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Performance of spectrum sharing cognitive radio network based on MIMO MC-CDMA system for medical image transmission

B. Rammyaa[1] · **K. S. Vishvaksenan**[2] · **Sumathi Poobal**[3]

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Abstract Cognitive radio (CR) is a futuristic technology which efficiently uses the underutilized TV band spectrum for mobile communication. The spectrum scarcity issue, mobile traffic due to ever-increasing number of clients utilizing the same spectrum and interference problems will be efficiently handled by CR networks. In this paper, we employ CR spectrum for safe transmission of medical reports consisting of magnetic resonance imaging (MRI) scanned images. An effective image encryption algorithm named Arnold cat-map (ACM) transform is used in order to prevent unauthorized alterations in the MRI scanned image by any un-authenticated personnel. Further, we upgrade the resolution of the MRI scanned image by super-resoluting it by SPARSE super-resolution technique. Furthermore, we analyze the transmission of MRI scanned image by considering turbo code as channel encoder. We incorporate space time block code (STBC) as multiple-input and multiple-output (MIMO) profile due to its supremacy in spatial diversity and code division multiple access (CDMA) for simultaneous data transmission to numerous users, for transmission of the MRI scanned report. We utilize CR sub-band frequency to realize multi-carrier (MC) communication and to generate orthogonal spread-spectrum. Furthermore, we also analyse the error rate performance of the system for various Stanford University Interim (SUI) channel models. Finally, from the simulations we divulge that CR defined MIMO MC-CDMA system obtain MRI image with enhanced resolution and upgraded privacy when communicating through realistic channel model specifications.

Keywords Code division multiple-access (CDMA) · Multi-carrier modulation (MCM) · Multi-user interference (MUI) · Multiple input multiple output (MIMO) · Turbo decoder

1 Introduction

Cognitive radio (CR) is an enabling technology for next generation wireless systems. Cognitive radio networks leverage the underutilized spectrum and effectively share the spectrum among the licensed and un-licensed users. It adapts to the current situation according to the information monitored and acts instantly without any delay. The applications involving surveillance systems, public safety and emergency communications, intelligence systems etc use CR networks.

In [1], the authors propounded an algorithm for cognitive radio which operates in mobile cellular environment. The algorithm was also pertinent to multiple secondary user scenario. In the performance investigation, TV white space channel (TVWS) was compared with sensing error probability. The results showed a significant improvement in throughput.

In [2], the authors designed a framework that employs CR in Time domain-long term evolution (TD-LTE) system that uses TVWS. They also analysed their performance in TV

✉ B. Rammyaa
rammya.ece@kcgcollege.com

K. S. Vishvaksenan
vishvaksenan2000@rediffmail.com

Sumathi Poobal
vpacad@kcgcollege.com

[1] Department of EIE, KCG College of Technology, Chennai, India

[2] Department of ECE, SSN College of Engineering, Chennai, India

[3] Department of ECE, KCG College of Technology, Chennai, India

system enabled with and without CR function. The former showed negligible performance loss on comparison with the latter. The results showed improvement in performance when TV acts as the primary user and TD-LTE acts as the secondary user.

In [3], the authors formulated a novel structure for non-contagious (NC)-multi-carrier (MC) code division multiple access (CDMA) system that operates in CR networks. It was shown from the simulation results that the proposed NC-MC-CDMA system reduces the burden in downlink path by minimizing the complexity of the receiver. Also, it solves the coding problem in hadamard codes and mitigates ISI thus enhancing the performance of the system.

The authors in [4], designed a CR based direct sequence MC-CDMA system that works along with several other narrowband networks under the same frequency band. This system effectively combats the interfering effects at the receiver. The authors also made a comparison between MC-CDMA and CR enabled MC-CDMA system and concluded that the latter yields robust performance and high reliability.

The authors in [5], analysed the outage capacity and outage problem of CR in co-operative relaying networks under Rayleigh fading conditions. The suggested system showed significant enhancement in terms of performance in co-operative relays.

The authors proposed an integrated hybrid MC CDMA system in [6], which maintains the orthogonality between the overlay and underlay approach. As both the techniques are amalgamated, the spectrum is being utilized in a better manner and the gain ascribed to diversity is improved.

In order to solve the problem of non-orthogonality, which persists in secondary users in CR networks, the authors in [7] introduced a complex Carrier Interferometry (CI) code, which effectively mitigates the interferences by total interference cancellation. The results also showed superior error rate performance by furnishing MMSE algorithm.

The authors devised a CR in [8], which could effectively work in mobile environment. The proposed CR is a spectrally modulated spectrally encoded (SMSE) overlay in software defined radio environment. Such system can sense the sub-carrier availability and thus regulates the transmission and also reduces the interference issues.

The authors in [9] investigated the problem of the spectrum admittance between the licensed and unlicensed consumers, targeting the same band. An algorithm was developed to solve the spectrum allocation issue and it was shown that the algorithm gives close to ideal results and also minimizes the complexity of the system.

Resolution enhancement plays a vital role in image reconstruction sector. There is an undeniable need for resolution enhancement in medical imaging systems. Even minuscule of details of the image is important because it ensures correct diagnosis and treatment offered to the patients. So, super resolution (SR) is performed in medical images in order to improvise the resolution.

The authors in the paper [10], suggested SPARSE representation as a super-resolution (SR) technique. Here, the images are reduced into patches and a dictionary is formulated. With the aid of SPARSE representation, from the low resolution (LR) input, high resolution (HR) output is generated. The aforementioned method generates images with enhanced quality in terms of resolution on comparison with other techniques.

In the paper [11], the authors introduced a novel technique named single-image SR. The SR is made possible by using single LR image. The algorithm works in two phases training and SR phase. All the image patches are collected in the first phase. The LR image compares itself with all the patches, stores it in the training set and the patch satisfying the criteria gets selected and finally SR is performed correspondingly. This method protects and enhances even the minute details present in the image.

Medical imaging systems play a major role in diagnostics and treatments offered to the patients. The delivery of such medical imaging reports like magnetic resonance imaging (MRI) scans, ultra-sound scans etc. are mostly done through wireless systems or cloud computing. So, the privacy of the images must be protected in order to avoid any intruders from altering the images via various attacks like static attacks, geometric attacks, cryptographic attacks etc. Image encryption is an effective approach for ensuring security to the images.

In [12], the authors analyzed the performance of chaos based ACM encryption algorithm. The potential flaws are corrected and security is upgraded in ACM algorithm.

The authors in [13] used an encryption scheme which is a combination of ACM and a set of random strategies, so that the intruder would find it difficult to crack all the strategies. This method ensured a good improvement in security of the images.

The researchers proposed an approach in [14], for colour image encryption by employing ACM and logistic chaotic map. In this approach, ACM transform and confusion process takes place simultaneously, thus protecting the system from various types of attacks.

The implementation of spatial diversity can improve the reliability in transmission. This is accomplished by space time block code (STBC) multiple-I/P and multiple-O/P (MIMO) architecture which is clearly elucidated by Alamouti [15]. One of the essential attributes of STBC is its orthogonal principle [16], which makes the detection process simpler. Also, the performance of correlated Nakagami fading channels with STBC system is evaluated. Further, the performance of STBC in flat fading channel is analysed and improvement is done by joint estimation scheme in [17,18]. The literatures [19–23], deals with the performance parameters of STBC system in a variety of channels like Stanford

University Interim (SUI), LTE etc. at varied channel conditions.

From the techniques inferred from the above literatures, resolution enhancement is exerted by sparse SR, ACM is employed for the process of encryption, the spectrum utilized for the entire process is CR spectrum. We use turbo coded STBC MIMO-CDMA system for efficient and reliable transmission of images.

Further the paper is organized in the following format:

- Initially, a basic overview of the paper and the mathematical theory behind the whole process is stated in Sect. 2.
- The depiction of the simulation results and performance discussion is illustrated in Sect. 3.
- Finally, the Sect. 4 gives the conclusion of the proposed work.

2 Mathematical background

An overview of the entire process is depicted in the transceiver representation of secured transmission of super-resoluted image through cognitive radio network as shown in Fig. 1. We assign secondary user dynamic CR Spectrum having bandwidth of 54–648 MHz .We allocate the frequency from each sub-band of CR spectrum with channel spacing of 6 MHz to carry out MC modulation.The MRI scanned medical image is the input image. The resolution of the MRI scanned image is enhanced by SR technique.

2.1 Resolution enhancement

Resolution enhancement is done by implementing SPARSE SR technique. The first step in SPARSE SR method is the formation of dictionary, followed by training the dictionary elements. The dictionary is basically formed by dividing the image into subsequent patches. Such patches are further classified into HR patch and LR patch respectively. These patches form their corresponding HR and LR dictionary.

The HR and LR images are assumed as A_h and B_l while a_h and b_l represent their corresponding patches. The HR dictionary D_{hr} is formed by using a_h and the LR dictionary D_{lr} is formed by using b_l. Thus a couple dictionaries are formulated from which D_{hr} patches can be obtained from D_{lr} patch and vice-versa. The SPARSE co-efficient is denoted by β and the dictionary to be trained is indicated by $\bar{D}$.

After forming the couple dictionary, a process called dictionary learning is executed. This process takes place in two steps. In the first step, the dictionary is kept fixed while the

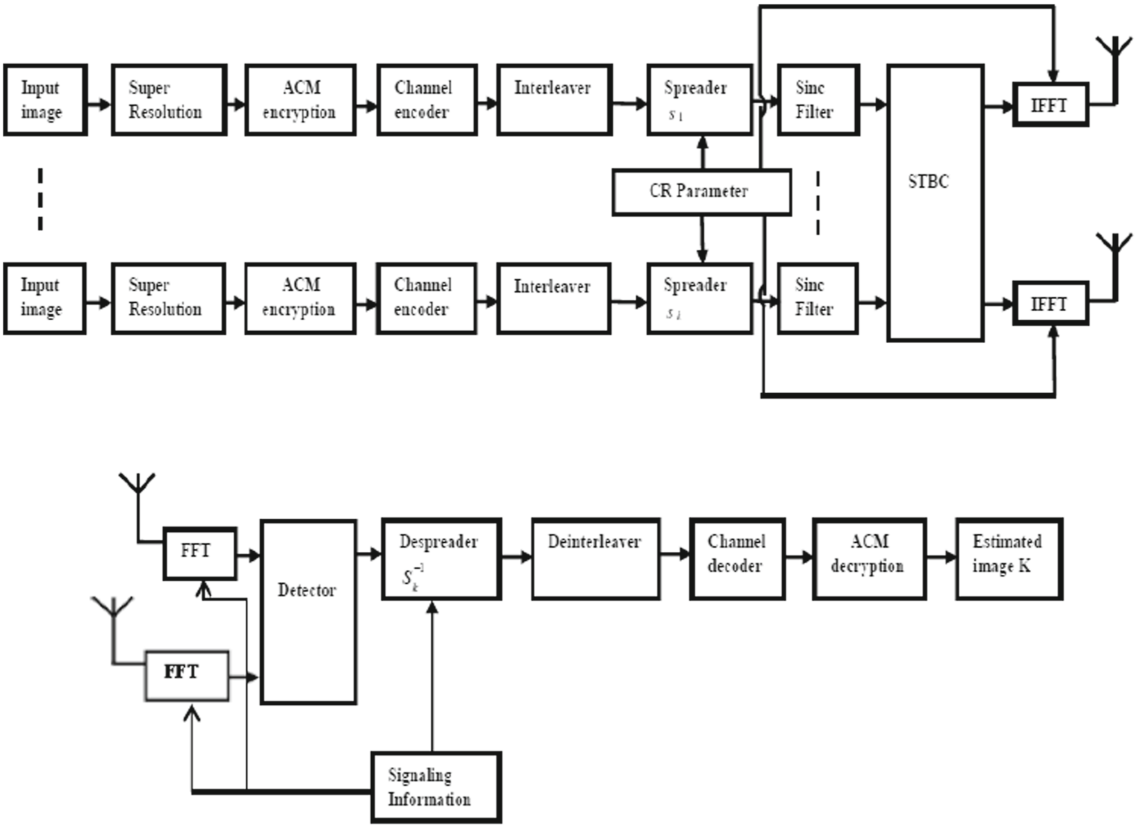

Fig. 1 Transceiver structure of CR enabled STBC-CDMA system with resolution and security enhancement for downlink transmission

sparse co-efficient β is updated. The second step involves keeping β as fixed, while the dictionary is updated. Since we need to do SR, the HR image patches training is realized. The dictionary training and optimization is materialized as explained by authors in [10].

Let us assume that the training be

$$A_h = \{a_{h1}, a_{h2}, a_{h3}, \ldots a_{hn}\} \tag{1}$$

$$\bar{D} = \boldsymbol{arg}\ \underset{\bar{D},\beta}{\boldsymbol{min}} \left\| A_h - \bar{D}\beta \right\|_2^2 + \lambda \left\| \beta \right\|_1$$

$$\text{s.t.} \left\| \bar{D}_k \right\|_2^2 \leq 1, k = 1, 2, \ldots, K \tag{2}$$

The optimization process for dictionary training includes the following steps

1. The dictionary $\bar{D}$ has to be initialized and each column is unit normalized.
2. The dictionary $\bar{D}$ must be kept fixed, while updating β.

$$\beta = \arg \underset{\beta}{\boldsymbol{min}} \left\| A_h - \bar{D}\beta \right\|_2^2 + \lambda \left\| Y \right\|_1 \tag{3}$$

3. Similarly, β is kept fixed, while updating the dictionary $\bar{D}$.
4. Many iterations are carried out till convergence.

Finally, HR image is reconstructed from LR image patches and super-resoluted medical image is obtained. Thus, SR is achieved by SPARSE technique.

2.2 Security enhancement

The security of the image is enhanced by enforcing any image encryption scheme to the medical image. The ACM transform algorithm [12] is an effective encryption procedure for safe image transmission. Now the super-resoluted image is encrypted by ACM algorithm. The position of the pixels is shuffled in a sequential manner. The transform is done using the mathematical formula given below

$$\Gamma \begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} p+q \\ p+2q \end{bmatrix} \bmod n \tag{4}$$

Here, (p, q) indicates the initial position of the pixels. The process of encryption happens by shuffling these pixel positions. This is done by substituting the initial pixel positions (p, q) to the formula in (1). On substituting the pixel position values, the new position of the pixels will be obtained. So this leads to entire shuffling of pixels of the entire image, so that the image will not be viewed by any intruders. Thus encryption is achieved by ACM and the privacy of the images is highly protected.

2.3 System configuration

After the process of SPARSE super-resolution followed by ACM encryption, the image is transmitted through the wireless channel. The pixels are converted into bits and it is encoded by channel encoder. The encoder used is a parallel type with concatenated transmission of bits. The bit steam after the coding process is expressed as,

$$\boldsymbol{x}_k = [x_{k1}, x_{k2}, \ldots, x_{km}]^T \quad k = 1, 2, \ldots, K \tag{5}$$

where, $\boldsymbol{x}_k$- Bit stream after encoding, $\boldsymbol{m}$- No. of bits, k - No. Of users

Then it gets interleaved and the bits are evenly spread out in a fashion to combat source data corruption, thus preventing the system from any deep error burst [11–14]. The nature of the spreader used here is consumer specific .Then the signal is passed through pulse shaping filter. We choose ***Sinc*** filter as pulse shaping filter which is non-causal filter and has linear phase characteristic. This process is explained in detailed in the upcoming equations:

$$\mathbf{c}_k = \frac{1}{\sqrt{N}} \left[c_{k0}, c_{k1}, \ldots, c_{k(N-1)} \right]^T \tag{6}$$

where,

$\boldsymbol{c}_k$- orthogonal spreading code for k^{th} user.

N - length of spreading sequence.

$$\boldsymbol{C}_k = diag\,\{\boldsymbol{s}_k, \boldsymbol{s}_k, \boldsymbol{s}_k, \ldots, s_k\}$$

$$= \boldsymbol{I}_m \otimes \boldsymbol{S}_k,\ k = 1, 2, \ldots, K \tag{7}$$

where,

$\boldsymbol{C}_k$ - spreading matrix for k^{th} user.

$Nm \times m$ - dimensions for the spreading matrix.

The obtained sequence is filtered by S*inc* filter .Finally we sum all the spread sequence signals and is expressed as,

$$\boldsymbol{Y} = \sum_{k=1}^{K} \boldsymbol{C}_k \boldsymbol{x}_k \tag{8}$$

This summed sequence enters the STBC MIMO profile which works by offering both transmit and receive diversity. At each time instant, the transmission of data takes place in a particular sequential manner to confirm diversity. At the time instant t_1 $\left[y_1 \ y_2 \right]^T$ gets transmitted and at the consecutive time instant t_2, $\left[-y_2^* \ y_1^* \right]^T$ is transmitted. Then we carry out multi-carrier modulation

For our analysis, we model the impulse response of the channel that connects the secondary users and BS as

Table 1 Channel model parameters

Path number	SUI-1 channel model	
	Delay (μs)	Power (dB)
1	0	0
2	0.4	– 15
3	0.9	– 20
Doppler frequency	0.5 Hz	
Antenna correlation	0.7	

Table 2 Simulation parameters

Parameters	Attributes
Modulation technique	BPSK
No. of transmit antennas	2
No. of receive antennas	2
Channel model	SUI
Channel coding	Turbo coding
Channel decoder	Iterative log MAP decoder

frequency-selective with multi-path propagation. To be precise, we design the channel model based on the Standard University Interim (SUI) channel specifications.The channel model parameters is listed in Table 1. To realize the multi-path propagations, the channel matrix connecting the j^{th} receive antenna and the i^{th} transmit antenna is represented as

$$\boldsymbol{h}_{ji}(t) = \sum_{l=1}^{L} h_{ji}^{l} \partial(t - \tau_l) \tag{9}$$

where L - No. of paths connecting jth-receive antenna with ith- transmit antenna

On the receiver side, we obtain R which is $\boldsymbol{N}_2 \times 2$ component matrix. After multi-carrier demodulation using FFT, the compact form of the acquired matrix is represented as,

$$\boldsymbol{R} = \bar{\boldsymbol{H}}\boldsymbol{Y} + \eta \tag{10}$$

where,

$\bar{H}$ - Impulse response matrix of the channel.

Y - Transmitted data or image, with the dimension of $\boldsymbol{N}_t \times 2$.

η - Noise parameter due to sum of AWGN channel and primary-MUI (P-MUI) users obtained at the receiver, with the dimension of $\boldsymbol{N}_r \times 2$.

The transmitted bit stream is estimated using maximum likelihood detection algorithm [16,23].Then the estimated sequence is de-spread and de-interleaved .Consequently,we execute the decoding process with the help of an iterative turbo decoder [21,23]. Finally, the MRI medical scanned image is decrypted and the SR image with better clarity is estimated at the receiver. Thus our considered CR MC-CDMA system obtain image with high resolution and enhanced privacy protection at the receiver when communicating through the multi-path wireless channel.

3 Simulation results and performance discussion

In this section, we present performance curve and MRI images at various stages for our coded CR MC-CDMA system .For our analysis, we implement CR spectrum having the frequency-range of 54–648 MHz. For our analysis, we presume that each sub-band frequency is having channel bandwidth of 6 MHz.We simulate the performance for SUI-1 channel specifications . Further, we have tested the results for 25,000 channel realizations for each SNR. We study the results considering BPSK modulation technique.We describes the simulation parameters in Table 2. We have simulated the graph using MATLAB tool.

The results obtained during each stage of the entire transmission process through CR aided STBC-CDMA system is depicted in Fig. 2. Here, the MRI-1 is the ultra-sound scanned image of foetus. The original MRI-1 has a peak-signal-to-noise ratio (PSNR) of 60.647. The MRI-1 after resolution enhancement has an improved PSNR of 74.881. Now the next image MRI-2 is the scanned image of brain tumour. The input image has a PSNR = 58.72, while the PSNR of MRI-2 after SR = 72.667. MRI-3 is the scanned image of benign brain tumour with input PSNR = 61.442 and PSNR after SR = 78.472. The scanned image of the cell infected by cancer is shown in MRI-4. The PSNR of input = 65.224 and MRI-4 with SR has a PSNR = 79.175. Finally the last scanned image is denoted as MRI-5. This has an input PSNR of 56.428 and PSNR of 73.956 after SR.

The initial image Fig. 2a, is the input MRI scanned medical image which we have to resolute and encrypt for safe transmission. The next stage is where resolution enhancement is done by sparse SR. From the Fig. 2b,we infer that the resolution of the image is improved after SR process. Then the encryption process is carried out by ACM. The positions of the pixel are shuffled and the encrypted image is shown in Fig. 2c. Finally, Fig. 2d shows the decrypted image. So, from Fig. 2 we discern that, medical image with better resolution is acquired while also maintaining its privacy.

Figure 3 depicts the performance evaluation graph for the CR based coded STBC aided MIMO MC-CDMA system through SUI-1 channel model [24]. From the graph, we observe that in order to produce BER of 10^{-5}, we require signal to noise ratio of 4 dB for CR enabled coded MIMO MC-CDMA system.Further,we discern from the results that our considered system achieves better results while obtaining higher data rate with less signal-to-noise ratio.

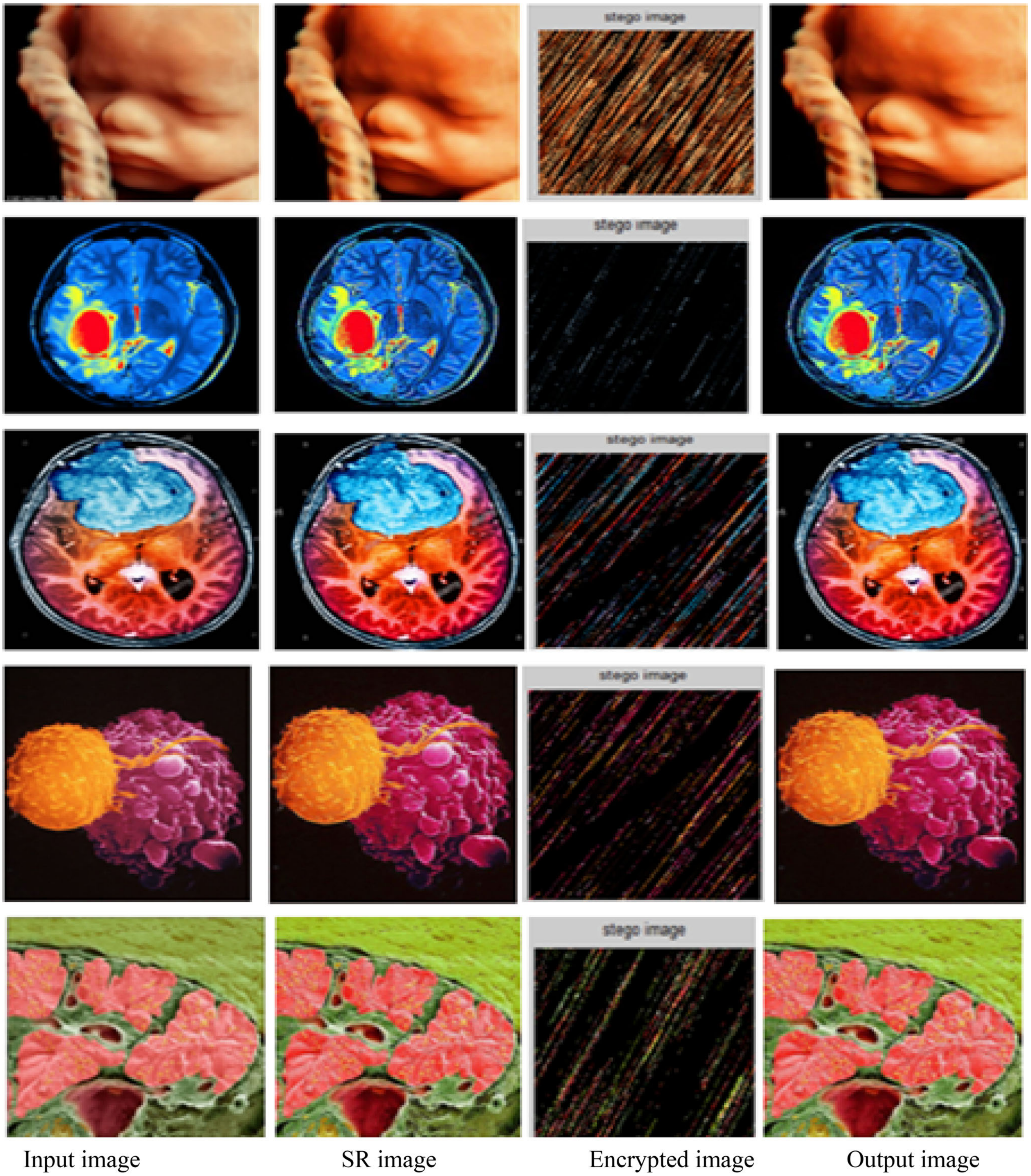

Fig. 2 Simulation results for resoluted and secured transmission of scanned images MRI-1, MRI-2, MRI-3,MRI-4, MRI-5 at various stages through CR enabled STBC-CDMA system: **a** input image, **b** super-resoluted image, **c** ACM encrypted image and **d** final decrypted output image

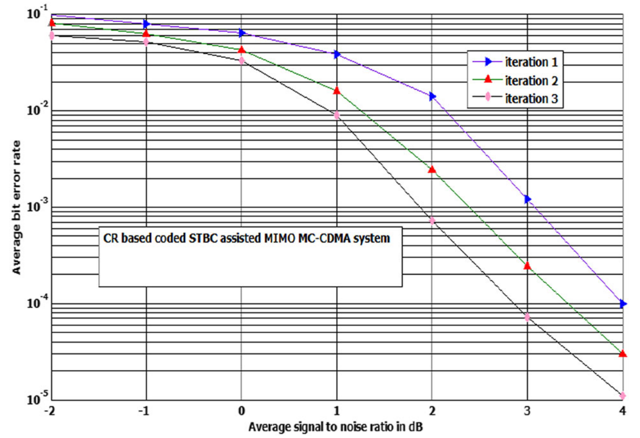

Fig. 3 Performance evaluation graph of CR based coded STBC aided MIMO MC-CDMA system through SUI-1 channel model

4 Conclusion

In this article, we analyzed the performance of medical image transmission for CR MIMO MC-CDMA system in the context of DL transmission. We accomplished unused TV band spectrum for medical image transmission. We established link between base station and secondary users using cognitive network environment considering frequency allocation for various users and sub-band formation and analyzed the performance in terms of error probability for coded MIMO MC-CDMA system. It is observed that ACI and S-MUI along with P-MUI hosts error-floor in cognitive environments. Further, we noticed that coded CR MIMO MC-CDMA system with super resolution block obtain better picture quality in the presence of the above mentioned interferences while retaining higher data rate. Furthermore, coded system with iterative decoder obtain better error-rate results with less Signal-to-noise ratio .We clinched that we can meet the demand of higher spectral efficiency by exploring the availability of unused cognitive radio spectrum.

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B. Rammyaa Assistant Professor, Department of Electronics and Communication Engineering is working in KCG College of Technology, Chennai. She received the B.E. degree in Electronics and Communication Engineering from the Hindusthan College of Engineering and Technology, Coimbatore, India and M.E., in Applied Electronics from Arunai Engineering College, Tiruvannamalai, India. Her research interest includes Wireless communication, Mobile Ad hoc networks and Sensor Networks.

K. S. Vishvaksenan received M.S. degree (System software) from Birla institute of Technology and Science, Pilani, Rajasthan, India in 1997. He obtained M.E. degree and Ph.D. degree from College of Engineering, Guindy, Anna University, Chennai, India in 2007 and 2013 respectively. He authored or co-authored 30 IEEE International conferences and 20 International journals. His research field includes MIMO detection, Antennas design, iterative receiver algorithm, multi-user communications, transmitter preprocessing techniques and Co-operative communication.

Dr. Sumathi Poobal Professor, Department of Electronics and Communication Engineering is working in KCG College of Technology, Chennai since 1998. She worked as teaching and research fellow at College of Engineering, Guindy, Chennai. She received B.E. (ECE), M.E. (Applied Electronics) from College of Engineering, Guindy, Chennai in 1983 and 1989 respectively. She has been awarded Ph.D. in the field of Medical Image Processing,Anna University, Chennai in 2009. She is the coordinator of innovation and entrepreneurship centre funded by DST, India, at KCG College of Technology, Chennai. She has more than 25 years of experience in teaching, industry and research. Her research interests are Digital image processing, VLSI Design.