Modified Hard Fusion Rule for Improving Throughput in Cognitive Radio Network

Hikmat N. Abdullah[1], Nuha Sh. Bakr[2]

Al-Nahrain University, College of Information Engineering, Baghdad, Iraq

Abstarct: *One of the main challenges in cognitive radio (CR) is throughput maximization. In cooperative CR, suitable decision rule can enhance the throughput. In this paper, an efficient hard decision rule is proposed to improve the detection of the primary user, and improve CR throughput. The performance of the proposed rule is evaluated in both AWGN and Rayleigh fading channels and compared with OR, AND, and Majority rules . The simulation results showed that the proposed method enhances the throughput over other rules. The results also demonstrated the proposed rule enhances the probability of false alarm (P_{FA}) by 38.7% and 45% over the MAJORITY rule when SNR equals -1 dB in AWGN and Rayleigh fading channel respectively.*

Keywords: Cognitive radio, spectrum sensing, energy detection, throughput maximization, cooperative sensing, fusion center

1. Introduction

The fast evolution in wireless communication has led to huge request of frequency spectrum. Some frequency bands are congested and other frequency bands are underutilized. In this regard, cognitive radio has developed as a new technology to avoid this problem. It enables the access of unoccupied spectrum holes. The Cognitive Radio share the unused spectrum with the secondary unlicensed user (SU) without causing any interference to the primary user (PU) [1]. Different spectrum sensing techniques are available such as energy detection, matched filter detection and cyclostationarity-based sensing. Energy detection is a simple technique for spectrum sensing. It does not require any prior knowledge about the primary users signals [2].

To reducing the effect of multipath fading and shadowing, the cooperative sensing scheme is used, in cooperative scheme the secondary user shares sensing information which result in the secondary users have a higher detection for the primary signals.

In cooperative sensing SU perform a local decision and then send this decision independently to the fusion center [3], in hard decision the secondary user send a one bit decision to the FC. After the binary decision reached to FC the global decision is made by combining the decisions by using one of the existing rule [4]. The rules used in hard combination is OR rule [5-6], AND rule [7] and majority rule [8].

In this paper, the performances of existing hard decision rules are evaluated and a proposed rule is presented to optimize the throughput of the cognitive radio network. The rest of the paper is organized as follows. In Section II, present the system model. In Section III, present the proposed decision rule. Simulation results showing the performance of the proposed method are given in Section IV. We conclude in Section V.

2. The Model of Cooperative Sensing

The cooperative sensing has the two hypotheses as follows:

$$\begin{aligned} H_0: \ & r(n)=n(n). \\ H_1: \ & r(n)=hs(n)+n(n). \end{aligned} \qquad (1)$$

Where r(n) is the received signal and h is the channel gain, s(t) is the signal transmitted by primary user. n(t) is the additive white Gaussian noise (AWGN).a CR network consist of a primary user (PTX) and N number of secondary users as shown in Figure 1. SUs simultaneously sense for the spectrum hole and send their local decision to the fusion center (using the energy detector). In other words, the energy of ith secondary user is used for the detection of the primary user. The energy of ith secondary user is:

$$E = \frac{1}{N}\sum_{i=1}^{N}|r(n)|^2 \qquad (2)$$

Where τ is the sensing time. There is two channels used by SU (sensing channel and reporting channel). Sensing channel is used to sense for the existence of the hole by comparing the energy signal with predetermined threshold ϵ. Reporting channel is used to send the local decisions to the fusion center. After all SUs send their one-bit decision result to the fusion center, then the global decision is made [9]. in a hard decision, the fusion center implements an k–out-of-N rule. The probability of detection and probability of false alarm at the fusion center is given by,where the detection probability is usually expressed with the value between 0-1.

$$P_D = \sum_{k}^{N}\binom{N}{k}\left(P_{D,i}\right)^k (1-P_{D,i})^{N-k}$$

$$P_{FA} = \sum_{k}^{N}\binom{N}{k}\left(P_{FA,i}\right)^k (1-P_{FA,i})^{N-k} \qquad (3)$$

Where $P_{D,i}$, $P_{FA,i}$ is the probability of detection and probability of false alarm for each node respectively .The existing rules are as follows:

2.1 AND rule

If all of the local decisions sent to the fusion center are one, the global decision made is one, the detection performance for AND fusion rule can be evaluated by setting k=N in Equation (3) the detection probability and false alarm probability is [10]:

$$P_{D, AND}=(P_{D,i})^N$$
$$P_{FA, AND}=(P_{FA,i})^N \qquad (4)$$

2.2 OR rule

If any one of the local decisions sent to the fusion center is one, the global is one. The detection performance for OR fusion rule can be evaluated by setting k=1 in Equation (3) the detection probability and false alarm probability is [10]:

$$P_{D, OR}=1-(1-P_{D,i})^N$$
$$P_{FA, OR}=1-(1-P_{FA,i})^N \qquad (5)$$

2.3 MAJORITY rule

If half or more of the local decisions sent to the fusion center are one, the global decision is one. The detection performance for Majority fusion rule is evaluated as in Equation (6-9) [10]:

$$P_{D,MAJORITY}=\sum_{ceil(\frac{N}{2})}^{N}\binom{N}{ceil\left(\frac{N}{2}\right)}(P_{D,i})^{ceil(N/2)}*(1-P_{D,i})^{N-(ceil(N/2)} \text{ , N is odd} \qquad (6)$$

$$P_{D,MAJORITY}=\sum_{N/2}^{N}\binom{N}{N/2}(P_{D,i})^{(N/2)}*(1-P_{D,i})^{N-(N/2)} \text{ , N is even} \qquad (7)$$

$$P_{FA,MAJORITY}=\sum_{ceil(\frac{N}{2})}^{N}\binom{N}{ceil\left(\frac{N}{2}\right)}(P_{FA,i})^{ceil(N/2)}*(1-P_{FA,i})^{N-(ceil(N/2)} \text{ , N is odd} \qquad (8)$$

$$P_{FA,MAJORITY}=\sum_{N/2}^{N}\binom{N}{N/2}(P_{FA,i})^{(N/2)}*(1-P_{FA,i})^{N-(N/2)} \text{ , N is even} \qquad (9)$$

Where ceil(x) rounds the elements of N/2 to the nearest integers greater than or equal to x.

Figure 2 shows the frame structure for a cognitive radio with periodic spectrum sensing where each frame consists of one sensing slot and one data transmission slot. There are two parameters effect the spectrum sensing: probability of detection (PD) and probability of false alarm (PFA). The lower the probability of false alarm, the more chances the channel can be reused, thus the higher achievable throughput [11]. The normalized achievable throughput for the secondary network is defined as:

$$Throughput = (1-\frac{\tau}{T})(1-P_{FA}) \qquad (10)$$

3. The Modified Decision Rule

The modified hard decision rule optimize the performances of OR, AND and majority rule. This can be done by letting the fusion center makes a final decision of one when half plus one or more (middle plus one MPO) of the local decisions sent to the fusion center are one. The detection performance with MPO fusion rule can be evaluated by setting k = ceil(N/2)+2 when N is odd and k = (N/2)+1 when N is even in Equation (3) .So, the detection probability and the false alarm probability would be:

$$P_{D,MPO}=\sum_{ceil(\frac{N}{2})+1}^{N}\binom{N}{ceil\left(\frac{N}{2}\right)+1}(P_{D,i})^{ceil(N/2)+1}*(1-P_{D,i})^{N-(ceil(N/2)+1)} \text{ , N is odd} \qquad (11)$$

$$P_{D,MPO}=\sum_{(\frac{N}{2})+1}^{N}\binom{N}{\left(\frac{N}{2}\right)+1}(P_{D,i})^{(N/2)+1}*(1-P_{D,i})^{N-((N/2)+1)} \text{ , N is even} \qquad (12)$$

$$P_{FA,MPO}=\sum_{ceil(\frac{N}{2})+1}^{N}\binom{N}{ceil\left(\frac{N}{2}\right)+1}(P_{FA,i})^{ceil(N/2)+1}*(1-P_{FA,i})^{N-(ceil(N/2)+1)} \text{ , N is odd} \qquad (13)$$

$$P_{FA,MPO}=\sum_{(\frac{N}{2})+1}^{N}\binom{N}{\left(\frac{N}{2}\right)+1}(P_{FA,i})^{(N/2)+1}*(1-P_{FA,i})^{N-((N/2)+1)} \text{ , N is even} \qquad (14)$$

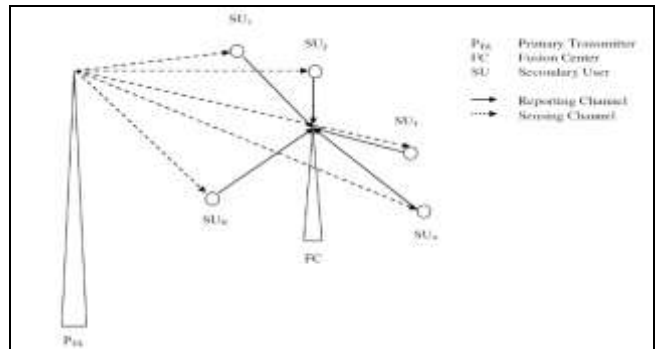Figure 3 shows the flowchart of the MPO method

Figure 1: System model of cooperative sensing
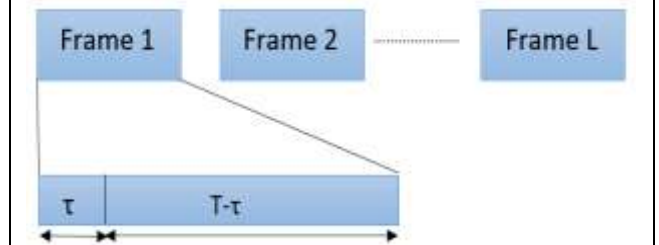

Figure 2. Frame structure for cognitive radio networks with periodic spectrum sensing (τ: sensing slot duration; $T - \tau$: data transmission slot duration; L: number of frames)
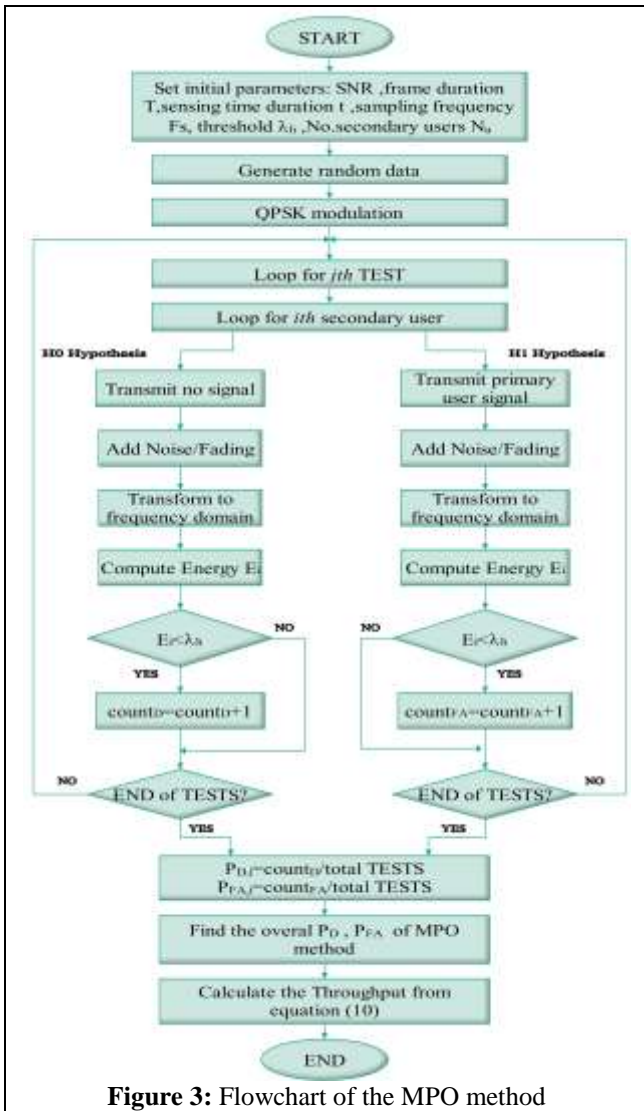
Figure 3: Flowchart of the MPO method

The simulation is done under AWGN and Rayleigh multipath fading channels. Table 1 shows the path delays for ITU Indoor Channel Model used for modeling the Rayleigh multipath fading channel in this paper.

Table 1.Multipath fading properties of ITU Indoor Channel Model

Tap	Relative delay (ns)	Average power(dB)	Doppler spectrum
1	0	0	Flat
2	50	-3	Flat
3	110	-10	Flat
4	170	-18	Flat
5	290	-26	Flat
6	310	-32	Flat

4. Simulation Result

This section presents the simulation results of the MPO decision rule and an evaluation to its performance. In simulations, quadrature phase shift keying (QPSK) signal is used for the primary user's signal. The energy detection scheme is employed for sensing the spectrum of the primary user, with sampling frequency of 6 MHz. The signal to noise ratio (SNR) is changed from -2 dB to 8dB and 18 dB in AWGN and Rayleigh fading channel respectively. The number of secondary user is changed from 1 to 7 and the

range of the sensing time is 0.5ms to 4ms and the frame duration (T) is 100 ms .the results are recorded by averaging the outcomes of 1000 simulation runs to obtain precise statistics.

The throughput versus different number of secondary users for the conventional methods and the proposed one under Rayleigh fading is presented in Figure 4. It is clear in this figure that the throughput increases when the number of sensing users increase for all rules types. The proposed method offers better throughput over all the conventional methods when the number of sensing nodes is 4 or more. The optimal sensing time is the time that achieves highest throughput.

Figure 5 shows the optimal sensing time versus the number of sensing users when majority and proposed rules are applied. It is seen that for each rule, the optimal sensing time decreases when the number of sensing nodes increases, and when number of users is 4, the proposed rule reduce the sensing time by 20% as compared with majority rule.

The signal to noise ratio (SNR) versus the probability of false alarm over AWGN and Rayleigh fading channels are presented in Figure 6 and Figure 7. In these two figures, the number of users is 7. As seen in these figures, the proposed rule achieves less false alarm probability as compared with majority rule especially at low signal to noise ratio values less than 4 dB. For instance, the PFA enhancement of the proposed method reaches 38.7% as compared with the conventional one in Figure 6 when SNR equals -1 dB. Under Rayleigh fading condition shown in Figure 7, the improvement introduced by the proposed rule over majority rule at SNR equals -1dB is around 45%.
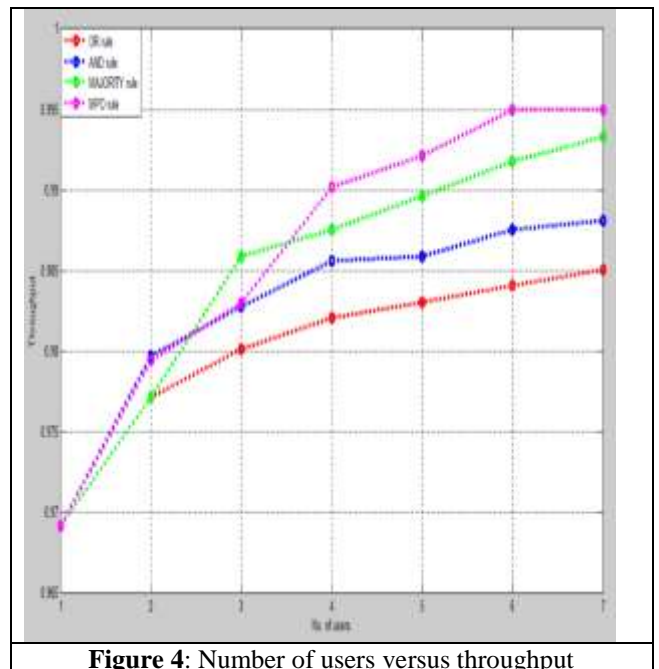

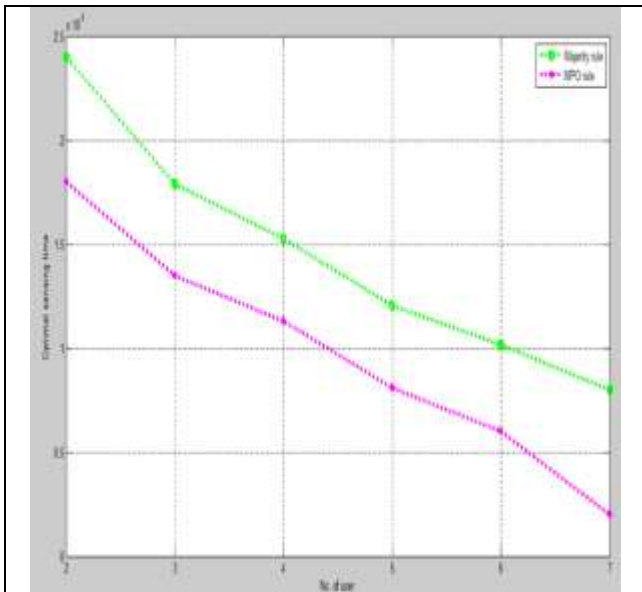**Figure 4**: Number of users versus throughput

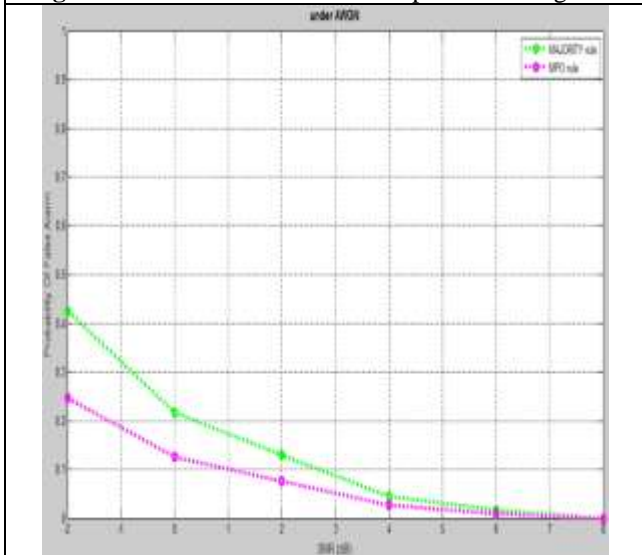**Figure 5:** Number of users versus optimal sensing time

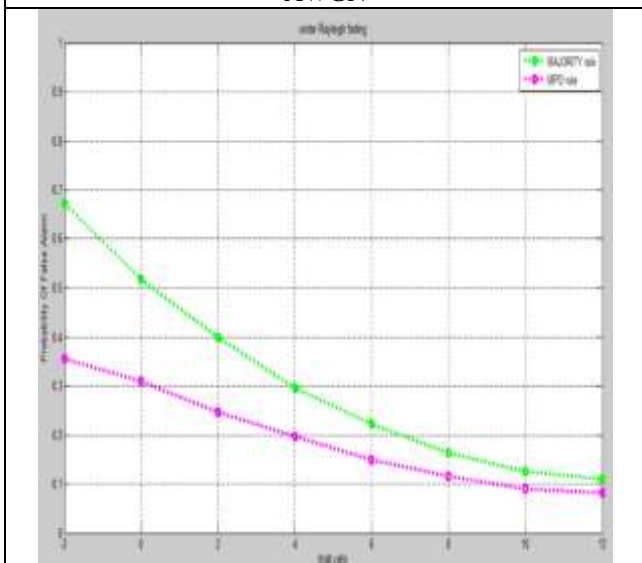**Figure 6:** SNR versus probability of false alarm over AWGN

Figure 7: SNR versus probability of false alarm over Rayleigh fading channel

5. Conclusion

An effective decision rule is required to decide the global decision accurately. In this paper, we proposed a modified decision rule to maximize the achievable throughput for the secondary users under the constraint that the primary users are sufficiently protected. The probability of false alarm is significantly decreased in the proposed rule as compared with majority rule. This decreasing in false alarm probability implies increasing the throughput. However, the proposed rule offers a good way to improve the throughput without too much complicating the decision mechanism. The optimal use of the proposed method is when the number of sensing nodes exceed or equal 4.

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