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Performance Analysis of Optimal Spectrum Sensing Frameworks for Cognitive Radio

R. Jayarani
Lecturer, Dept. of Electronics and Communication Engineering, Government Polytechnic College, Trichy, India

***Abstract*: Cognitive Radio (CR) technology is considered as a promising technology for the issues of spectrum scarcity. It has been more popular in recent years, one of the best cognitive capability is environment awareness. Spectrum measurement is very important in the radio environment awareness for to use the spectrum effectively. Since ground-truth observation is the most convincing method for spectrum measurement. A constraint in the cognitive radios is the lack of knowledge about the primary signal and channel gain statistics at the secondary users. Therefore, a practical composite hypothesis approach is used which does not require any prior knowledge or estimates of these unknown parameters. Detection delay is an important performance measure in spectrum sensing. Quickest detection aiming to minimize detection delay so it apply here to spectrum sensing. Interference threshold based on energy setting in cognitive radios is a non-convex optimization problem. Genetic algorithm solves optimization problem, it takes several iterations to fix the threshold. The proposed Hybrid Differential evaluation algorithm significantly improves the long term achievable throughput which, reduces the spectrum sensing time and increases the performance by fully utilizing the spectrum.**

***Keywords*: Radio environment awareness, spectrum measurement, spectrum sensing, cognitive radio.**

1. Introduction

Today wireless field is rapidly evolving. This started with Guglielmo Marconi first radio broadcast from England to one person in Nova Scotia. It was the radio equivalent of flying an airline's passengers across the Atlantic one at a time. New radio technologies keep coming along Wi-Fi, WiMAX, Bluetooth, ZigBee, the growing panoply of cellular voice and digital services, broadcast satellite, and more. Each requires a unique hardware appropriate to its special way of sending and receiving radio waves. Due to the large number of standards, spectrum availability has become an important issue. Spectrum usage regulations not allowing unlicensed users to operate in a licensed spectrum. However, it has been observed that the entire licensed spectrum is not used at all places all the time. An unlicensed user can take advantage of such a situation to communicate thereby increasing spectrum efficiency. This is the basic idea behind Cognitive Radio (CR). Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming RF stimuli by making corresponding changes in certain operating parameters (e.g., transmit-power, carrier-frequency, and modulation strategy) in real-time, with two primary objectives in mind: highly reliable communication whenever and wherever needed; efficient utilization of the radio spectrum [1]. Cognitive radio shall sense the environment, analyze and learn sensed information and adapt to the environment. A cognitive radio can sense spectrum and detect "spectrum holes" which are those frequency bands not used by the licensed users or having limited interference with them.

Spectrum sensing refers to detecting the unused spectrum (spectrum holes) and sharing it without harmful interference with other secondary users. In cognitive radio technology, primary users can be defined as the users who have the highest priority on the usage of a specific part of the spectrum. Secondary users have lower priority, and should not cause any interference to the primary users when using the channel. Spectrum sensing is still in its early stages of development. A number of various methods are proposed for identifying the presence signal in transmissions. In some another approaches, characteristics of the identified transmission are detected for deciding the signal transmission as well as identifying the type of signal. Spectrum sensing is a key element in cognitive radio communications as it must be performed before allowing unlicensed users to access a vacant licensed band. The essence of spectrum sensing is a binary hypothesis-testing problem:

H0: Primary user is absent
H1: Primary user is present (1)

The key metric in spectrum sensing are the probability of correct detection(Pd) and two types of error in spectrum sensor, the first error occurs when the channel is vacant (H0) but the spectrum sensor can decide the channel is occupied, the probability of this event is the probability of false alarm(Pf), the second error when channel is occupied (H1) the spectrum sensor can decide the channel is unoccupied, the probability of this event is probability of misdetection(Pm).

Pd=prob {Decision=H1/H1} (2)
Pf=prob{Decision=H1/H0} (3)
Pm=prob{Decision=H0/H1} (4)

We proposed the hybrid differential evaluation method for spectrum sensing. Its main objective is to reduce the unsuccessful tries in differential evaluation algorithm to increase the performance of DE. Other methods that are previously used for spectrum sensing are co-operative, non-cooperative and interference based detection.

2. Co-operative techniques

Decentralized uncoordinated techniques: In uncoordinated techniques Cognitive Radio will independently detects the channel and will vacate the channel when it finds a primary user without informing the other users. So Cognitive Radio users will experience bad channel realizations detect the channel incorrectly thereby causing interference at the primary receiver. So these are not advantageous when compared to coordinated techniques.

Centralized coordinated techniques: Here in this technique we have Cognitive Radio controller. When one Cognitive Radio detects the presence of primary user then it intimates the Cognitive Radio controller about it. Then that controller informs all the Cognitive radio users by broadcast method. This is further more classified into two types as partially cooperative in which network nodes cooperate only in sensing the channel. The other technique is totally cooperative in which nodes cooperate in relaying each other's information in addition to cooperatively sensing the channel [2].

Decentralized coordinated techniques: This type of coordination implies building up a network of cognitive radios without having the need of a controller. Various algorithms have been proposed for the decentralized techniques among which are the gossiping algorithms or clustering schemes, where cognitive users gather to clusters, auto coordinating themselves. The cooperative spectrum sensing raises the need for a control channel, which can be implemented as a dedicated frequency channel or as an underlay UWB channel.

3. Non Co-operative techniques

Matched filter detection: Matched filtering is known as optimal method for detection of primary users when the transmitted signal is known. It is a linear filter designed to maximize the output signal to noise ratio for given input signal. It is obtained by correlating a known signal, with an unknown signal to detect the presence of the known signal in the unknown signal. This is equivalent to convolving the unknown signal with a time-reversed version of the signal. Convolution is at the heart of matched filters. Convolution does essentially with two functions that it places one function over another function and outputs a single value suggesting a level of similarity, and then it moves the first function an infinitesimally small distance and finds another value. The end result comes in the form of a graph which peaks at the point where the two images are most similar. The matched filter is the optimal linear filter for maximizing the signal to noise ratio (SNR) in the presence of additive white stochastic noise. Matched filtering requires cognitive radio to demodulate received signals. Hence it requires perfect knowledge of the primary users signalling features such as bandwidth, operating frequency, modulation type, pulse shaping and frame format. A matched filter compares two signals and outputs a function describing the places at which the two signals are most like one another. This is carried out by taking Fast Fourier Transform (FFT) of two signals, then multiplying their coefficients and after that taking Inverse Fast Fourier Transform (IFFT) of the result, the output can be find out.

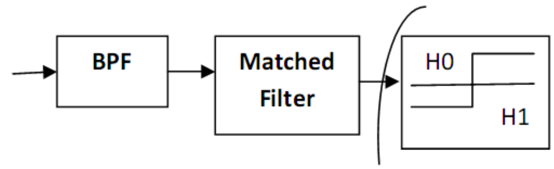

Fig. 1. Block Diagram of matched filter

The operation of matched filter detection is expressed as:

$$Y[n] = \Sigma\, h[n-k]\, x[k] \tag{5}$$

Where 'x' is the unknown signal (vector) and is convolved with the 'h', the impulse response of matched filter that is matched to the reference signal for maximizing the SNR. Detection by using matched filter is useful only in cases where the information from the primary users is known to the cognitive users.

Energy detection method: In this technique there is no need of prior knowledge of Primary signal energy. The block diagram for the energy detection technique is shown in the Figure. In this method, signal is passed through band pass filter of the bandwidth W and is integrated over time interval. The output from the integrator block is then compared to a predefined threshold [3]. This comparison is used to discover the existence of absence of the primary user. The threshold value can set to be fixed or variable based on the channel conditions

$$y(k) = n(k) \ldots\ldots\ldots\ldots\ldots\ H0 \tag{6a}$$

$$y(k) = h * s(k) + n(k) \ldots\ldots\ H1 \tag{6b}$$

Where y (k) is the sample to be analyzed at each instant k and n (k) is the noise of variance σ^2. Let y(k) be a sequence of received samples $k \epsilon \{1, 2\ldots.N\}$ at the signal detector, then a decision rule can be stated as,

$$H0\ldots\ldots \text{ if } \varepsilon > v \tag{7a}$$

$$H1\ldots\ldots \text{ if } \varepsilon < v \tag{7b}$$

Where $\varepsilon = E\ \ |y(k)|^2$ the estimated energy of the received signal and v is chosen to be the noise variance σ^2.

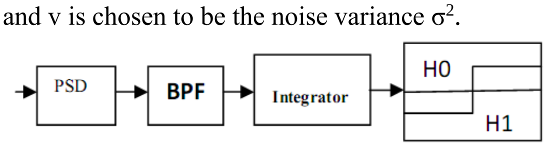

Fig. 2. Block diagram of energy detection

4. Interference based detection

Primary receiver detection: Primary receiver emits the local oscillator (LO) leakage power from its RF front end while receiving the data from primary transmitter. It has been suggested as a method to detect primary user by mounting a low cost sensor node close to a primary user's receiver in order to detect the local oscillator (LO) leakage power emitted by the RF front end of the primary user's receiver which are within the communication range of CR system users [6]. The local sensor then reports the sensed information to the CR users so that they can identify the spectrum occupancy status. We note that this method can also be used to identify the spectrum opportunities to operate CR users in spectrum overlay.

Interference temperature management: Unlike the primary receiver detection, the basic idea behind the interference temperature management is to set up an upper interference limit for given frequency band in specific geographic location such that the CR users are not allowed to cause harmful interference while using the specific band in specific area. Typically, CR user transmitters control their interference by regulating their transmission power (their out of band emissions) based on their locations with respect to primary users. This method basically concentrates on measuring interference at the receiver [2]. The operating principle of this method is like an UWB technology where the CR users are allowed to coexist and transmit simultaneously with primary users using low transmit power that is restricted by the interference temperature level so as not to cause harmful interference to primary users.

5. Differential evolution

DE are population based direct search algorithms used to solve continuous optimization problems. DE aims at evolving NP population of D dimensional vectors which encodes the G generation candidate solutions $X_{i,G}=\{ X^1_{i,G} \ldots\ldots X^D_{i,G}\}$ towards the global optimum, where i = 1…….NP. The initial candidate solutions at G = 0 are evolves in such a way as to cover the decision space as much as possible by uniformly randomizing the candidates within the search domain [4].

$$X_{i;G} = X_{min} + rand(1; 0) * (X_{max} - X_{min}) \quad (8)$$

where i = 1…….NP.
$X_{min} = \{X^1_{min} \ldots X^D_{min}\}$,
$X_{max} = \{X^1_{max} \ldots X^D_{max}\}$ and
rand(1; 0) is a uniformly distributed random number between 0 and 1.

1) The population

Differential evolution is a population based optimization method. Assume the population contains Np individuals. $X'_{i,G}$ is the i^{th} individual of G^{th} generation of the population. The first population is selected randomly in differential evolution. Figure shows the first random population in a two dimensional.

For every individuals (target vectors) $X_{i;G}$ at generation G,a mutant vector $V_{i;G}$ called the provisional or trial offspring is generated via certain mutation schemes. The mutation strategies implemented in this study are:

- DE/rand/1:

$$V_{i;G} = X_{r1;G} + F *(X_{r2;G} - X_{r3;G}) \quad (9a)$$

- DE/best/1:

$$V_{i;G} = X_{best;G} + F * (X_{r1;G} - X_{r2;G}) \quad (9b)$$

- DE/rand-to-best/1:
-

$$V_{i;G} = X_{i;G}+F*(X_{best;G}- X_{i;G})+F*(X_{r1;G}- X_{r2;G}) \quad (9c)$$

- DE/best/2:
-

$$V_{i;G} = X_{best;G}+F*(X_{r1;G}- X_{r2;G})+F*(X_{r3;G}- X_{r4;G}) \quad (9d)$$

Where the indexes r1, r2, r3 and r4 are mutually exclusive positive integers and distinct from i. These indexes are generated at random within the range [1 PN]. $X_{best;G}$ is the individual with the best fitness at generation G while F is the mutation constant.

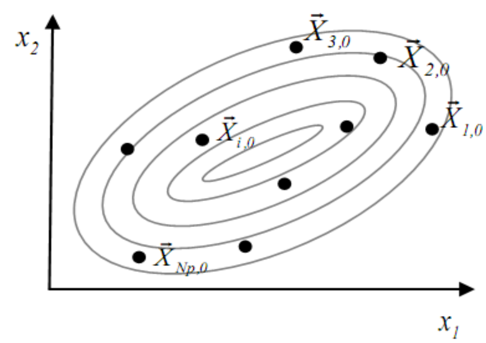

Fig. 3. Random population in a two dimensional problem Mutation

2) Cross over

After the mutants are generated, the offspring $U_{i;G}$ are produced by performing a crossover operation between the target vector $X_{i;G}$ and its corresponding provisional offspring $V_{i;G}$. The two crossover schemes i.e. exponential and binomial crossover are used in this study for all the DE algorithms implemented. The binomial crossover copied the jth gene of the mutant vector $V_{i;G}$ to the corresponding gene (element) in the offspring $U_{i;G}$ if rand(0; 1) <=CR or j = j_{rand}. Otherwise it is copied from the target vector $X_{i;G}$ (parent). The crossover rate CR is the probability of selecting the offspring genes from the mutant while jrand is a random number in the range [1 D], this ensure that at least one of the offspring gene is copied from the mutant. The binomial crossover is represented as:

$$U^j_{i;G} = \begin{cases} V^j_{i;G} \text{ if } (rand(0;1) <= CR \text{ or } j = j_{rand}) \\ X^j_{i;G} \text{ otherwise} \end{cases} \quad (10)$$

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3) The Selection

The final step in DE algorithm is the selection of the better individual for the minimization of the objective function X. This process can be defined as follows:

$$X^{j}_{i;G+1} = \begin{cases} U^{j}_{i;G} & \text{if } U^{j}_{i,G} <= X^{j}_{i,G} \\ X^{j}_{i;G} & \text{if } U^{j}_{i,G} > X^{j}_{i,G} \end{cases} \quad (11)$$

The selection process involves a simple replacement of the original individual with the obtained new individual if it has a better fitness. There are three control parameters in the DE algorithm: the mutation scale factor F, the crossover constant CR, and the population size NP. F€ [0.5,1.0]CR€ [0.8,1.0] NP≈10.n

6. Proposed method

Based on this interpretation, in this work, a hybrid differential evolution algorithm is proposed. In the hybrid version of differential evolution algorithm, in each generation, all individuals of the population are sorted based on their fitness. As evolved individual is evaluated based on three random selected individuals, this modification does not change the differential evolution algorithm. After that, to increase the number of successful tries in selection process of differential evolution algorithm, only half the of population which has worse fitness is evolved in each generation[5]. This modification can increase the probability of the selection of evolved individuals and consequently can increase the performance of differential evolution algorithm. The hybrid differential evolution algorithm (Hybrid DE/rand/1/bin).

- Step1: Select NP individuals $X_{i,G}$ randomly.
- Step2: For i = 1 to NP let $X_i = X_{i,G}$
- Step 3: If Np is even then let m = Np/2 else m = (Np+1)/2
- Step 4: While (convergence criterion not yet met) do steps 5 to 15
- Step 5: For i = 1 to Np do steps 6, 7
- Step 6: For j = i+1 to Np do steps 7
- Step 7: If $X_j > X_i$ then swap $X_{i,G}$, $X_{j,G}$ and swap X_i, X_j
- Step 8: For i = 1 to m do steps 9 to 14
- Step9: Select three different random indexes r1, r2 and r3
- between 1 to NP(i≠r1≠ r2≠r3)
- Step10: Let $V_{i;G} = X_{r1;G} + F *(X_{r2;G} - X_{r3;G})$
- Step11: For j = 1 to n do steps 12 to 13
- Step12: Select randomly r_j variable $(0 \le r_j < 1)$ and j_{rand} index
- $(1 \le j_{rand} \le n)$
- Step13: If r_j<=CR or $j=j_{rand}$ then $U^{j}_{i;G} = V^{j}_{i;G}$ else $U^{j}_{i;G} = X^{j}_{i;G}$
- Step14: : If $U^{j}_{i;G} <= X_i$ then $X^{j}_{i;G+1} = U^{j}_{i;G}$; $X_i = U^{j}_{i;G}$ else $X^{j}_{i;G+1} = X^{j}_{i;G}$
- Step15: For i = m+1 to NP let $X^{j}_{i;G+1} = X^{j}_{i;G}$

A. Comparison between DE and HYBRID DE

The comparison of the number of successful tries in the selection process of the original differential evolution algorithm with that of the modified algorithm was shown in figure. It is clear that the modified differential evolution algorithm was able to increase the number of successful tries and consequently increase the performance of the optimization algorithm [5].

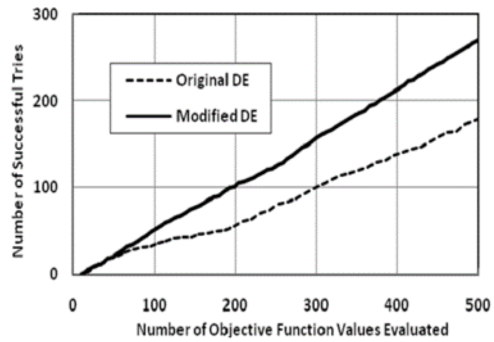

Fig. 4. Number of successful tries in the selection process of the original and modified differential evolution algorithms (DE/rand/1/bin version)

7. Simulation outputs

The proposed method hybrid differential evaluation algorithm is a genetic algorithm it performs the spectrum sensing through iteration process. Its main objective is to reduce the number of unsuccessful tries in the DE algorithm by choosing the best fitness value [7]. The results was used to find out the unused spectrum in the particular location. In that the number of subchannels M=1024, the modulation level is 4and Fs=20.

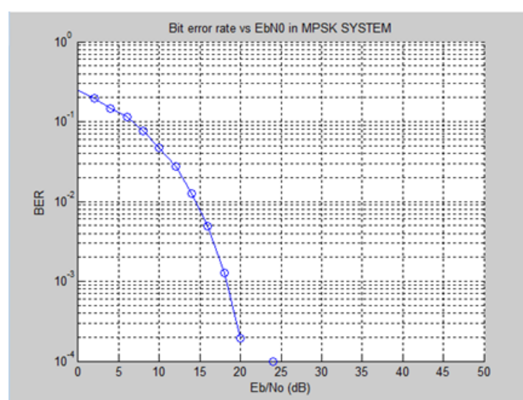

Fig. 5. Bit error rate vs EbN0 in MPSK system

The bit error rate of the transmitted signal was calculated for the normal region (i.e. SNR range between 0 to 20). The BER and the SNR was related as BER=Eb/N0

The iteration process was done in the above result to choose the better value. The minimum number of iterations that fixed for this process was 10.

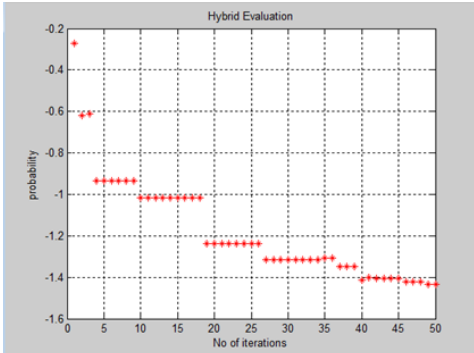

Fig. 6. Hybrid evaluation

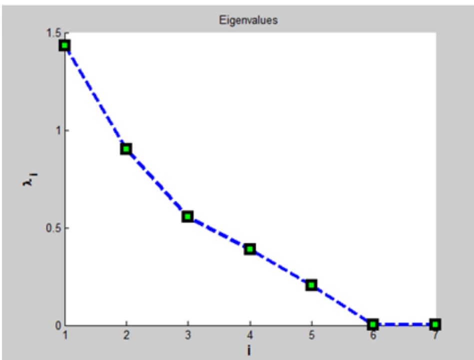

Fig. 7. Eigen values

The above result is between number of iteration and eigen values (error rate). It was performed to select the best signal from the channel with zerobit error rate.

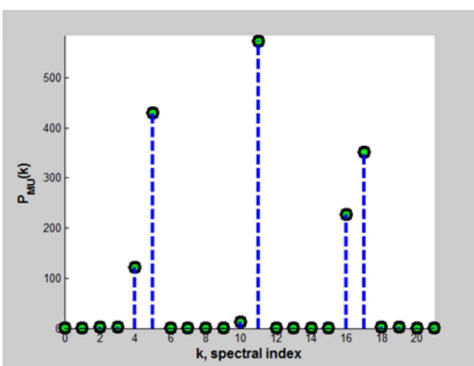

Fig. 8. Power spectral density of band

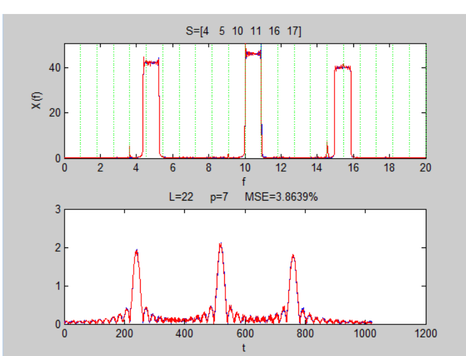

Fig. 9. Band occupied in particular time slot

The power spectral density was calculated to know usage of the particular spectrum through power. If the power is maximum, then the spectrum was fully occupied by the primary user's. it was calculated between the spectral index and power of the mobile unit.

The band occupied in the particular time slot was given and the mean square error also calculated the value is MSE=3.8639% where the p is the number of active cells in the particular channel and S is the support signal.

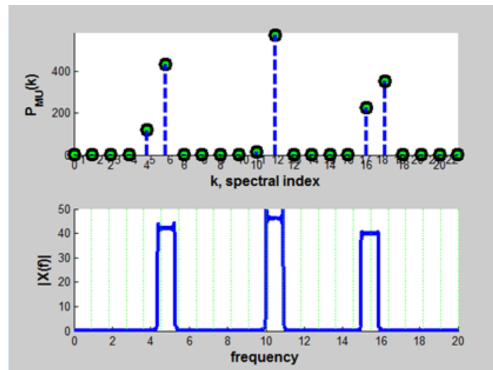

Fig. 10. Occupancy & unoccupancy of spectrum band using PSD and frequency

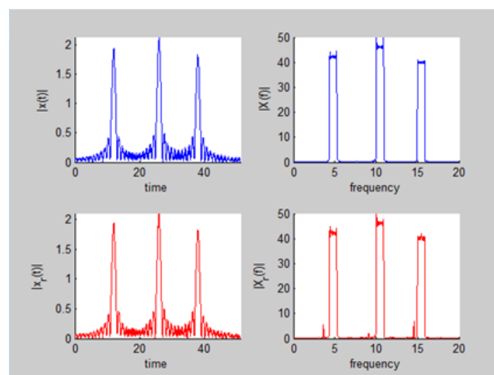

Fig. 11. Initial and changed condition of occupied band

The usage of spectrum was shown both in PSD and frequency. The occupancy of the channel was checked for every second to get the unused spectrum. The initial and changed condition of the spectrum band was shown in the result.

8. Conclusion

Hybrid Differential spectrum sensing method outperforms the traditional detection method when the noise was unknown which is the real scenario. Hence it is quite a robust method for spectrum sensing in Cognitive Radio when the noise is unknown. As the sample number increases for performing spectrum sensing, the performance of this method rises evidently. When the sample number is large enough the probability of detection is close to 1. In this prosed system we compare the performance of existing methods of spectrum sensing and finally we got the highly efficient performance by using hybrid differential evolution in terms of number of iterations, consistency of throughput and Localization of solution. Thus we reduced the time delay to sense the spectrum and the complexity of algorithm.

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