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Research Article

Improved Energy Detection in MIMO-OFDM Cognitive Radio Systems using Physical Layer Security based Space-Time Block Coding Technique

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ABSTRACT

Spectrum Sensing (SS) is the challenging component for Cognitive Radio (CR) systems, allowing the utilization and detection of underutilized frequency bands. The assessment of Energy Detection (ED) effectiveness is employed in a relation to prominent communication technology according to Multiple-Input Multiple-Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) transmissions. However, noise instability, unavoidable noise variation which exists in any communication link, significantly minimizes the output of ED, particularly when the signal-to-noise ratio (SNR) is deprived. Hence, this research proposes the Physical Layer Security (PLS) based Space-Time Block Coding (STBC) for the coding process in MIMO-OFDM based CRN. PLS-STBC enhances the reliability of data transmission through using various antennas to design redundant copies of the transmitted signal. This redundancy supports in addressing the effects of fading and interference, which are common in wireless channels. Thus, this research determined an influence of Noise Uncertainty (NU) disparities as well as Dynamic Detection Threshold (DDT) adjustments on detection probability for different phases of false alarm probability. The experimental results shows that the proposed PLS-STBC approach attains the probability of detection of 0.96 at ρ =1.03, ρ' =1.05 at Pfa is fixed to 0.5 for 2×2 MIMO-OFDM.

Keywords: Cognitive Radio, Energy Detection, Multiple-Input Multiple-Output, Orthogonal Frequency Division Multiplexing, Physical Layer Security based Space-Time Block Coding and Spectrum Sensing.

1 INTRODUCTION

In recent days, the developing the wireless communication system has enhanced the demand for greater system capability through pampering in 5G mobile communication network technologies [1]. Cognitive Radio Network (CRN) has been introduced to enhance an insufficient spectrum utilization. In CRN, the different types of users are involving like Primary Users (PUs) as well as Secondary Users (SUs) [2]. CR allows the SU to employ Dynamic Spectrum Access (DSA) in epochs, while the PU lack of utilizing a spectrum. PU most often have a priority while manipulating the enthusiastic certified spectrum and the SU utilize the certified bands and it lack of impacting the interface with PU [3][4]. Hence the significant aim of the DSA in CRN is to enhance the effectiveness of spectrum utilization. Spectrum Sensing (SS) is a crucial purpose of the CRN, which allows the users in CRN to known the environmental data as well as accessibility of the spectrum [5]. The Energy Detection (ED) is the most common approach in SS, which is local non-cooperative method and lack of demanding the prior information to the features of the PU signal. The spectrum sensing takes care about the energy usage of the CR in the promising technology is called energy harvesting in CRN [6][7].

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As associated to the additional bulging local SS approaches, ED has the minimum implementation and computational complexity [8]. Nevertheless, an ED is penetrating to the fluctuations in noise power, maximum energy consumption, minimum data transmission, minimum Signal-to-Noise Ratio (SNR) value and diminishing, particularly in areas with the large population densities [9]. Hence, the effectiveness of the ED is constrained through the noise power dissimilarities, commonly called Noise Uncertainty (NU) [10][11]. Though in communication systems, the Orthogonal Frequency Division Multiplexing (OFDM) system enhances the spectral effectiveness as well as robustness over the Inter-Symbol Interface (ISI), whereas, Multiple-Input Multiple-Output (MIMO) system enhances a system capability as well as its dependability [12][13]. An NU challenges an efficient determination of the channel tenancy when Dynamic Detection Threshold (DDT) is performed in MIMO-OFDM system [14]. Through designing the large number of antennas at receivers, massive MIMO is capable to intensely enhance the spectral efficiency to the additional degree of freedom in a spatial domain [15]. However, noise instability, unavoidable noise variation which exists in any communication link, significantly minimizes the output of ED, particularly when the SNR is deprived. The important contributions of this research are listed as following.

- This research proposes the Physical Layer Security (PLS) based Space-Time Block Coding (STBC) for the coding process in MIMO-OFDM based CRN.
- An achievement of an obvious systematic mathematical modelling for the ED performance estimation procedure by Sparse Learning-based Clustering (SLC) method influenced through NU as well as DT adjustments in MIMO-OFDM CR systems.
- A simulation approach for an execution of ED procedure through manipulating the SLC approach in MIMO-OFDM CR systems which influenced through various levels of DT adjustments as well as NUs.

The rest of the paper is organized as follows: Section 2 surveys the existing works related to ED and SS in MIMO-OFDM. Section 3 highlights the proposed methodology. Section 4 presents the results and discussion and Section 5 describes the conclusion of the paper.

2 LITERATURE SURVEY

In this section, the existing works related to ED and SS in CRN for MIMO-OFDM are surveyed. Furthermore, this section discusses the advantages and limitations faced through the existing works in MIMO-OFDM.

Ivana Ramljak *et al.* [16] presented a SLC approach for the parameters valuation of efficiency of ED process in MIMO-OFDM systems which influenced through NU adjustments and variation of DDT. The SLC approach allows the process of ED valuation simulation in SISO and MIMO-OFDM systems. The mathematical modelling was introduced to determine relationship among PU detection probability and to describe the important ED parameters. However, the presented approach does not inherently compensate for multipath fading effects, which can lead to inaccurate energy detection.

Josip Lorincz *et al.* [17] introduced the SLC approach for the analysis of the effectiveness of ED SS with the DT based on NU adjustments in MIMO-OFDM based CRN. The mathematical modelling of significant parameters was utilized for an estimation of ED effectiveness in the constrained SS approach. Furthermore, the approach for pretending an ED in adaptable operating environments considered through the effect of the various levels of NU as well as DT adjustments were introduced. However, The SLC approach involves operations like squaring and summing the received signal's amplitude from each antenna, which can be computationally intensive, especially in systems with a large number of antennas.

D. Raghunatha Rao *et al.* [18] presented the Gannet Optimization Algorithm (GOA) approach for enable the SS in OFDM based CR systems. The test statistics generation like signal energy, wavelets, Eigen statistics and matched filter were performed to make sure the effective CR communication without an interface. Moreover, the fusion centre experiences the fusion process, at which the weights were determined through the presented GOA as well as final decision was processed. The GOA effectively enabled the exploitation phase to make sure the better solution to estimate the weight vector. However, the presented GOA approach was difficult to navigate the optimization landscape, leads to suboptimal detection performance.

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Mustefa Badri Usman *et al.* [19] implemented an Additive White Gaussian Noise (AWGN) model with the help of false alarm probability, detection, as well as miss detection probability. The simulation plots of AWGN were helped to improvise the spectrum sensing at lower SNR. The entropy approach utilized in this research was based on the discrete Gaussian distribution function due to its ability of energy measurement ratio. The efficiency of the suggested framework was based on SNR and the probability of a false alarm rate. However, the randomization of threshold values tended to diminish the efficiency of detecting false alarm rates.

Arun Kumar *et al.* [20] developed the Deep Learning (DL) approach of Convolutional Neural Network (CNN) and Recurrent Neural Network (RNN) for the SS in CRN. Furthermore, the SS performance of the RNN was explored, especially for the processing time-series data. The RNN was ability to capture the temporal dependencies in the sequential data, which was important for SS operation where the signals evolved over the time. However, RNNs was struggle with scalability, particularly when dealing with large-scale spectrum data or networks with many users and channels, limits their applicability in extensive CRN.

From this section, some of the limitations have been identifies such as lack of inherent compensate for multipath fading effects, computationally intensive, randomization of threshold values tended to diminish the efficiency of detecting false alarm rates and limits their applicability in extensive CRN. Hence, this research proposes the PLS-STBC for the coding process in MIMO-OFDM based CRN.

3 PROPOSED METHODOLOGY

In this research, the PLS-STBC coding technique is proposed for the SS and ED in MIMO-OFDM CRN. Figure 1 depicts the block diagram of the proposed PLS-STBC method in MIMO-OFDM. This research comprises of two significant steps such as system design of the analysis of the ED operation and encoding and decoding using PLS-STBC technique.

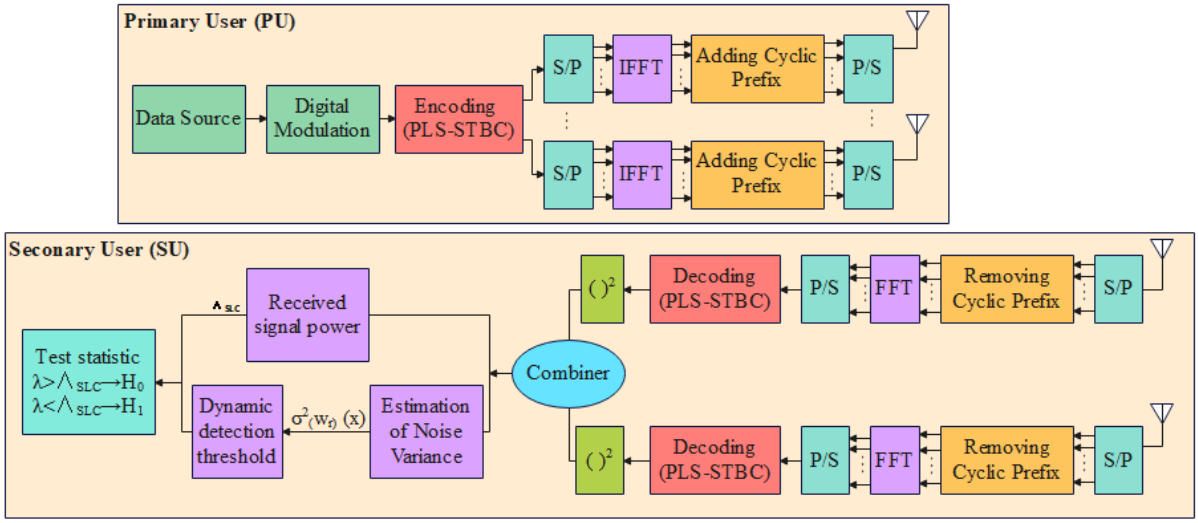


Figure 1. Block diagram of the proposed method in MIMO-OFDM

3.1 System design of the analysis of the energy detection operation

Figure 1 depicts the conception of block diagram of an analysed individual-cell MIMO-OFDM CR system of PU as well as SU. A signal in an analysed MIMO-OFDM CRN system is transmitted through PLS-STBC coding technique. The ED analysis procedure is employed for the model of system involving PU and SU. PU is a certified users which has the priority with respect to spectrum utilization and SU is the unlicensed users which performs SS. In this case, the SU employs SS through the ED approach, which performing SLC approach. In SLC procedure, SU prepared by ED employs the signal squaring operation in SLC tool, trailed through integrating a received signals at $R\ Rx$ chains in a limited time unifier.

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A PU Tx power in MIMO system released through m-th chain (antenna) is expressed as P_m, where, $P = \sum_{m=1}^{M} P_m$ describes a whole prompt Tx power transmitted by M Tx chains. The challenging signal is expressed as $s_m = s_{m,r} + js_{m,i}$ is considered as signal transmission through m-th Tx chains of PU. Thus, a signal is passed through M Tx chains is formulated as $s = \sum_{m=1}^{M} s_m$. The signal is received through SU at each R Rx chain as well as sampled through n samples, which is formulated in equation (1) as follows:

$$y_r(n) = \begin{cases} w_r(n) \\ h_r(n)s_r(n) + w_r(n) \end{cases} \quad (1)$$

Where, $n = 1, \ldots, N$, $h_r(n)$ represents a size $C^{1\times M}$ and it is challenging vector which depicts the wireless channel obtain between M Tx channels of PU as well as rth Rx chain of SU. The challenging vector $s_r(n)$ is a size of $C^{M\times 1}$, which depicts the Tx PU signal, which is received at rth Rx SU chain in nth sample. Furthermore, the challenging noise signal $w_r(n)$ is an AWGN channel affecting a received signal at rth Rx chain of SU. The influence of the noise is considered as identically distributed as well as self-determining arbitrary procedure contains mean value which equals to zero as well as variance of σ_w^2 and its distribution is significantly symmetric, which is expressed as $\mathcal{N}\left(0,2\sigma_w^2 r(n)\right)$. Since, the PU signal is influence through SNR at rth chain of SU, which is formulated in equation (2) as follows:

$$\mathrm{SNR}_r(n) = \Upsilon_r(n) = \frac{|h_r(n)|^2 \frac{1}{N}\sum_{n=1}^{N}|s_r(n)|^2}{2\sigma_w^2 r(n)} \quad (2)$$

The sum of SNR at each M Rx chain during nth SS epoch is formulated as $\Upsilon_{SLC} = \sum_{r=1}^{R} \Upsilon_r(n)$. Moreover, a mean of SNR value at SU antenna for entire R Rx chains in nth sampling epoch is formulated as $\Upsilon_{SLC} = \sum_{r=}^{R} \Upsilon_r(n)$. The SNR value of the mean at antenna of SU for each R Rx chain in nth sampling epoch is expressed as $\overline{\Upsilon_{SLC}} = \frac{1}{R}\sum_{r=1}^{R} \Upsilon_r(n) = \frac{1}{R}\Upsilon_{SLC}$.

SS is the procedure where the SU frequently controls the PU actions in terms of detecting spectrum holes. The complete information about the spectrum accessibility acquired by binary hypothesis H_0 and H_1 testing is formulated in equation (3). This procedure targets to choose among the hypotheses based on which the PU signal is considered to be preoccupied (H_0) or contemporary (H_1). Hence, the result on SS tenancy is an outcome of the testing the hypothesis.

$$Y(n) = \begin{cases} \sum_{r=1}^{R} w_r(n) : H_0 \\ \sum_{r=1}^{R} h_r(n)\, s_r(n) + \sum_{r=1}^{R} w_r(n) : H_1 \end{cases} \quad (3)$$

Where, $Y(n)$ represents a sum of detected signal from entire R Rx chains in a n-th SS epoch at the SU site. The emphasis of an ED is judging whether the detected signal $Y(n)$ satisfies the hypothesis or not. Hence, in a procedure of determining the presence or absence of PU, the threshold is estimated with sensed energy at SU antenna. The decision hypothesis H_1 is pleased when the sensed energy is larger than the threshold. The decision hypothesis H_0 is satisfied when the detected signal is less than DT. Hence, the outcome of these two-hypothesis test identifies a SU action in order to appropriate transmission in PU frequency band.

3.2 Encoding and Decoding using PLS-STBC

Motivated through the full-rate of Orthogonal STBC method attained for the actual-numbered signal transmission by a utilization of various transmit antenna, this research proposes the effective PLS schema for STBC. In this proposed method, this research initially makes the non-orthogonal full-rate encoding matrix for the challenging-numbered signals through adding the challenging signals into X_{N_T}. After that, the proposed method transforms an encoding matrix by the utilization of phase distortion matrix which depicts the null space of channel phase gain. During the transmission, a channel phase will be pulled out, finally only an amplitude constituent of the channel improvement will reach at the receiver. Hence, the proposed scheme has the full orthogonal actual-numbered channel matrix at the receiver. Although, an encoding matrix with challenging numbered signals is non-orthogonal, the proposed method attains the better performance corresponding to that of the method with the full-rate as well as full-diversity.

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Assumes the wiretap Spatial Multiplexing (SM) MIMO-OFDM system with the N_T transmit antenna at A and N_R antenna at B and C. In this method, A transmits the spatially multiplexed $N_T \times 1$ complex signal vector $z = [z_1, z_2, \dots z_{N_T}]^T$ through N_T antenna for every time period. After that, z is transmitted by $N_R \times N_T$ channel metrices of $H = [h_1, h_2, \dots, h_{N_T}]$ as well as $G = [g_1, g_2, \dots, g_{N_T}]$ at B and C. Through assuming that the kth signal component of z, z_k is transmitted via h_k to B, the proposed method utilizes the phase distortion to z_k through the utilization of total of channel phases of h_k. For this persistence, the phase distorting vector q is the primary identified as expressed in equation (4) and (5) as follows:

$$q = [\theta_1, \theta_2 \dots \theta_{N_T}]^T \quad (4)$$

$$\theta_k = e^{\left(-j \sum_{j=1}^{N_R} \angle h_{ik}\right)} \quad (5)$$

Where, h_{ik} and $\angle h_{ik}$ represents a challenging channel improvement from the kth transmit antenna to the ith receive antenna and its phase correspondingly. After, the pre-distorted signal vector at A, the z' is identified, which is formulated in equations (6-8) as follows:

$$z' = dig(z)q \quad (6)$$

$$= \begin{bmatrix} z_1 & 0 & \dots & 0 \\ 0 & z_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & z_{N_T} \end{bmatrix} \begin{bmatrix} \theta_1 \\ \theta_2 \\ \vdots \\ \theta_{N_T} \end{bmatrix} \quad (7)$$

$$= [\theta_1 z_1, \theta_2 z_2, \dots, \theta_{N_T} z_{N_T}]^T \quad (8)$$

After, the received signal at B is expressed in equation (9-12) as follows:

$$y_b = Hz' + n_b \quad (9)$$

$$= [h_1, h_2, \dots, h_{NT}] \begin{bmatrix} \theta_1 z_1 \\ \theta_2 z_2 \\ \vdots \\ \theta_{N_T} z_{N_T} \end{bmatrix} + n_b \quad (10)$$

$$= [\theta_1 z_1 h_1 + \cdots + \theta_{N_T} z_{N_T} h_{N_T}] + n_b \quad (11)$$

$$= H'z + n_b, \quad (12)$$

Where, the resulting channel matrix is expressed in equation (13). Hence, the signal detection is attained through utilizing different detection approaches are expressed in equation (14) as follows:

$$H' = [\theta_1 h_1, \theta_2 h_2, \dots, \theta_{N_T} h_{N_T}] \quad (13)$$

$$\hat{z}_b = F_{y_b} \quad (14)$$

Where, F represents a detection matrix such as $F = (H'^H H')^{-1} H'^H$ for zero forcing (ZF) detection as well as $F = (H'^H H' + \sigma^2 I)^{-1} H'^H$ for the lowest Mean Square Error (MSE) detection. Where, σ^2 represents a noise variance as well as I represents the $N_T \times N_T$ identity matrix. Simultaneously, the received signal C is expressed in equation (15 and 16) as follows:

$$y_e = Gz' + n_e \quad (15)$$

$$= [\theta_1 z_1 g_1 + \cdots + \theta_{N_T} z_{N_T} g_{N_T}] + n_e \quad (16)$$

As in the prior case for STBC methods, z' involves H-dependent distortion as well as C cannot retrieve any data on the signal.

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4 RESULTS AND DISCUSSION

This section presents the experimental analysis while evaluating the proposed approach based on various scenarios. The suggested approach is implemented in MATLAB software and the system configuration of Intel i7 processor, windows 10 OS and 8 GB RAM. Table 1 depicts the simulation parameters of the proposed method.

Table 1. Simulation parameters of the proposed method

Parameters	Values
PU signal type	OFDM
NU factor ρ	1.03, 1.05
DT factor ρ'	1.03, 1.05
OFDM modulation type	QPSK, 16 QAM, 64 QAM
Detection sample numbers (N)	128, 512, 256
False alarm and detection probability range	[0 to 1]
PU Tx branches number	1 to 4
SU Rx branches number	1 to 4
SNR at SU point (dB)	-20, -15, -10

4.1 Performance Analysis

In this section, the effectiveness of the proposed method is estimated using various parameters which is mention in Table 1. Figure 2 depicts the ROC curve for 1 × 1 SISO system for NU and DT factors at P_{TX} = 10 W. Figure 3 depicts the ROC curve for 1 × 1 SISO system for NU and DT factors at P_{TX} = 100 mW. Figure 4 represents the ROC curve for 2 × 2 MIMO system for NU and DT factors at P_{TX} =10 W. Figure 5 represents the ROC curve for 2 × 2 MIMO system for NU and DT factors at P_{TX} = 100 mW.

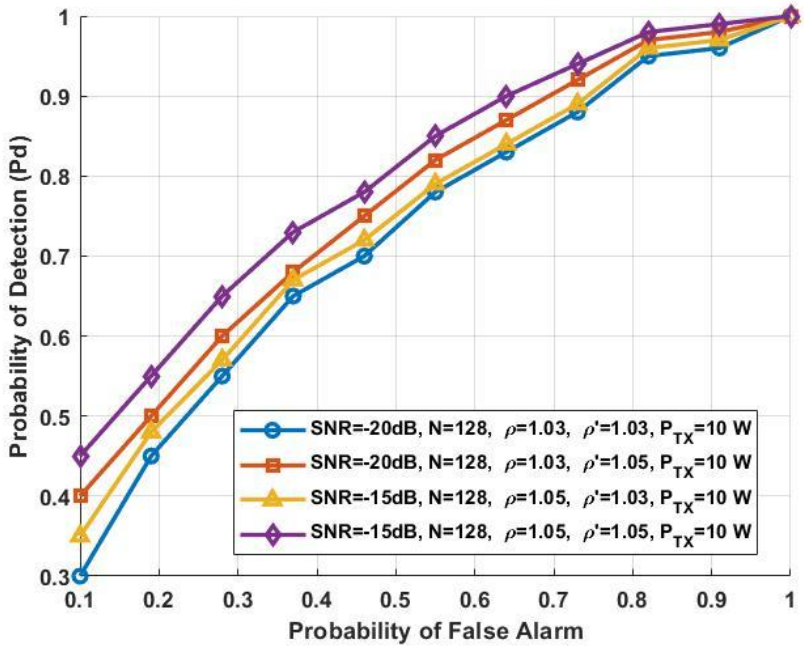


Figure 2. ROC curve for 1 × 1 SISO system for NU and DT factors at P_{TX} = 10 W

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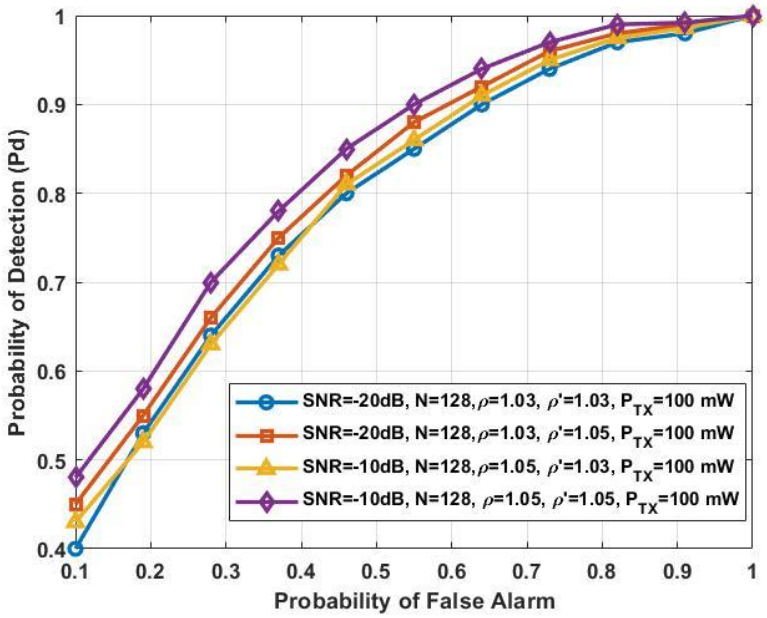


Figure 3. ROC curve for 1 × 1 SISO system for NU and DT factors at P_{TX} = 100 mW

In Figure 2, the ROC curve for 1 × 1 SISO system for NU and DT factors is estimated with respect to Probability of the Detection (Pd) and Probability of False Alarm with the SNR= -20dB and -10dB, N=128 and P_{TX} = 10 W. In Figure 3, the ROC curve for 1 × 1 SISO system for NU and DT factors is estimated with respect to Probability of the Detection (Pd) and Probability of False Alarm with the SNR= -20dB and -10dB, N=128 and P_{TX} = 100 mW. For the similar channel features, the probability of the detection is equal to the adaptable modulation approaches like Quadrature Phase Shift Keying (QPSK), 16 Quadrature Amplitude Modulation (QAM) as well as 64 QAM. The maximum number of Tx and Rx branches on PU and SU side provides an enhancement of an effectiveness of the energy detection.

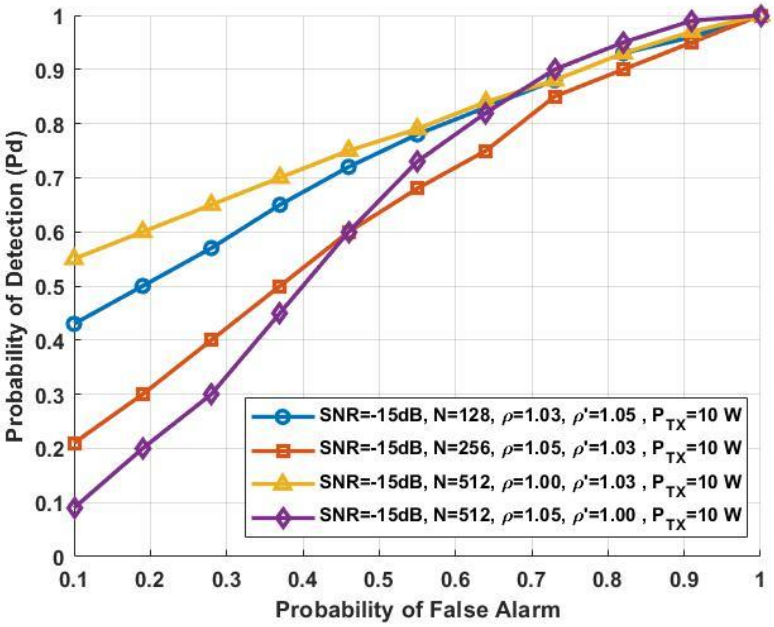


Figure 4. ROC curve for 2 × 2 MIMO system for NU and DT factors at PU transmitting at P_{TX} = 10 W

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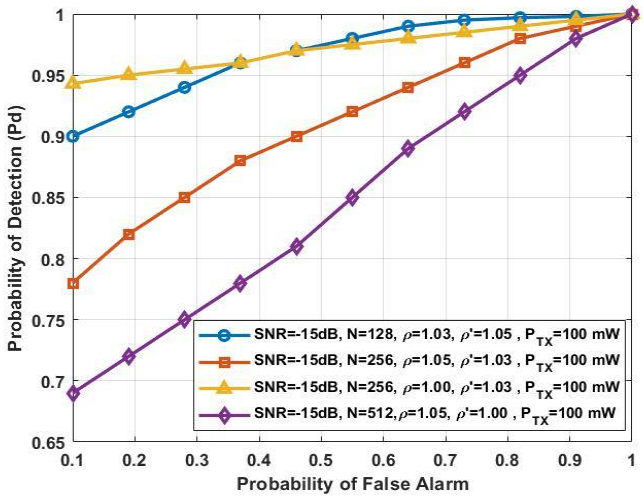


Figure 5. ROC curve for 2 × 2 MIMO system for NU and DT factors at P_{TX} = 100 mW

In Figure 4, ROC curve for 2 × 2 MIMO system for NU and DT factors is presented with respect to Probability of the Detection (Pd) and Probability of False Alarm with SNR = -15dB, N=28, 256 and 512 and P_{TX} = 10 W. In Figure 5, the ROC curve for 2 × 2 MIMO system for NU and DT factors is presented in terms of Probability of the Detection (Pd) and Probability of False Alarm with SNR = -15dB, N= N=28, 256 and 512 and P_{TX} = 100 mW. The PU transmission signals at maximum Tx power obtains the maximum detection probability. The results in Figure 4 and 5 are probable as the PU transmission at maximum Tx power, finally the results in maximum energy for received signal through SU Rx chains.

But, the OFDM signal is transmitted through maximum Tx as well as received through maximum Rx antenna and at the maximum Tx power level is crucially provide to the modification of the detection probability. The obtained results effectively contribute to an enhancement of ROC in terms of obtaining effective detection probabilities for the similar false alarm probabilities. Hence, an effectiveness of the energy detection is enhanced with an extension in PU Tx power and with the transmission of MIMO, where the large number of Rx and Tx branches performing in MIMO transmission depicts the most beneficial decision.

4.2 Comparative Analysis

Table 2 shows the simulation parameters for various scenarios. The different scenarios like 1 and 2 are depicted as SLC [16], and SLC [17] respectively. These different scenarios are compared with the proposed PLS-STBC encoding technique for estimating the efficacy of the model. Table 3 presents the comparison of proposed PLS-STBC encoding technique with [16] for probability of detection (pd) in terms of Probability of False Alarm (Pfa). Table 4 presents the comparison of proposed PLS-STBC encoding technique with [17] probability of detection (pd) in terms of SNR.

Table 2 Simulation parameter with the different scenarios

Parameters	**Scenario**	
	1	**2**
NU factor ρ	1.00, 1.03, 1.05	1.00, 1.03, 1.05
DDT factor ρ'	1.00, 1.03, 1.05	1.00, 1.03, 1.05
Target false alarm probability	0 to 1	0.01, 0.2
PU Tx branches number	1 to 4	1 to 4
SU Rx branches number	1 to 4	1 to 6

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Table 3. Comparison of proposed PLS-STBC with [16] at Pfa=0.5 for 2×2 MIMO-OFDM

Scenario	Parameters	SLC [16]	Proposed PLS-STBC
1	ρ =1.00, ρ' =1.00	0.85	0.88
	ρ =1.05, ρ' =1.00	0.74	0.79
	ρ =1.00, ρ' =1.03	0.95	0.97
	ρ =1.05, ρ' =1.03	0.79	0.83
	ρ =1.03, ρ' =1.05	0.92	0.96

Table 4. Comparison of proposed PLS-STBC with [17] at SNR=5 for 2×2 MIMO-OFDM and PTx = 100 mW

Scenario	Parameters	SLC [17]	Proposed PLS-STBC
2	ρ =1.00, ρ' =1.00	0.02	0.04
	ρ =1.05, ρ' =1.00	0.02	0.05
	ρ =1.00, ρ' =1.03	0.08	0.09
	ρ =1.05, ρ' =1.03	0.03	0.04
	ρ =1.03, ρ' =1.05	0.35	0.54

4.3 Discussion

In this section, the achievement of the proposed PLS-STBC coding approach is discussed along with their advantage. The existing works have the limitation such as lack of inherent compensate for multipath fading effects, computationally intensive, randomization of threshold values tended to diminish the efficiency of detecting false alarm rates and limits their applicability in extensive CRN. Hence, this research proposes the PLS-STBC for the coding process in MIMO-OFDM based CRN. The utilization of PLS-STBC in MIMO systems provides diversity gain, which enhances the overall performance of the communication system through minimizing the error rate. This is predominantly helpful in CRNs where the quality of the channel is varied significantly. The experimental results shows that the proposed PLS-STBC approach attains the probability of detection of 0.96 at ρ =1.03, ρ' =1.05 at Pfa is fixed to 0.5 for 2×2 MIMO-OFDM.

5 CONCLUSION

Among various MIMO-OFDM sensing techniques, ED is the most widely implemented, due to its effectiveness and scalability. However, it is highly sensitive to NU and resulted as minimum SNR. Hence, this research proposes the PLS-STBC approach for the estimation of the effectiveness of ED SS with the DT s based on NU adjustments in MIMO-ODFM CR systems. The mathematical modelling of the significant parameters utilized for an estimation of ED effectiveness as the constrained SS approach performing SLC in MIMO-OFDM CR systems is presented. The acquired outcomes represent an ED performing SLC in MIMO-OFDM CR systems involves various PU Tx as well as various SU Rx chains, exceeds in order to ED effectiveness in SISO communication systems. The experimental results shows that the proposed PLS-STBC approach attains the probability of detection of 0.96 at ρ =1.03, ρ' =1.05 at Pfa is fixed to 0.5 for 2×2 MIMO-OFDM. In future, the proposed method will expand to use various encoding and decoding techniques for enhancing the model effectiveness.

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