Enhancement of the Achievable throughput in Multi-Taper MIMO Spectrum Sensing using Cooperative Hard Decision Fusion Rules

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Abstract— **Cognitive radio is known as a smart technology due to its ability to adjust the operating parameters, according to the given conditions and environment. In this paper, a cooperative MT-MIMO (Multi-Taper Multiple Input Multiple Output) spectrum sensing system is proposed in order to enhance the sensing performance and the achievable throughput using different number of antennas. The obtained results of MT-MIMO are compared to the obtained results of Periodogram MIMO (PED-MIMO) under two scenarios. The first scenario is considered for single user detection while the second one is considered for multiple user detection. The proposed system should counteract the problem of hidden primary user nodes.**

Keywords-Multi-Taper MIMO spectrum sensing; Periodogram-MIMO spectrum sensing; Cooperative Spectrum sensing; Achievable Throughput

I. INTRODUCTION

Over the last two decades, wireless technologies have grown rapidly and more spectrum resources are necessary to support increasing expanded wireless services. Multi-Taper Spectrum Sensing (MTSS) technique is used to sense the spectrum trying to enhance the achievable throughput criteria in a small sensing time [1].

The licensed spectrum of the primary user is largely under-utilized in large temporal areas [2].Cognitive radio technology was recently proposed in order to determine whether the sensed spectrum is free or busy [3]. It can improve the efficient spectrum usage by allowing secondary users to borrow unused spectrum holes from primary network users to share the primary network spectrum.

As a smart wireless communication system, a cognitive radio knows as the radio frequency sensor. It adopts the communication parameters such as bandwidth, frequency, and transmission power to optimize the spectrum utilization and adjusts its transmission and reception operation. Spectrum sensing is the most effective components of cognitive radio. Through sensing and adapting the communication parameters, a cognitive radio has the capability to use the free spectrum holes and serve the secondary users (SU). This had been done without causing interference to the primary users (PU). To decide whether a PU exists or not, The MTM (Multi-taper Method) spectrum estimate in the frequency domain was compared against the noise variance in the time domain [4].

The hidden terminal problem is one of the greatest challenges of implementing spectrum sensing. It occurs when cognitive radio doesn't detect the presence of PU due to multipath fading or high penetration loss inside buildings, while a primary user (PU) is operating in the neighborhood [5]. By using multiple cognitive radio users that can cooperatively work, the hidden node problem can be decreased. By increasing the number of CR (Cognitive radio) spectrum sensing nodes and work cooperatively, the spectrum sensing performance can be more improved [6]–[11].

In this paper, the optimization of cooperative MT-MIMO spectrum sensing for maximizing the Achievable throughput even in small sensing time and low signal to noise ratio (SNR) is considered.

The rest of the paper is organized as follows; in section II the system model is presented. In section III the effect of MT-MIMO on the detection probability and the false alarm probability are presented. Discussion of the numerical results, simulations in the mentioned Cooperative MT-MIMO spectrum sensing and PED-MIMO Cooperative spectrum sensing are presented in Section IV. Finally, in Section V the conclusions are given.

II. PROPOSED SYSTEM MODEL

The proposed system model structure as shown in Fig.1.It consists of N_t transmitting antennas and M_r receiving antennas with channel coefficients $h_{i,j}$ where $i=1,........M_r$ and $j=1,.............N_t$. The two hypothesis tests are as follows:

$$H_0: y_i(n) = w_i(n) \qquad n = 0,......., N\text{-}1$$

$$H_1: y_i(n) = h_{i,j}(n)\, x_j(n) + w_i(n) \quad n = 0,......., N\text{-}1 \quad (1)$$

It can be written in matrix form as:
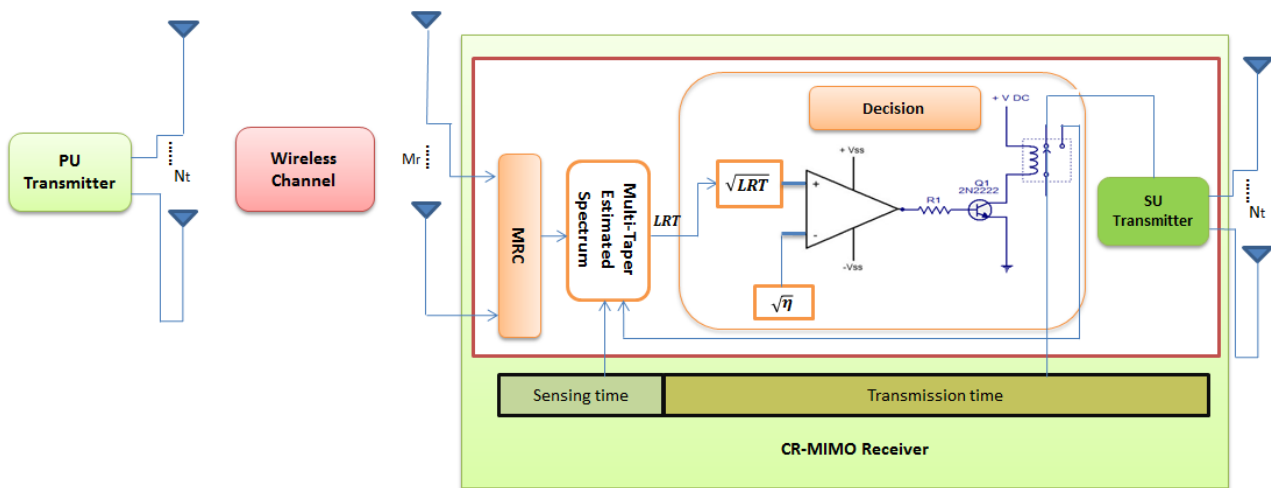
$$H_0: Y = W$$

$$H_1: Y=HX+W \qquad (2)$$

Fig.1 The proposed system model structure

where H_0, H_1 indicates that the channel is free or busy respectively, H is the N_t x M_r channel matrix, N is the number of received sequence and w_i (.) is AWGN associated with i channel weight and assumed to be $N \sim (0, \sigma_t^2)$.

To decide whether the observation vector Y was created under H_0 or H_1 spectrum sensing is considered. This can be done by formulation appropriate test statistic and comparing it with a predetermined threshold value η. In the scope of Neyman-Pearson (NP) criterion, the LRT maximization form [11]:

$$LRT = \ln\left\{\frac{f\,(Y\,/H_1)}{f\,(Y\,/H_0)}\right\} \begin{matrix} H1 \\ \lessgtr\ \eta \\ H0 \end{matrix} \qquad (3)$$

f(.) is the conditional probability density function (PDF).
In logarithmic form

$$LRT = L_1(\mathrm{x}) - L_0(\mathrm{x})$$

$$L_1(\mathrm{x}) = \frac{-tr(\mathrm{x})^2}{2(\sigma_n^2 + \sigma_s^2)} - \frac{L}{2}\ln(\sigma_n^2 + \sigma_s^2) - \frac{L}{2}\ln(2\pi) \qquad (4)$$

Where tr (.) is the trace of the matrix.

$$L_0(\mathrm{x}) = \frac{-tr(\mathrm{x})^2}{2\sigma_n^2} - \frac{L}{2}\ln(\sigma_n^2) - \frac{L}{2}\ln(2\pi) \qquad (5)$$

$$LRT = -\frac{tr(\mathrm{x})^2}{2(\sigma_n^2 + \sigma_s^2)} - \frac{L}{2}\ln(\sigma_n^2 + \sigma_s^2) + \frac{tr(\mathrm{x})^2}{2\sigma_n^2} + \frac{L}{2}\ln(\sigma_n^2)$$

$$LRT = \frac{tr(\mathrm{x})^2}{2\sigma_n^2}\left(1 - \frac{1}{1+\frac{\sigma_s^2}{\sigma_n^2}}\right) - \frac{L}{2}\ln\left(\frac{\sigma_n^2 + \sigma_s^2}{\sigma_n^2}\right)$$

$$LRT = \frac{tr(\mathrm{x})^2}{2\sigma_n^2}\left(\frac{1}{1+\frac{\sigma_s^2}{\sigma_n^2}}\right) - \frac{L}{2}\ln\left(1+\frac{\sigma_s^2}{\sigma_n^2}\right) \qquad (6)$$

Comparing the LRT function with a threshold results as:

$$\frac{tr(\mathrm{x})^2}{2\sigma_n^2}\left(\frac{1}{1+\frac{\sigma_s^2}{\sigma_n^2}}\right) - \frac{L}{2}\ln\left(1+\frac{\sigma_s^2}{\sigma_n^2}\right) \begin{matrix} H1 \\ \lessgtr\ \eta \\ H0 \end{matrix} \qquad (7)$$

Where η is the decision threshold and σ_s^2 / σ_n^2 is the Signal to Noise Ratio (SNR).

III.   MULTI-TAPER MIMO SPECTRUM SENSING
The multi-taper MIMO method utilizes multi-antenna arrangement environments for spectrum sensing. The Maximal Ratio Combining (MRC) is utilized as near to optimum for diversity combining technique, to approach the estimate spectrum at the output of multiple receiving antennas. The MRC output is the summation of all branches affected appropriately by the used tapers. The classifications of decision statistics differ in the hypothesis test literature and nearly extend either in the time or frequency domains. Each statistical approach is highly relevant to the mathematical models governing signals and systems [13].

The decision proposed earlier was also compared to the noise variance appearing in the time domain. A different extension of the same analysis can also be associated in [14]. In the proposed system model the square root of LRT (Likelihood Ratio Test) of Multi-Taper Estimated Spectrum output is applied to a comparator with reference square root of threshold η. The comparator output is applied to a transistor through a resistor. The transistor output controls the data transmitted through the transmission time or not. When the

output of transistor is high, the transistor conducts and the relay is activated so, the data of primary user is transmitted. Otherwise, the same technique is applied to the other output line which referring to sensing again and hence no data is transmitted. Referring to equation (3), this leads to the probability of detection and false alarm probability given as [15, 16, and 17]:

$$P_d = Q(\frac{\eta - LPM_t N_r(1+\text{SNR})}{\sqrt{2LPM_t N_r(1+\text{SNR})}}) \qquad (6)$$

$$P_f = Q(\frac{\eta - LPM_t N_r}{\sqrt{2LPM_t N_r}}) \qquad (7)$$

Where L is sequence length and P is number of tapers =4, Q (.) is the right-tail probability for normal Gaussian random variables and $Q(u) = \frac{1}{2}erfc(\frac{u}{\sqrt{2}})$ for any fixed value u. It is shown that the estimate spectrum performance in Multi-Taper MIMO environment depends on the number of transmitting and receiving antennas. This will maximize the detection and false alarm probability under low SNR. Now, the tradeoff between sensing capability and achievable throughput of the SU can be studied under different Cooperative spectrum sensing hard decision AND, OR, and Majority rules [1].

$$R_T(S) = \frac{T-S}{T}[C_0(1-P_f)P(H_0) + C_1(1-P_d)P(H_1)] \qquad (8)$$

Such that $R_T(S)$ is the achievable throughput, the channel capacities C_0 and C_1 are considered the capacities when the PU is absent or present respectively, $P(H_0)$ is the probability that the channel is idle and $P(H_1)$ is the probability that the channel is busy and *T, S* is the transmission time and sensing time respectively [1].

IV.   SIMULATION RESULTS

In this section, the proposed spectrum sensing system model scheme is evaluated. The factors taken are Slepian tapers of 4 taps. The MT-MIMO CR frame time is T=40 ms, sampling frequency 0.1 MHz and target probability of detection is set to 0.9.

Fig.2 shows the relation between the detection probability against SNR for different number of antennas used in case of PED-MIMO spectrum sensing. To satisfy Pd=0.9 the SNR must be (-8.5,-10,-11) for (1, 2, 3) antenna(s) used respectively. But in case of MT-MIMO to satisfy Pd=0.9, the SNR must be (-12,-13.3,-14) dB for (1, 2, 3) antenna(s) used respectively as shown in Fig.3. This indicates that MT-MIMO combining technique can improve the detection probability at low SNR compared to PED-MIMO combining technique.

Fig.4 shows the relation between the achievable throughput against sensing time in case of PED-2x1MIMO for single user detection compared to cooperative spectrum sensing (AND,OR,MAJORITY) different fusion rule detection. The maximum achievable throughput is (0.78, 1.75, 0.13, 0.6) for (PED-2x1MIMO, AND, OR, MAJORITY) at sensing time (6, 4, 18, 10) respectively. But in case of using MT-2x1 MIMO spectrum sensing, the maximum achievable throughput is (1.15, 2.05, 0.6, 1.15) b/s/Hz at sensing time (8, 4, 18, 10) msec in case of (MT-2x1MIMO, AND, OR, MAJORITY) respectively as shown in Fig.5.
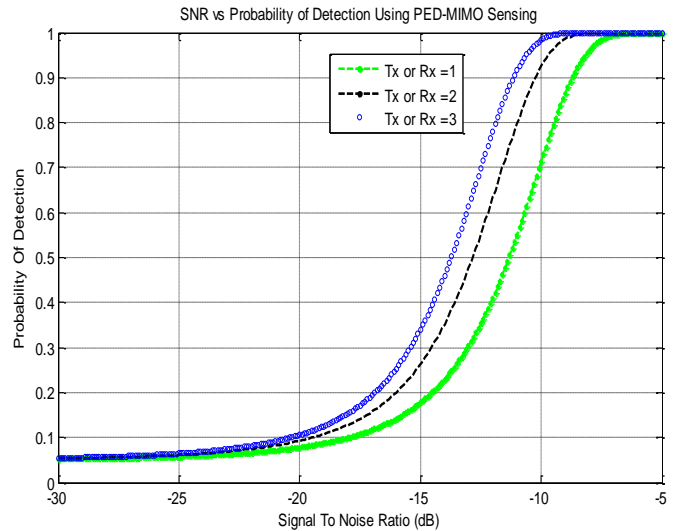

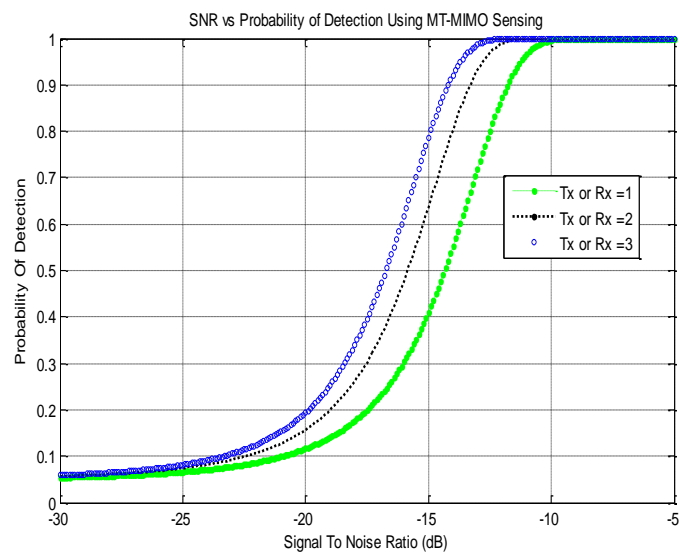Fig.2. Periodogram-MIMO Pd versus SNR

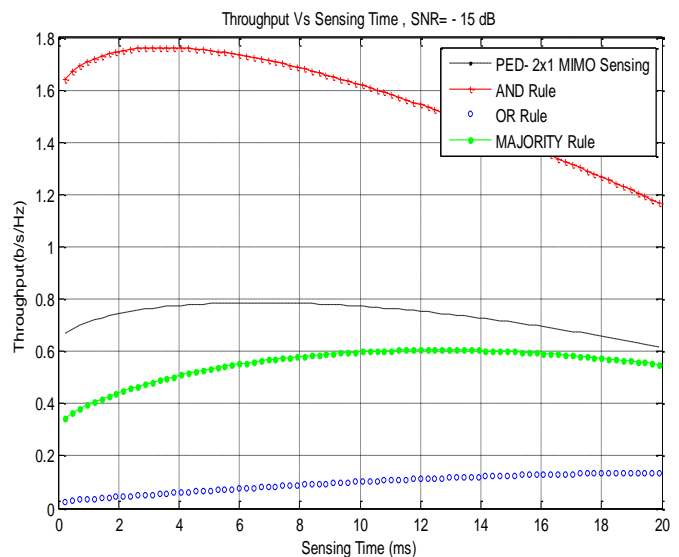Fig.3 MT-MIMO Pd versus SNR

Fig.4 Throughput versus Sensing Time
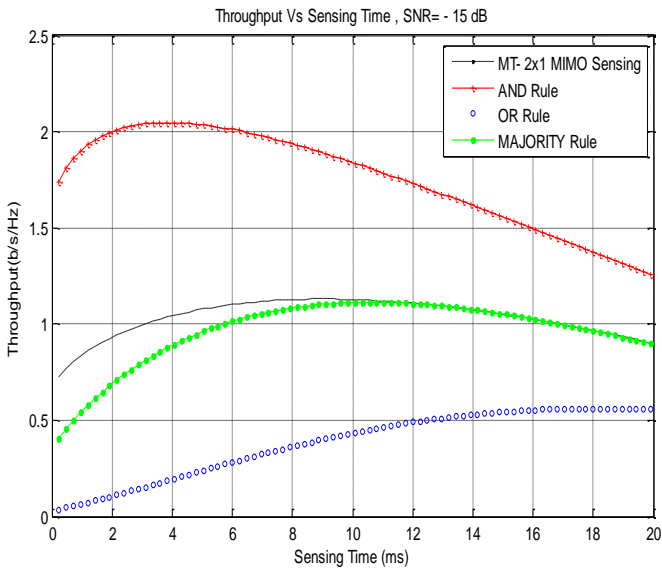(SNR=-15, K=3, PED-2x1 MIMO)

Fig.5 Throughput vs Sensing Time
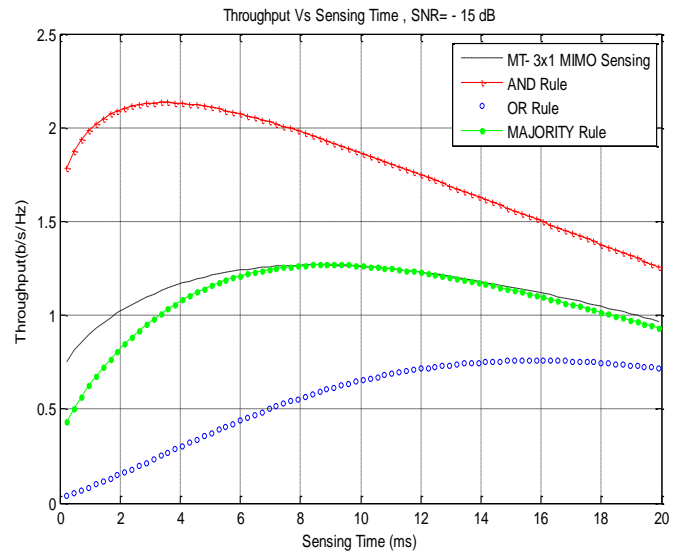(SNR=-15, K=3, MT-2x1 MIMO)

Fig.7 Throughput vs Sensing Time
(SNR=-15, K=3, MT-3x1 MIMO)

The different fusion rules of cooperative spectrum sensing are compared in case of PED 3x1 MIMO; the achievable throughput is (0.87, 1.85, 0.2, and 0.72) at sensing time (8, 4, 18 and 12) msec for (PED 3x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.6. But the achievable throughput is (1.25, 2.2, 0.75, 1.25) at sensing time (8, 2.8, 15, 8) in case of (MT- 3x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.7.

Achievable throughput is (1.37, 2.2, 0.98, 1.37) at sensing time (7, 3, 12, 7) in case of (PED- 2x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.8. But the achievable throughput in case of MT-2x1 MIMO is (1.75, 2.36, 1.46, and 1.68) at sensing time (3.5, 1, 5, 2)for (MT- 3x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig. 9.
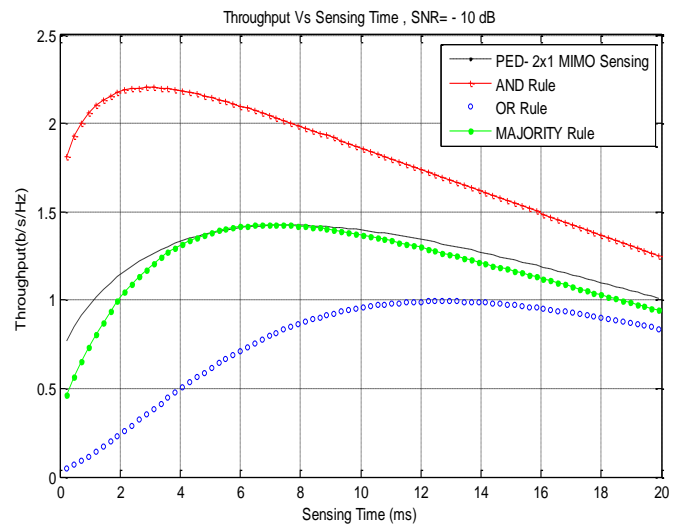

Fig.8 Throughput vs Sensing Time
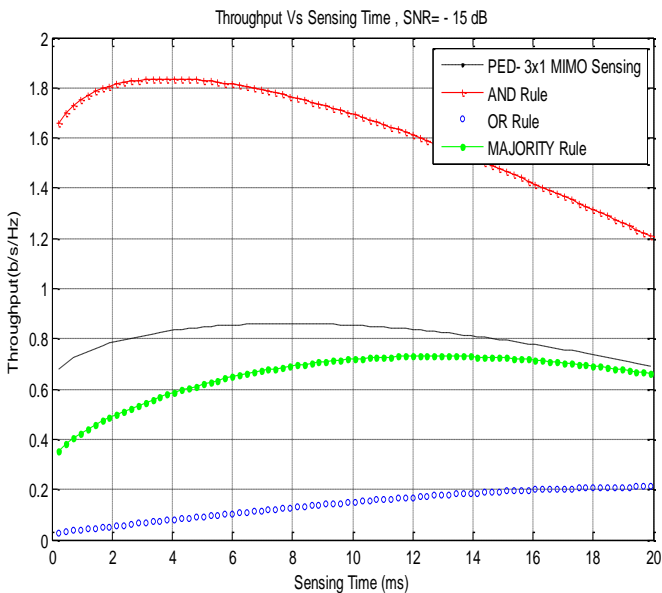(SNR=-10, K=3, PED-2x1 MIMO)

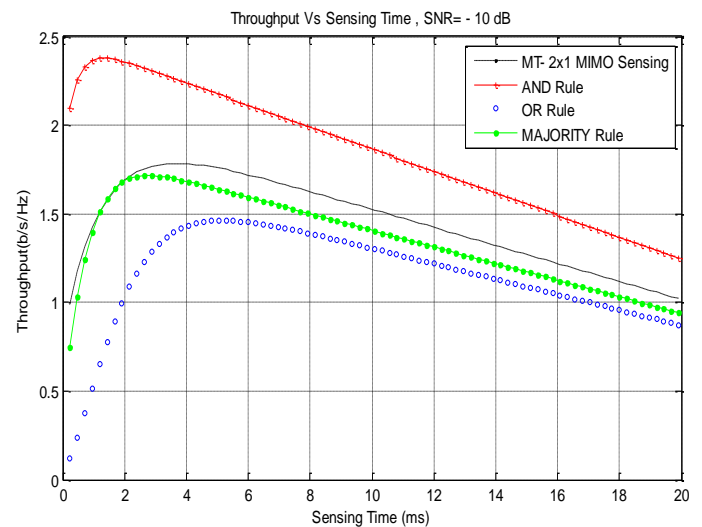Fig.6 Throughput vs Sensing Time
(SNR=-15 PED-3x1MIMO, k=3)

Fig.9 Throughput vs Sensing Time
(SNR=-10, K=3, MT-2x1 MIMO)

By increasing the number of antennas to 3x1 MIMO under conditions (SNR=-10 dB and K=3); the achievable throughput is (1.57, 2.27, 1.2, 1.57) at sensing time (6, 2, 10, 5) in case of (PED 3x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.10. But in case of MT-3x1 MIMO spectrum sensing , the achievable throughput is (1.75, 2.4, 1.55, 1.75) at sensing time (3, 1, 4, 2) in case of (MT 3x1 MIMO, AND, OR, MAJORITY) respectively as show in Fig.11. All above results indicates that the MT-MIMO spectrum sensing can improve sensing capability at low sensing time with maximizing the achievable throughput in case of MT-MIMO more than PED-MIMO.

The achievable throughput can be improved in case of MT-MIMO more than the PED-MIMO case by increasing number of antennas used at CR receiver; however MT-MIMI takes much sensing time. The achievable throughput is (0.72, 1.68, 0.08, 0.45) at sensing time (4, 2, 18, 9) for (PED 10x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.12. But in case of MT-10x1MIMO spectrum sensing; the achievable throughput is (0.93, 1.92, 0.3, 0.85) at sensing time (7, 4, 18, 12) for (MT-10x1 MIMO, AND, OR, MAJORITY) respectively as shown in Fig.13.
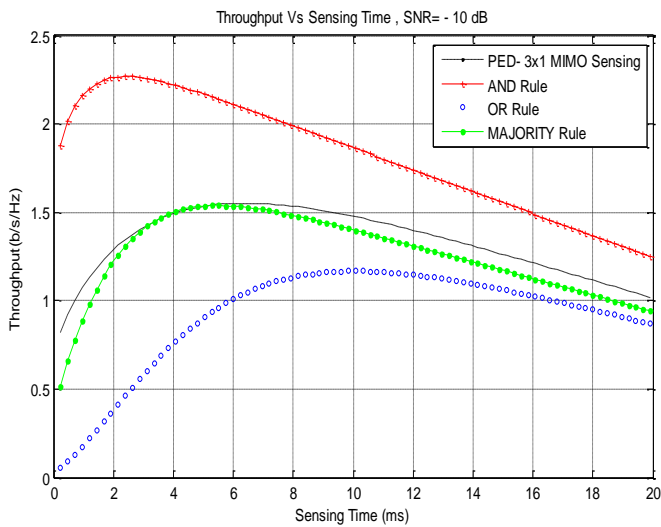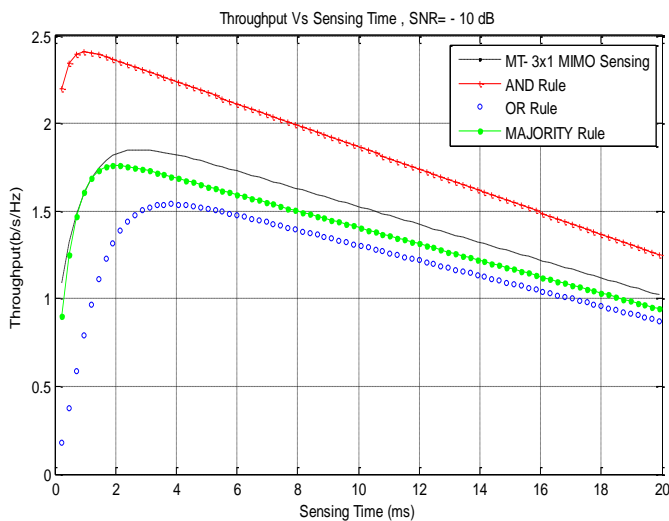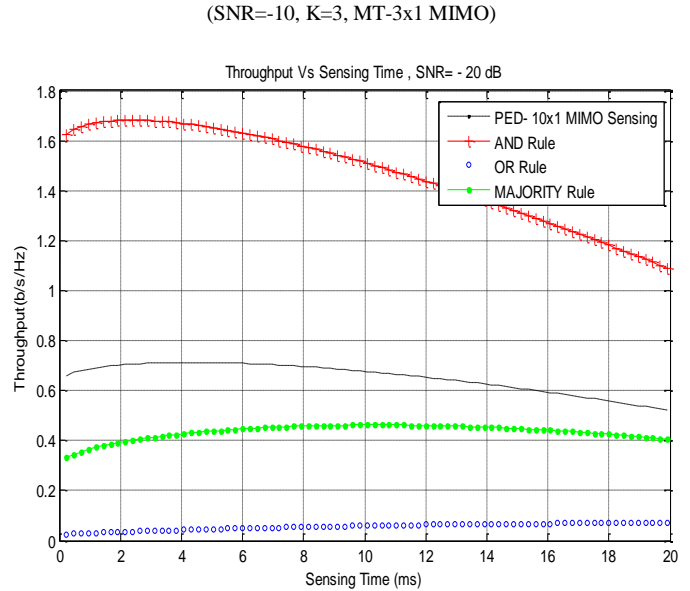
(SNR=-10, K=3, MT-3x1 MIMO)

Fig.12 Throughput vs Sensing Time
(SNR=-20, K=3, PED-10x1 MIMO)

Fig.13 Throughput vs Sensing Time
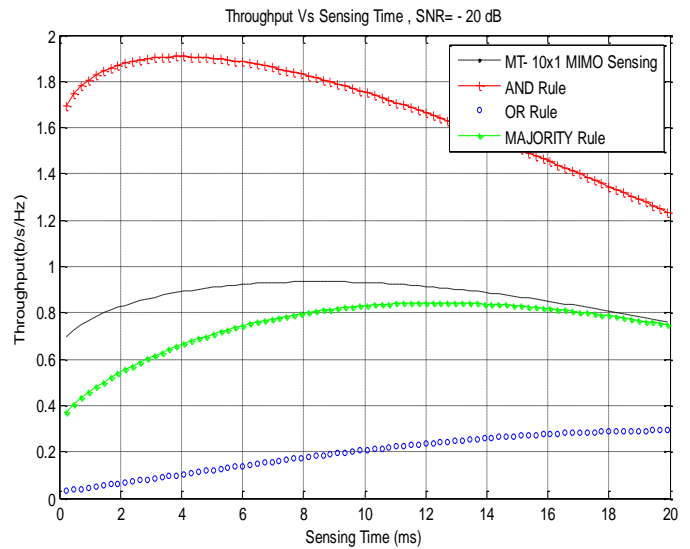(SNR=-20, K=3, MT-10x1 MIMO)

Fig.10 Throughput vs Sensing Time
(SNR=-10, K=3, PED-3x1 MIMO)

Fig.11 Throughput vs Sensing Time

V. CONCLUSIONS

In this paper, we proposed a cognitive radio system that improves the achievable throughput of secondary user by performing data transmission and spectrum sensing at the same time. We studied the average achievable throughput of the proposed cognitive radio system under single user detection and multiple user detection. The simulation results showed that the achievable throughput have been improved in case of MT-MIMO compared to the PED-MIMO cognitive radio systems. In addition to the ability to solving the hidden node problem which make more protection for primary user. Also, Cooperative MT-MIMO Spectrum sensing is more efficient than PED-MIMO Cooperative spectrum sensing specially at low SNR of PU.

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