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Accuracy Analysis of 5-Bit Data and Decision Fusion Strategies in Cognitive Radio Networks

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Abstract

Cognitive radio allows unlicensed users to access licensed frequency bands through dynamic spectrum access so as to reduce spectrum scarcity. This requires intelligent spectrum sensing techniques like co-operative sensing which makes use of information from number of users. This paper investigates the use of energy detector and its simulation in MATLAB for licensed user detection. Simulation results show that implementing cooperative spectrum sensing help in better performance in terms of detection. Quantized combination scheme provides a better compromise between detection performance and complexity. This paper is further extended to the 5 bit data and decision fusion. Simulation results shows the accuracy of 5-bit decision at variable SNR values.

Keywords: Cognitive radio (CR), Dynamic Spectrum Access (DSA), Cooperative spectrum sensing, Energy detection, Fusion rules, Decision fusion, Data fusion.

Introduction

The traditional scheme of allocating radio frequency bands for wireless services results in an inefficient usage of the spectrum. Recent measurement in the United States show that more than 70% of licensed spectrum is not employed efficiently. For example, figure-1 shows an actual spectrum occupancy measured in Lawrence, Kansas during a weekday afternoon in August 2005[1]. Typically, there are a lot of gaps in the licensed spectrum. Inefficient usage of the radio spectrum, where a large portion of the licensed spectrum are underutilized and a small portion of the spectrum allocated to unlicensed users are congested, led Federal Communications Committee (FCC) to consider opportunistic access to the licensed spectrum by secondary users conditioned on limited or no interference on the primary users (PU) or licence holders[2]. Based on this ruling, new systems are under development to take advantage of the available bandwidth. With FCC's ruling both academia and industry showed considerable amount of interest in creating a cognitive radio system. Currently, several cognitive radio systems are being finalized by standardization bodies around the world. In 2008, a European group called the Cognitive Networking Alliance (Cognea) started to standardize their cognitive radio system. In Cognea, personal and portable devices should be capable to operate over unused bands in TV spectrum, known as the TV white space (TVWS) to transmit data and voice.

In section II, we revealed cognitive functionalities which includes cognitive cycle too. Formulation methods for hypothesis is being examined in Section III. Section IV, illustrates different types of spectrum sensing techniques. In Section V, we formulate the system model in CR networks. Then we investigate different fusion rules and propose a new quantized four-bit hard combination scheme in Section VI. Comparison between one to four bit hard combination scheme is shown in Section VII, respectively. Conclusions are given in Section VIII.

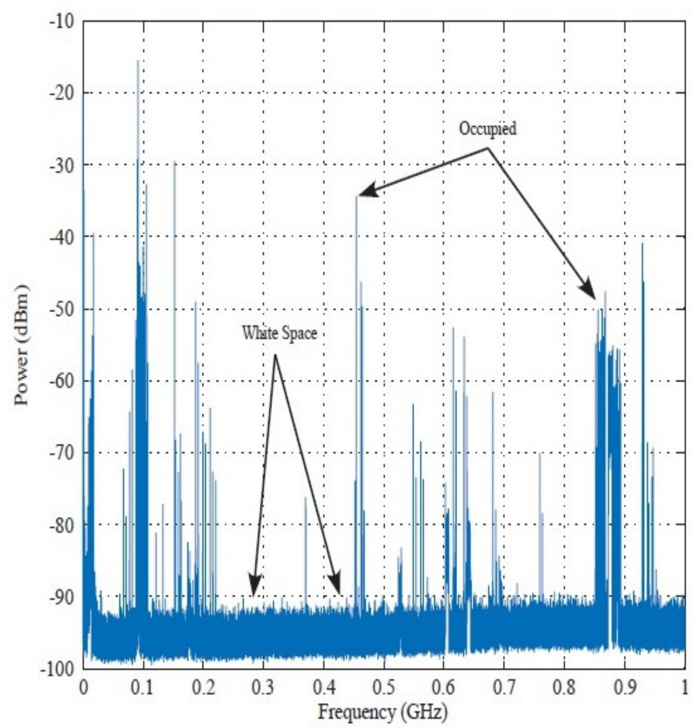

Figure-1
A spectrum occupancy measurement from 9kHz-1GHz[1]

Decision Fusion versus Data Fusion

The cooperative spectrum sensing approach can be seen where each cooperative partner makes a binary decision based on the local observation and then forwards one bit of the decision to the common receiver. At the common receiver, all 1-bit decisions are fused together according to an OR logic. We refer to this approach as decision fusion. An alternative form of cooperative spectrum sensing can be performed as follows. Instead of transmitting the 1-bit decision to the common receiver each CR can just send its observation value directly to the common receiver. This alternative approach is referred to this approach as data fusion. Obviously, the 1-bit decision needs a low bandwidth control channel.

Energy Detection

When the noise power is identified to the secondary user energy detection can be useful to detect the existence of the primary signal in case of Gaussian noise model. In this scheme it accumulates the energy of the received signal during the sensing interval and declares the band to be occupied if the energy surpasses a certain threshold. This threshold is set based on the desired probability of false alarm[3-4]. Energy detection, unlike the other schemes, does not require any information about the primary signal and channel gains and is robust to unknown fading channel. Compared to other methods it has simpler implementation and hence is less expensive. Therefore, in literature energy detection is mainly adopted for spectrum sensing. In order to measure the signal energy in frequency domain, the received signal is first selects the interesting bandwidth by a band pass filter and sampled, then converted to frequency domain taking FFT followed by squaring the coefficients and then taking the average over the observation band. Finally, according to a comparison between the average and threshold, the presence or absence of the PU can be detected as shown in figure-2. It is the simplest detection technique for spectrum sensing is Energy Detection.

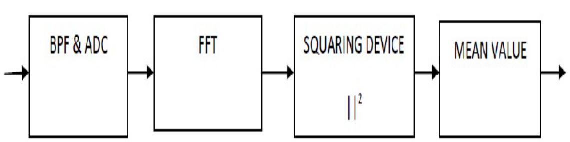

Figure-2
Frequency Domain Representation of Energy Detection

Energy detector measures the energy received from primary user during the observation interval. If energy is less then certain threshold value then it declares it as spectrum hole. Let r(t) is the received signal which we have to pass from energy detector. The working of this receiver section can also be well understood by the flow chart as shown in figure-3. We will consider a system model for explaining the whole process of data and decision fusion.

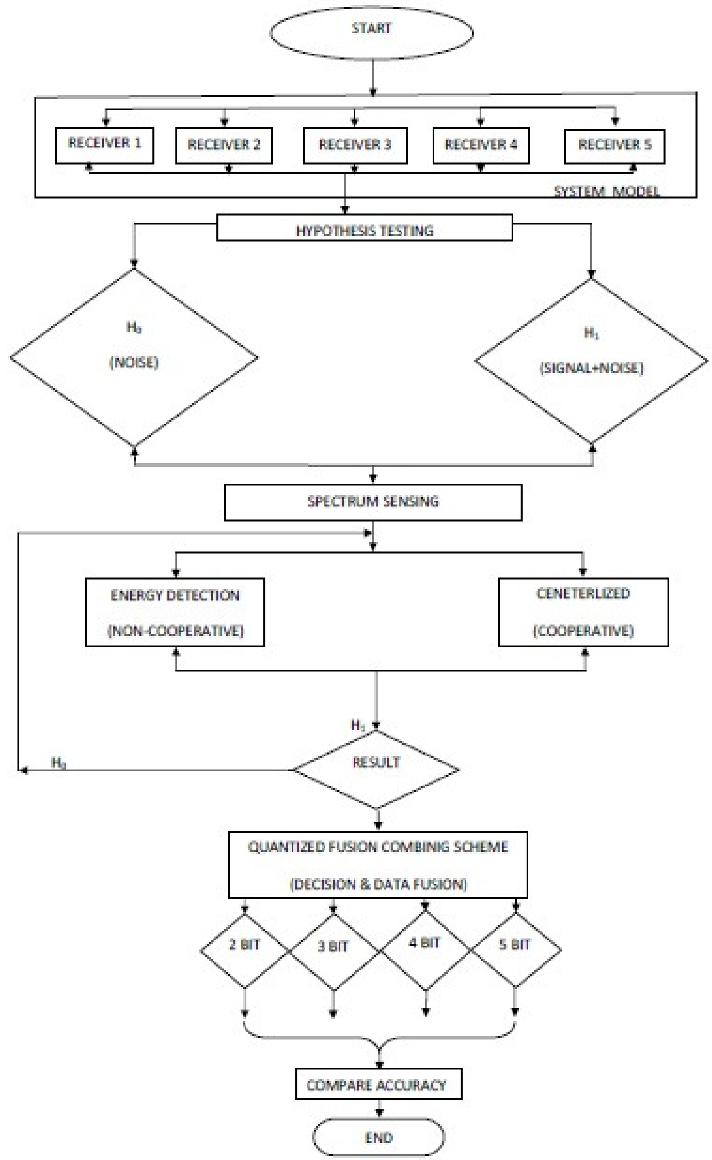

Figure-3
Receiver Section

System Model

Let there be a cognitive network with K cognitive users (such that K = 1,2,3,.....K) to sense the spectrum in order to detect the presence of PU. Assume that each CR performs local spectrum sensing independently by using N samples of the received signal. By taking two possible hypothesis H0 and H1 in binary hypothesis testing problem the problem of spectrum sensing can be formulated as:

$$H0 : x_k(n) = w_k(n) \quad (1)$$
$$H1 : x_k(n) = h_k\, s(n) + w_k(n) \quad (2)$$

where s(n) are samples of transmitted signal also known as primary signal, wk(n) is the receiver noise for the kth CR user, which is assumed to be an i.i.d. random process with zero mean and variance and h_k is the complex gain of the channel between the PU and the k^{th} CR user. H0 and H1 represents whether the signal is present or absent correspondingly. Using energy detector, the k^{th} CR user will calculate the received energy as:

$$E_k = \sum_1^N x_k^2(n) \quad (3)$$

If we consider the case of soft decision, each CR user forwards the entire result Ek to the FC where as in case of hard decision, the CR user makes one-bit decision given by Δk by comparing the received energy E_k with the predefined threshold λk .

$\Delta k = \{1, E_k > \lambda_k \}$ (4)

$\Delta k = \{0, \text{otherwise}\}$ (5)

$P_{d,k} = P\,r\{\Delta k=1|H1\} = Pr\{Ek > \lambda k\ |H1\}$ (6)

$P_{f,k} = P\,r\{\Delta k = 1|H0\} = P\,r\{Ek > \lambda k\ |H0\}$ (7)

Let λk = λ for all CR users, the detection probability, false alarm probability and miss detection $P_{m,k}$ over AWGN channels can be expressed respectively.

$$P_{d,k} = Q_m(\sqrt{2\gamma}, \sqrt{\lambda}) \quad (8)$$

$$P_{f,k} = \Gamma(m, \lambda/2)/\Gamma(m) \quad (9)$$

$$P_{m,k} = 1 - P_{d,k} \quad (10)$$

where γ is the signal to noise ratio (SNR), m=TW is the time bandwidth product, QN (., .) is the generalized Marcum Q function(.) and Γ(., .) are complete and incomplete gamma function respectively.

Quantised fusion or softened hard fusion:

As the best detection performance had been observed by soft combination scheme which is based on instantaneous SNR's of CR users. But in case of soft combination a large overhead is required for each CR user to feedback observation periodically. Whereas it requires only one bit of overhead for each CR user in hard combination scheme, but there is loss of information caused by local hard decisions that leads to performance degradation. A new softened hard combination scheme with till know two and three bit overhead is been observed till know. Now we have extended this up to five bit for each CR user, which accomplishes a good transaction among detection performance and complexity [5-6].

Two Bit Hard Combination Scheme: In this scheme of hard combination it is proposed that divide the entire range of the energy which is detected into four regions. The presence of the signal of interest is decided at the FC by using the following equation:

$$\sum_{i=0}^{3} \text{wi ni} \geq L \quad (11)$$

where the number of observed energies falling in region i known as n_i and the weight value of region i with w0 = 0;w1 = 1;w2 = 2 and w3 = 4 is known as w_i shown in Figure-4.

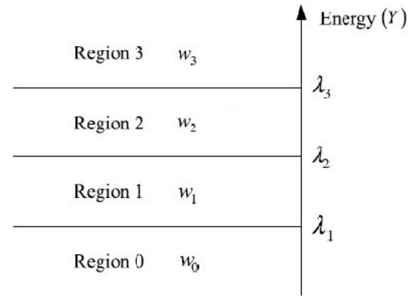

Figure-4
2-bit hard combination

Three Bit Hard Combination Scheme: In the three-bit scheme, similarly the threshold divides the whole range of the statistic into 8 regions, λ1 , λ2 , ...and λ7 as depicted in Figure-5. 3 bit of information is forwarded by each CR user where it points the region of the observed energies. Higher value will be forwarded for nodes which observes higher energies in upper region than those nodes that observe lower energies in lower regions. The final decision is made by comparing this sum with a threshold L [7-8].

$$\sum_{k=1}^{k} \text{wi ki} \geq L \quad (12)$$

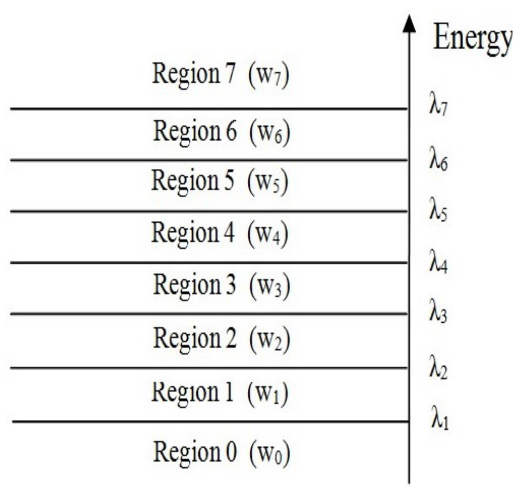

Figure-5
3-bit hard combination

Four Bit Combination Scheme: In the four-bit scheme, correspondingly the threshold divides the whole range of the statistic into 16 regions, λ_1, λ_2, and λ_{15} as depicted in Figure-6. 4 bit of information is forwarded by each CR user where it points the region of the observed energies. Higher value will be forwarded for nodes which observes higher energies in upper region than those nodes that observe lower energies in lower regions. The final decision is made by comparing this sum with a threshold L[7-8] shown in equation 4.13.

$$\sum_{k=1}^{k} wi\ ki \geq L \quad (13)$$

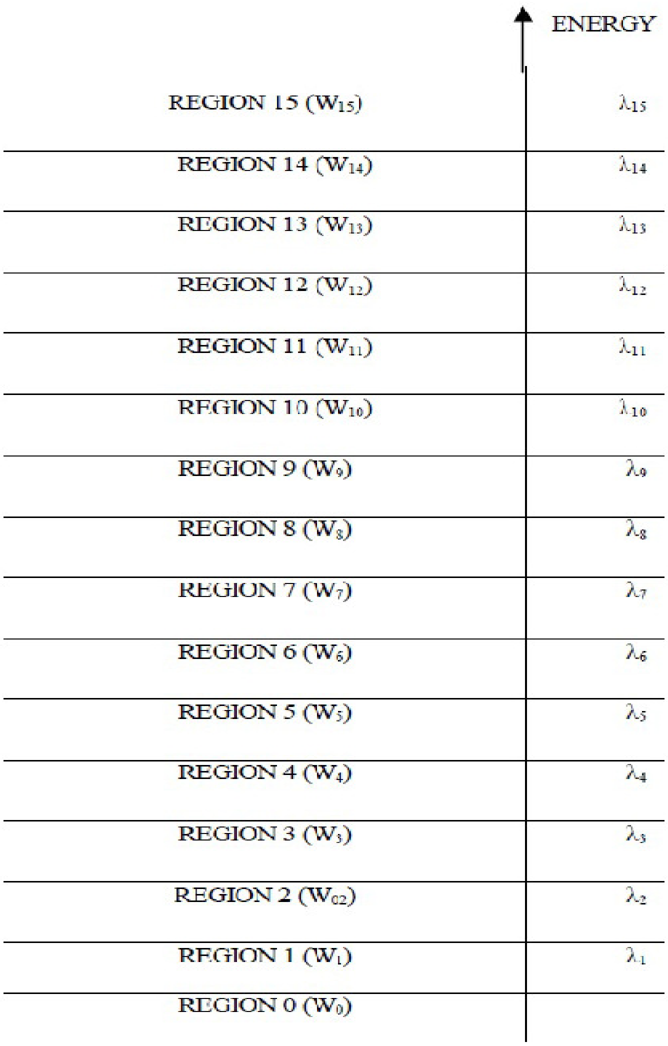

Figure-6
4-bit hard combination

D) Five Bit Combination Scheme: As shown in figure-7 in the five-bit scheme, same way the threshold divides the whole range of the statistic into 32 regions, λ1 , λ2 , ...and λ32 . 5 bit of information is forwarded by each CR user where it points the region of the observed energies. Higher value will be forwarded for nodes which observes higher energies in upper region than those nodes that observe lower energies in lower regions. The final decision is made by comparing this sum with a threshold L as shown in equation 13.

Simulation and Results

In this section we will show the detection performance of our scheme through simulations, and compare its performances using different combination fusion schemes. From two till five bit quantized schemes are compared in term of detection performance. For the simulations, we consider 20 CR users. Each user has different SNR, the OR rule has better detection performance than the AND rule, which provides slightly better performance at low P_{fa} than the OR, because the data fusion centre decide in favour of H1 when at least one CR user detects. For much better performance than the 2-bit and 3-bit combination scheme Figure-indicates that the proposed 4-bit and 5-bit combination scheme is more effective at the cost of one more bit of overhead for each CR user, this scheme had achieve a good trade-off among detection performance and overhead.

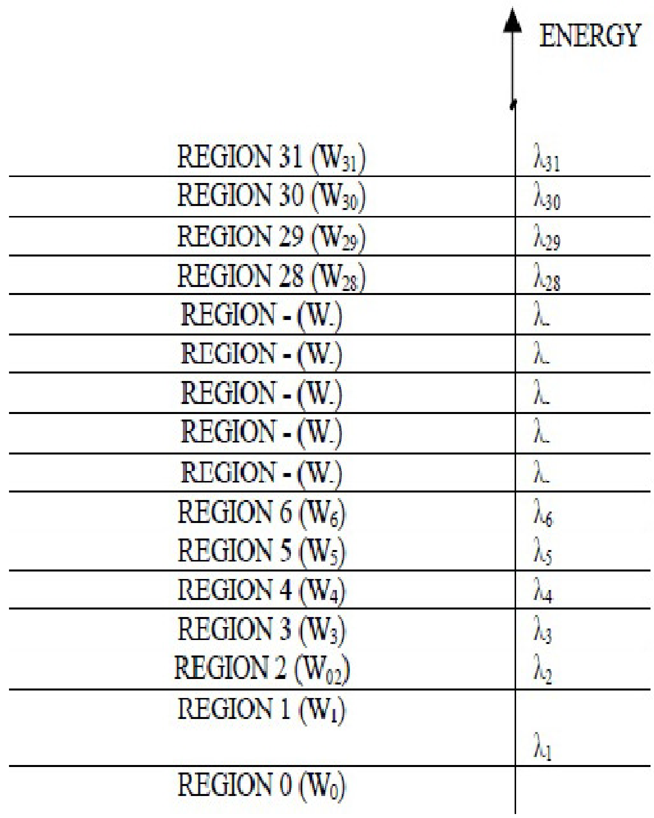

Figure-7
5-bit hard combination

2 bit combination scheme: In 2-bit combination scheme we will perform simulation for SNR versus decision accuracy which reveals that OR-ing gives best result when we take only 2 bit of the decision as shown in Figure-8. Different value of SNR is used for this simulation. ROC curve between Pd Vs Pf is also shown in Figure-9.

3 bit combination scheme: 3-bit combination scheme also shows simulation for SNR versus decision accuracy which reveals that OR-ing gives best result when we take only 3 bit of the decision as shown in Figure-10. Different value of SNR is used for this simulation also. ROC curve between Pd Vs Pf is also shown in Figure-11.When we compare it with 2-bit scheme we will observe that 3-bit provides much better results.

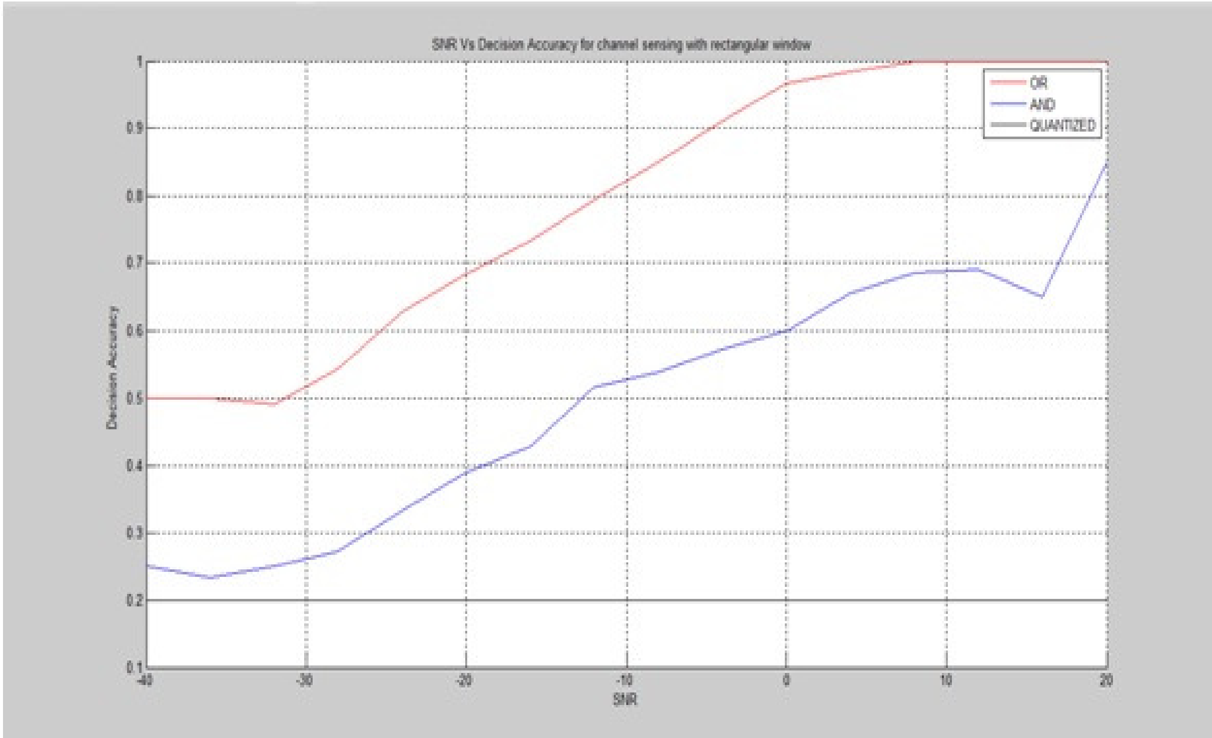

Figure-8
2-bit SNR Vs Decision accuracy

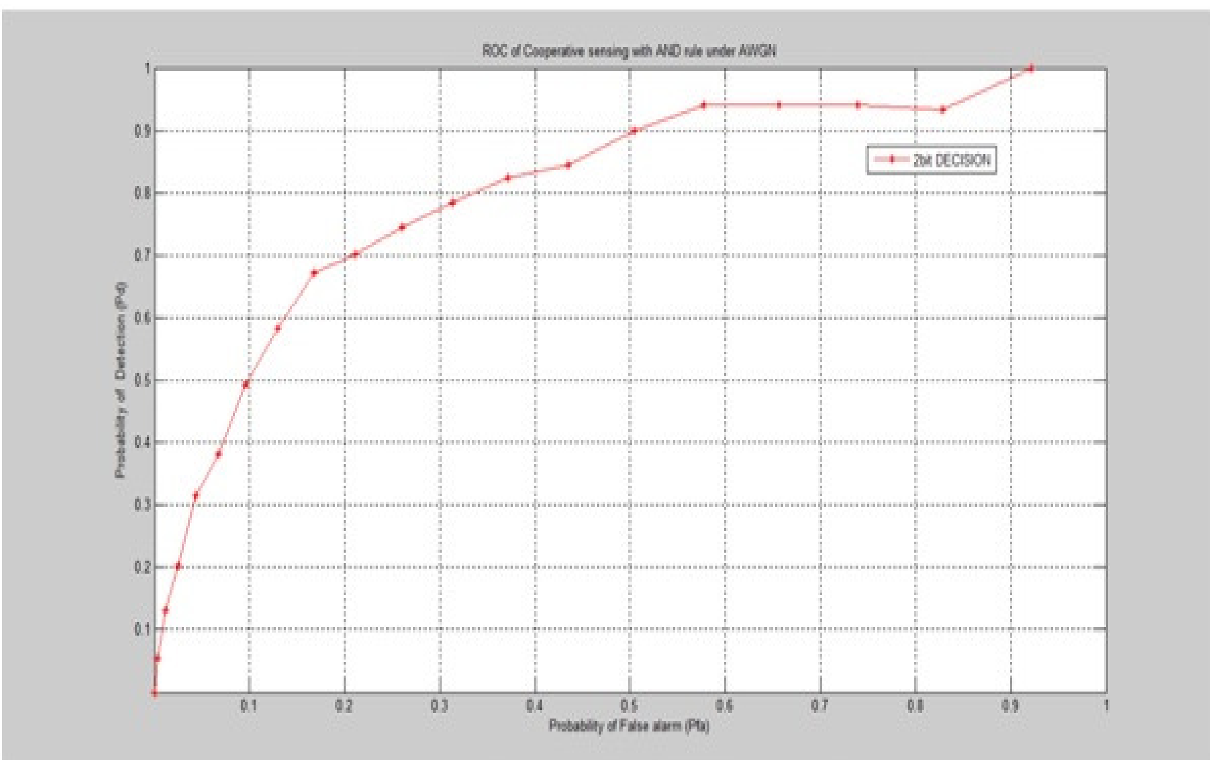

Figure-9
ROC curve for 2-bit quantized data fusion under AWGN channel

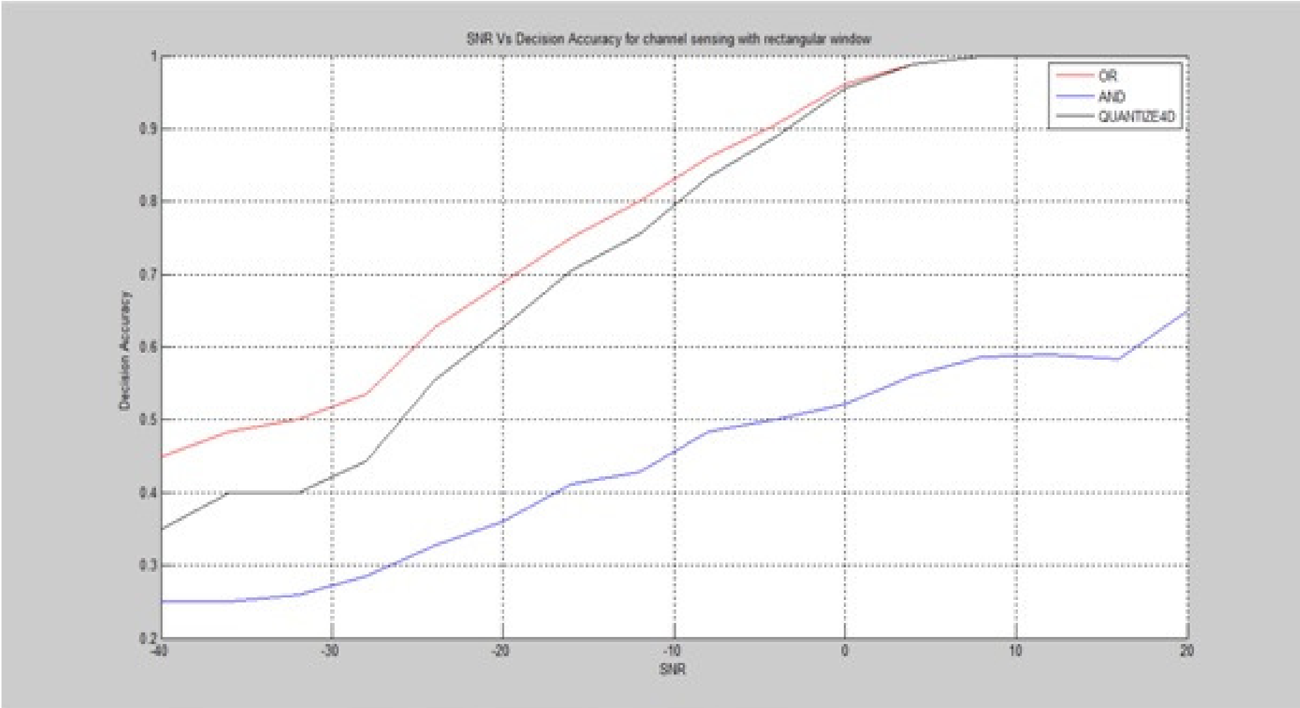

Figure-10
3-bit SNR Vs Decision accuracy

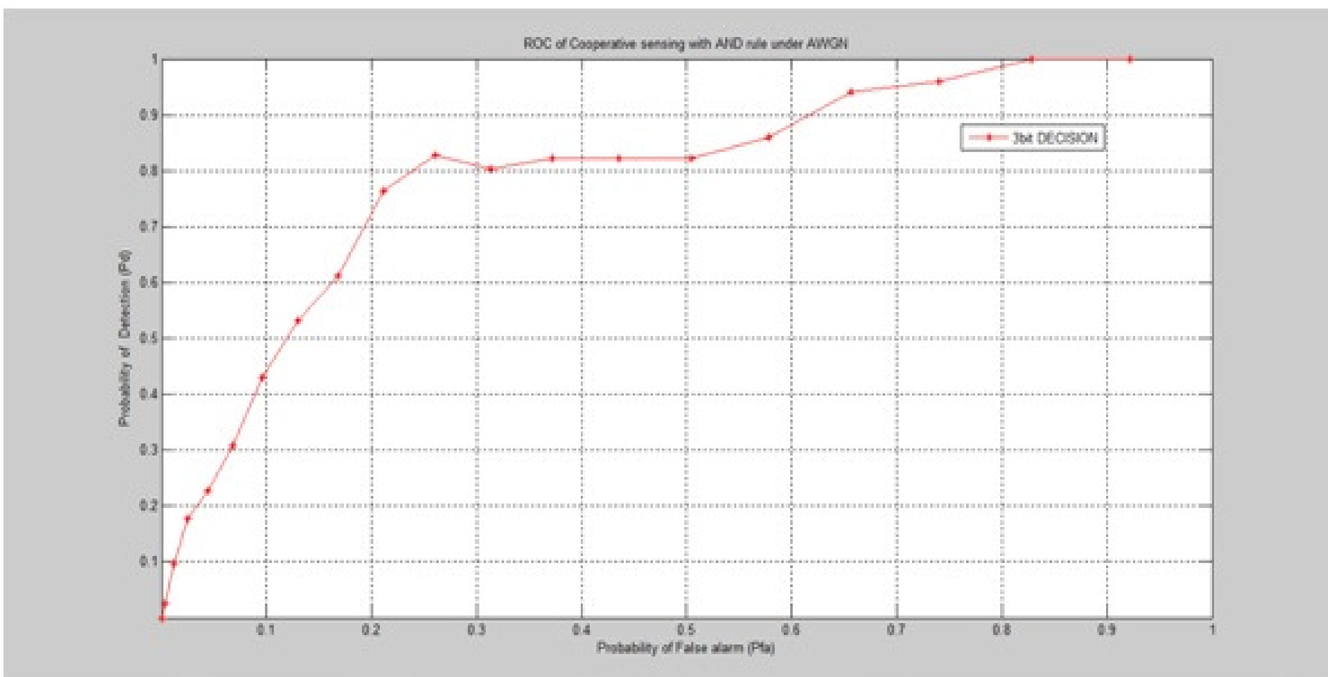

Figure-11
ROC curve for 3-bit quantized data fusion under AWGN channel

4 bit combination scheme: In case of 4-bit combination scheme when we compare it with 2 and 3-bit we will detect that 4-bit provides much more better results. simulation for SNR versus decision accuracy which reveals that OR-ing gives best result when we take only 4 bit of the decision as shown in Figure-12. Different value of SNR is used for this simulation also. ROC curve between Pd Vs Pf is also shown in Figure-13.

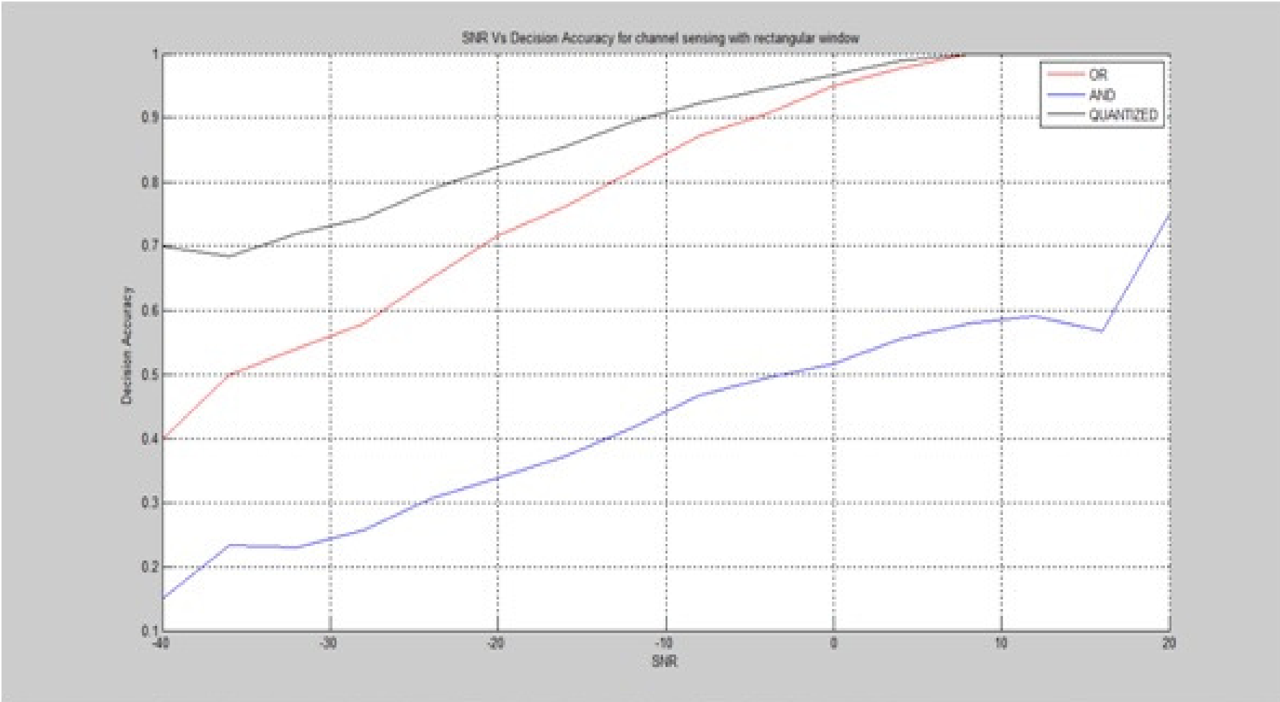

Figure-12
4-bit SNR Vs Decision accuracy

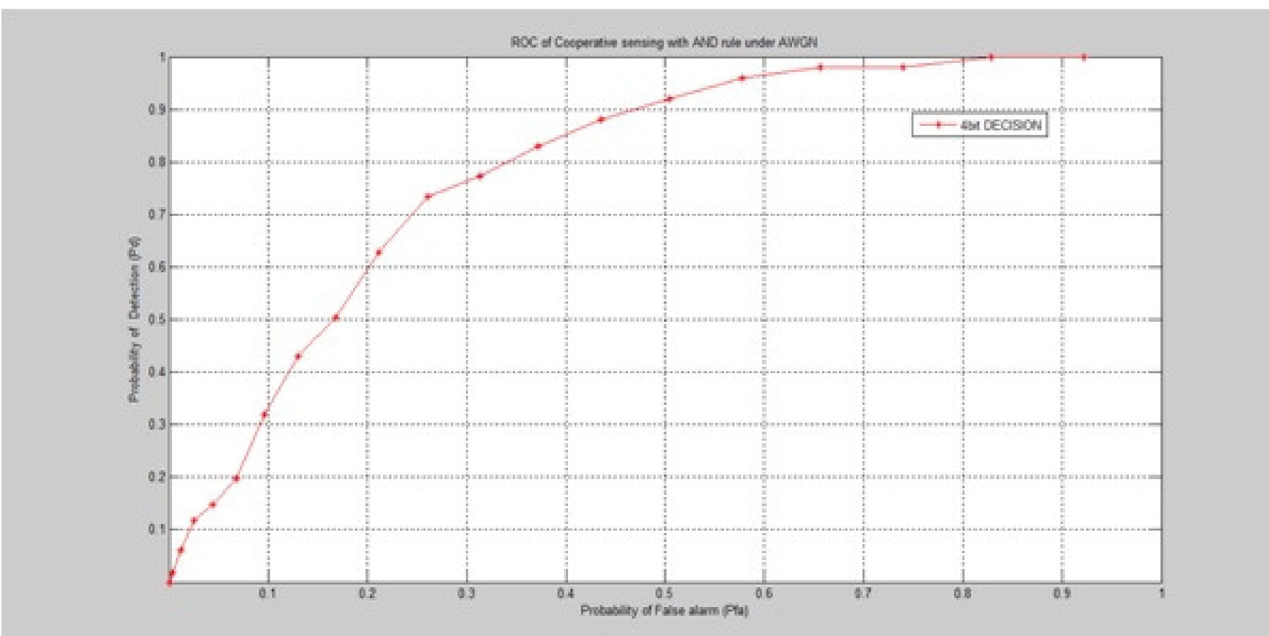

Figure-13
ROC curve for 4-bit quantized data fusion under AWGN channel

5 bit combination scheme: In 5-bit combination scheme illustrates simulation for SNR versus decision accuracy which reveals that OR-ing gives best result when we take only 5 bit of the decision as shown in figure-14. Different value of SNR is used for this simulation also. ROC curve between Pd Vs Pf is also shown in figure-15. When we compare it with all other scheme we will monitor that 5-bit decision provides best results.

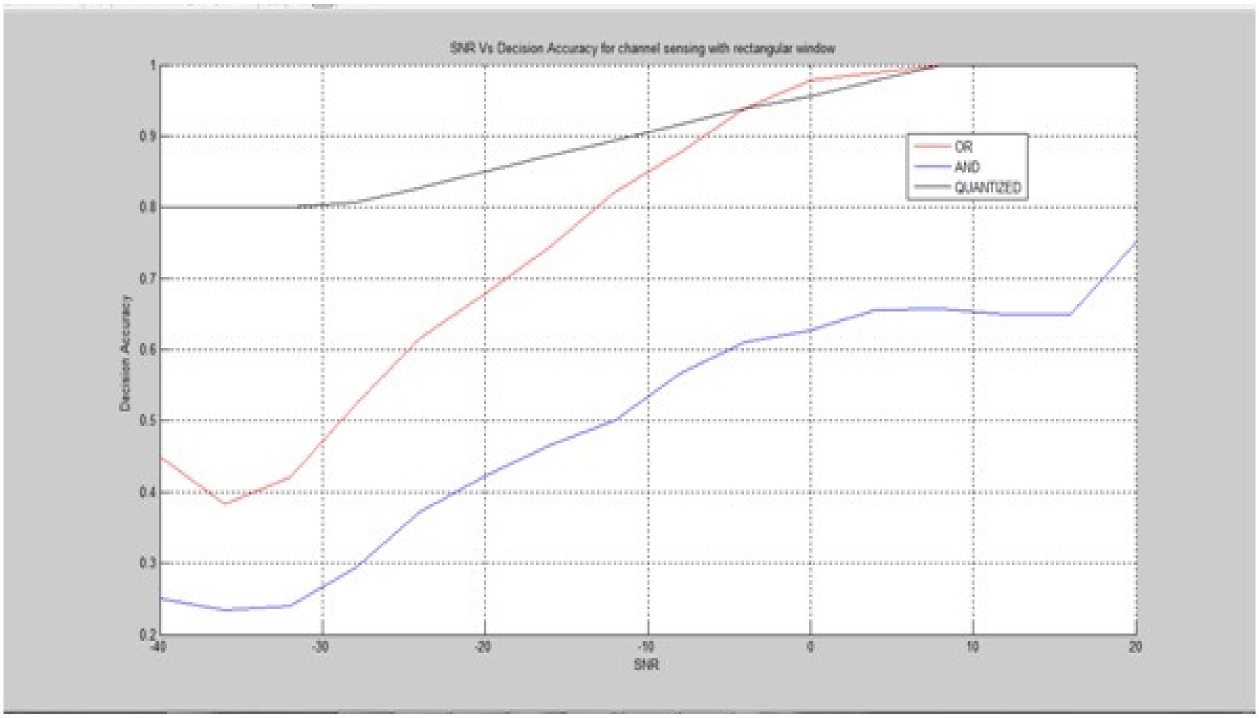

Figure-14
5-bit SNR Vs Decision accuracy

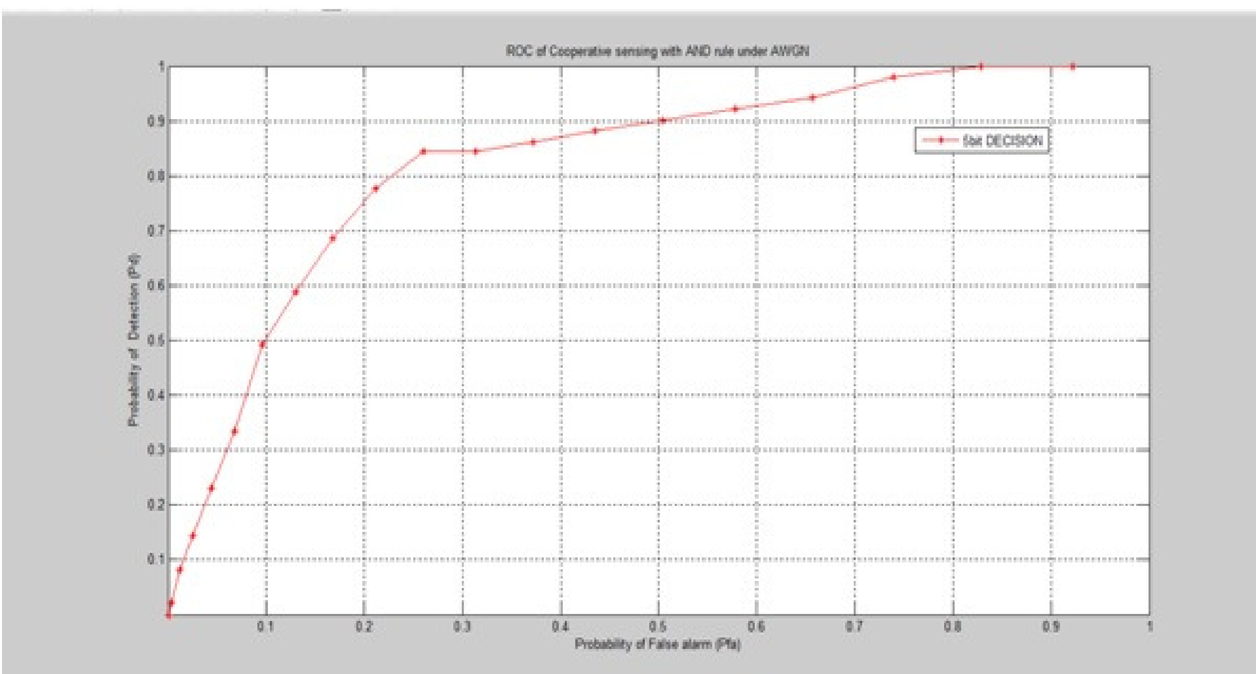

Figure-15
ROC curve for 5-bit quantized data fusion under AWGN channel

Conclusion

In this paper we have extended the three bit scheme and proposed a new scheme with four and five-bit overhead for each CR user. Simulation results demonstrates that the proposed combination scheme exhibits comparable performance between hard and soft combination scheme and thus achieves a good trade-off among performance and complexity. We have illustrated simulation results for starting from 2-bit up to 5-bit decision. It demonstrates that as we increase the no. of bits of decision our accuracy will also increase with also an increase in overhead. Different SNR are values are considered for curves that are shown between SNR Vs Decision accuracy and ROC curve for quantized data fusion under AWGN channel.

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