map exhibits chaotic behavior and depends crucially on the initial conditions as shown in Fig 4.

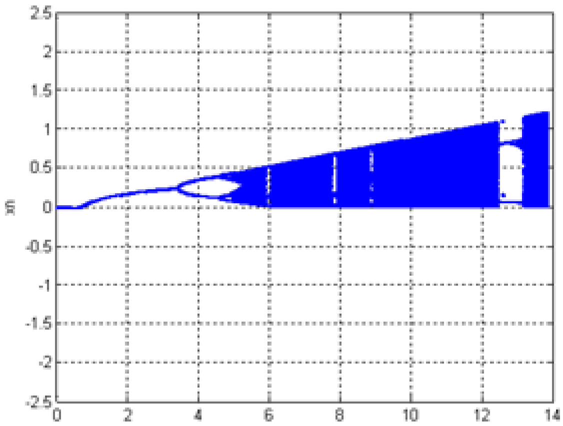


Fig. 4 Bifurcation diagram of the modified Logistic map.

For a gray-scale image of size M×N, we use a 1-D lexicographically-ordered vector im = { im1 , im2 , … , imL }, where L= M×N. Given the initial value of the modified Logistic map x0 =0.02 and the chaotic parameter r=10, the modified Logistic map uses the plain image to generate the current chaotic number, and then takes the generated chaotic number as the next input of the chaotic iterations. This process is repeated and the last output value is used as the initial key. This key is used to encrypt the image. By doing so, the correlation between the initial key and the plain image is created. The encryption can be described as follows:

Step 1: For n =1,iterate the modified Logistic map using Eq. (5) for only one time to get x1
Step 2:Modify x1 according to the following equation
$x_1 = \text{mod}\ (x_1 + (im_1 + 1)/255, 1)$ (6)
Step 3: For n =n+1 return to step 1 until n=L to get xL.
Let the new initial value of the Logistic map be (x0+xL)/2
Step 4: Iterate the modified Logistic map using Eq. (5) for L times with the new initial value. Then, we obtain the sequence
$X = \{x_{L+1}, x_{L+2}, \ldots, x_{2L}\}$ (7)

Step 5: To get the sequence K= {k1, k2,…,KL}:
$k_n = \text{mod}(\text{floor}(x_{L+n} \times 10^5), 256)$ (8)

where $n = 1, 2, \ldots$

Step 6: Examine the randomness of the sequence kn

H = runstest(kn) (9)

By using the Matlab function (runstest) for randomness,H returns (0) if the sequence is random and (1) if not. In our case H=0

Step 7: Compute the first cipher pixel by using the value of im1, the constant c and the first key k1

$c_1 = k_1 \oplus \mathrm{mod}(i$

Step 8: Let n=n+1

Step 9: Compute the nth pixel of the cipher image using the following equation in which the cipher output feedback is introduced

$c_n = k_n \oplus \mathrm{mod}(im_n + im_{n-1}, 256)$ (11)

Step 10: Repeat step 8 and step 9 until n reaches L, then the cipher image C= {c1, c2,…,cn} is obtained.

VI. Performance And Security Analysis

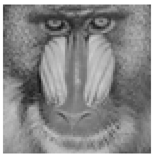
6.1 Key Space Analysis

In the proposed ciphering algorithm, the secret key depends on three independent variables = {x0, r, c}, x0 and rare double precision numbers, c is a constant integer, c ∈[1, 255]. The numbers for x0 and r are more than 1014. So, the key space is bigger than (1014x1014x 255). This big key space can resist brute-force attack.

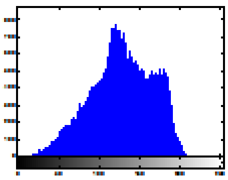
6.2 Statistical Analysis

6.2.1 Histogram

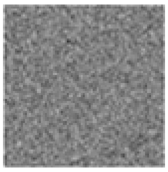
The histogram of the encrypted image for the proposed ciphering algorithm is fairly uniform and significantly different from that of the original image.



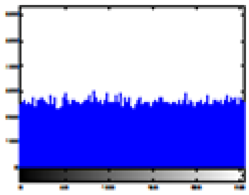
The original image.



The histogram of the original image.



The encrypted image



The histogram of encrypted image.

Fig. 5 Mandrill image encryption and histogram.

6.2.2 Correlation Of Two Adjacent Pixels

For a plain image, adjacent pixels have a large correlation. For a cipher image, the correlation between pixels should be as small as possible. To test the correlation between two adjacent pixels in the plain and cipher images, randomly select s pairs of two adjacent pixels (in vertical, horizontal and diagonal directions) from plain and cipher images and calculate the correlation coefficient (cc) of each pair [22]. Our experimental results show very small values of (cc), which means an excellent encryption process, see Table 2.

Table 2. Correlation coefficient of two adjacent pixels in the plain and cipher image.

Image	Horizontal	Vertical	Diagonal
Mandrill plain image	0.8908	0.8549	0.8152
Mandrill cipher image (Proposed Algorithm)	0.0007	0	0

6.3 Sensitivity Analysis

6.3.1 Differential Attack Analysis

In general, the encrypted image must be sensitive to small changes in the plain image and secret key. In order to avoid differential attack, small change in the plain image or secret key should cause a significant change in the encrypted image. Two parameters were used for differential analysis: Net Pixel Change Rate (NPCR) and Unified Average Changing Intensity (UACI) [23]. NPCR measures the number of pixels change rate of encrypted image, while one pixel of plain image is changed. UACI measures the average intensity of the differences between the plain image and the encrypted image. Table 3 shows the values of NPCR and UACI between encrypted images with keys (x0, r) and another one with a slightly different key (x0 +Δx0, r+Δr). Our results show that more than 99% of the pixels in the encrypted image change their gray values, when the key just changes by 10-10. This means that the proposed algorithm provides high key sensitivity.

Table 3. NPCR and UACI between cipher images.

Image	Keys	NPCR	UACI
Mandrill	$\Delta x_0=10^{-10}$, $\Delta r=0$	99.60%	33.35%
	$\Delta x_0=0$, $\Delta r=10^{-10}$	99.60%	33.35%

6.4 Time Complexity Analysis

The proposed algorithm uses only one round for diffusion operation, and so this reduces the computational complexity and hence the scheme is practicable in a wireless environment. All the simulation experiments have been carried out with MATLAB R2007a on windows XP system with a laptop computer having Intel Core 2 Duo Processor 1.6 GHz, 2 GB RAM, and 150 GB Hard Disk. We used the Mandrill image with 256 × 256pixels as the plain image. The processing time of the encryption / decryption process is 17.55 seconds.

VII. Low Density Parity Check Code

LDPC is a linear error correcting code used to transmit data over a noisy channel. LDPC transmits information reliably at rates close to Shannon's limit. LDPC is applied in some modern applications such as 10GBase-T Ethernet, Wi-Fi, WiMAX and Digital Video Broadcasting (DVB).The property of linearity in LDPC means that the sum of any two codewords is also a codeword. Linear block codes are summarized by their parameters, where k is the number of information bits and n is the number of code bits. The entropy rate R(code rate) is equal to k/n. LDPC can be specified by generating a Sparse Parity-Check Matrix H. Sparse means that the number of ones per column is very small compared to the numbers of zeros.

7.1 Channel Encoder (LDPC)

Given a codeword u and an M x N parity check matrix H, we have [24]:

u.HT=0 (12)

In our case, the code rate is 0.5, the codeword is 512 bits and the H matrix is 512 x 1024. Assume that the message bits, s, are located at the end of the codeword and the check bits, c, occupy the beginning of the codeword i.e.

u= [c|s] (13)

Also, let,

H= [A|B] (14)

where A is an M x M matrix and B is an M x N-M matrix

Using Eqs.(13) and (14) in (12), we get

Ac + Bs = 0 (15)

c=A-1Bs (16)

Given the received codeword y, the syndrome vector is

z = y× H (17)

If z = 0, then the received codeword is error-free, else, the value of z is the position of the flipped bit. For more details about LDPC coding and decoding, readers can refer to [9].

VIII. Noise Reduction Filters

Noise reduction filters are mainly used for smoothing the image such as a conservative smoothing filter, main filter and median filter. Conservative filter is designed to remove noise spikes and is less effective in removing Gaussian noise. Mean filter replaces each pixel value in an image with the average value of its neighbors. The main problems in mean filter are that, for any unrepresentative value of image pixel, it significantly affects the mean value of all the pixels in its neighborhood. The other problem is the edge blurring.

The best choice of our case is the median filter. Hence, instead of simply replacing the pixel value with the mean value; it replaces it with the median of neighboring values. The median is calculated by first sorting all the pixel values from the surrounding neighborhood into numerical order and then replacing the pixel being considered with the middle pixel value.

IX. The Proposed Scheme

We introduce a new scheme for secure image transmission over noisy channels. It combines ciphering and coding in one algorithm as follows: at the transmitter, the image is encrypted using a key related to the plain image. Then; the encrypted image is coded using LDPC code for channel coding. The encrypted encoded image is modulated using BPSK modulation. The resulting image is then transmitted via AWGN channel. At the receiver, the reverse process is done such that the image is demodulated, decoded and decrypted to obtain the reconstructed image, which can be passed through a median filter to reduce the noise as shown in Fig. 6.

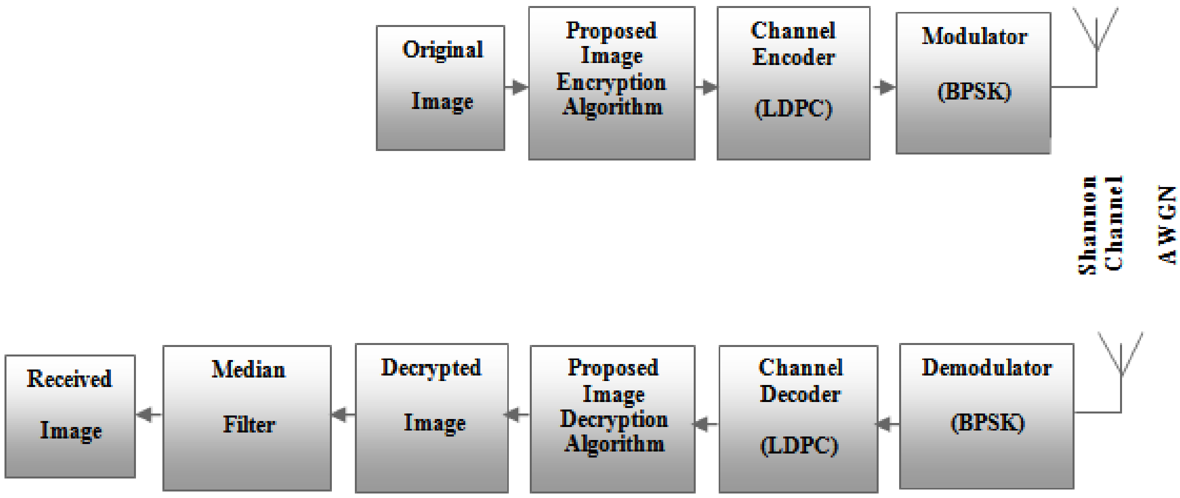


Fig. 6 Basic block diagram of the proposed scheme.

X. Simulation Results

The performance of the proposed combined ciphering and coding scheme for image transmission through AWGN channel has been demonstrated under the simulation parameters shown in Table 4. The result of the combination of different encryption algorithms and LDPC can be shown in the following subsections.

Table 4 The simulation parameters of the proposed scheme.

Image	Cameraman
Ciphering	Modified chaotic Logistic map
Coding	LDPC Code Rate = ½ Block length = 512 bits
Modulation	BPSK
Channel	AWGN
Filter	Median filter
SNR (dB)	From -5 to 2.75

10.1 Peak Signal-To-Noise Ratio

The simulation results show that the proposed combined ciphering and coding scheme has higher values of PSNR than the combined LDPC with RC6 and with old Logistic map at all values of SNR. The proposed scheme is very sensitive to the change in the SNR; small changes in SNR achieve large changes in PSNR. When SNR =2.31 dB, the PSNR of the proposed scheme reaches infinity, and this means that the reconstructed image is identical to the original image. See Table 5 and Fig. 7.

10.2 Bit Error Rate

To demonstrate the quality of transmission with the proposed scheme, BER should be measured. BER is computed after decoding with SNR variation. The results show that the BER of the proposed scheme has too small values at small SNRs, SNR ϵ [0, 2], BER tends to zero at SNR = 2.31dB. This means an error-free transmission and that the image is reconstructed without distortion. Then, we do not need to retransmit the image again. Therefore, the proposed combined ciphering and coding scheme increase the throughput of the system, see Table 5 and Fig. 8.From these results, it is clear that the proposed combined ciphering and coding scheme gives the best results compared with LDPC with RC6 and with old Logistic map.

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Table 5 The simulation results of the combination of different encryption and LDPC.

SNR	RC6		Old Logistic Map		Proposed Algorithm (Modified Logistic Map)		
	PSNR	**BER**	**PSNR**	**BER**	**PSNR**	**PSNR after Median filter**	**BER**
-5	7.7139	0.29586	5.3456	0.2999	8.1145	10.7282	0.28592
-4	7.751	0.28191	5.3789	0.2876	8.1234	10.763	0.26217
-3	7.7504	0.27526	5.4237	0.2789	8.1945	10.6912	0.23572
-2	7.7407	0.26566	5.5356	0.2687	8.2345	10.6944	0.20596
-1	7.7692	0.21161	5.5777	0.2134	8.2976	10.6263	0.1718
0	7.7438	0.13986	5.5824	0.13917	8.3519	10.6285	0.12927
0.5	7.7787	0.12209	5.5824	0.12235	8.3793	10.5868	0.10042
1	7.8767	0.12062	5.5831	0.120501	8.3941	10.5391	0.057903
1.5	8.2147	0.115583	5.5912	0.116426	8.4921	10.83	0.0154
2	8.3334	0.1111234	5.6061	0.112417	8.5537	10.939	0.001655
2.25	8.3335	0.11131662	5.6068	0.112417	16.7873	18.1258	0.00011063
2.26	8.3214	0.11114687	5.6068	0.112417	19.4636	20.4636	0.00011063
2.27	8.3216	0.11116594	5.6068	0.112417	25.352	27.3956	7.6294e-005
2.28	8.3232	0.11117166	5.6068	0.112417	35.9487	37.9183	6.8665e-005
2.29	8.3319	0.1111545	5.6068	0.112417	50.241	52.0523	7.2479e-005
2.30	8.3343	0.11196785	5.6068	0.112417	71.824	73.955	7.0572e-005
2.31	8.3355	0.11127466	5.6068	0.112417	Inf	Inf	0
2.5	8.3275	0.11117466	5.6108	0.116426	Inf	Inf	0
2.75	8.3275	0.11117466	5.6111	0.116426	Inf	Inf	0

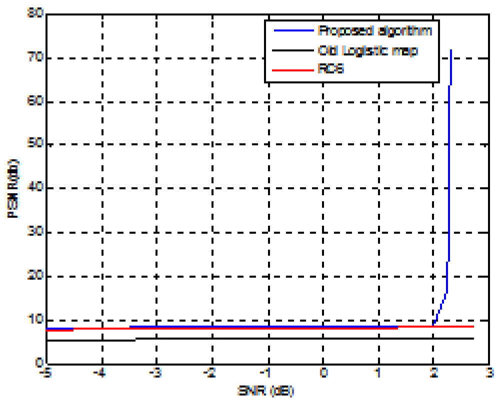


Fig. 7 PSNR versus SNR of the proposed algorithm, old Logistic map and RC6.

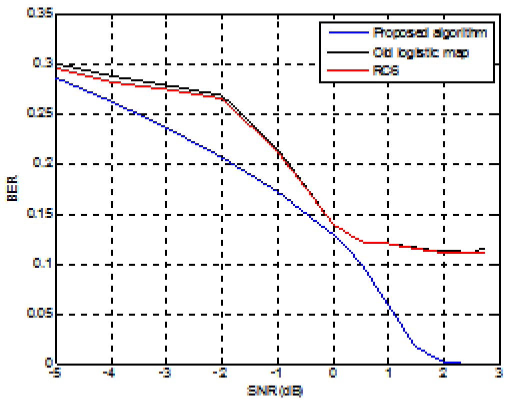
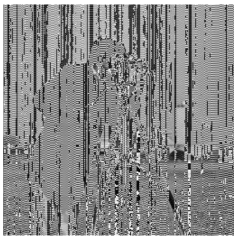
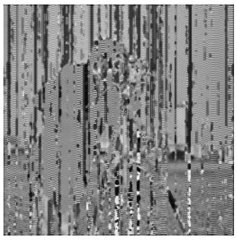


Fig. 8 BER versus SNR of the proposed algorithm, old Logistic map and RC6.

10.3 The Reconstructed Image Of The Proposed Scheme

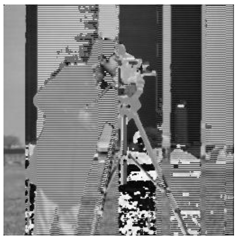
Fig. 9 gives the reconstructed images of the proposed combined ciphering and coding scheme at different values of SNR over AWGN channels before and after the median filter. As shown, a small change in SNR yields high quality in the reconstructed image. In addition, the median filter enhances the PSNR.

Before median filter. After median filter.

SNR=1
PSNR=8.3941 dB

SNR=1
PSNR=10.5391dB

SNR=2
PSNR=8.5537 dB

SNR=2
PSNR=10.939 dB


SNR=2.25
PSNR=16.7873 dB

SNR=2.25
PSNR=18.1258 dB


SNR=2.26
PSNR=19.4636 dB

SNR=2.26
PSNR=20.4636 dB


SNR=2.27
PSNR=25.352 dB

SNR=2.27
PSNR=27.3956 dB

SNR=2.31
PSNR=Inf

SNR=2.31
PSNR= Inf

Fig 9 The reconstructed image of the proposed scheme before and after the median filter.

XI. Conclusion

We proposed a scheme for the combination of image encryption and error correction coding. The proposed scheme combines image encryption based on modified chaotic Logistic map, and error control coding based on LDPC channel coding, and it uses median filtering. Simulation results show that the proposed scheme enhanced the performance parameters and achieved both security and reliability of image transmission through the wireless noisy channel. A comparison between the proposed scheme using the modified Logistic map, using the old Logistic map and the RC6 showed that the proposed scheme has a higher PSNR and lower BER than the other schemes. The proposed scheme is suggested for secure image transmission over wireless channels. A future work is needed to develop an optimization scheme to simulate the real wireless channel such as fading model and study the security and error correction schemes for wireless image transmission.

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