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Hybrid Differential Evolution based Throughput Optimized Cooperative Spectrum Sensing (CSS) in Cognitive Radio Network

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ABSTRACT

Cognitive radio network is considered as an eminent technology for dynamic accessing of wireless spectrum. The emergent wireless services like 5G and IoT faces the problem of spectrum scarcity. The shortage of wireless spectrum is mitigated by using the cognitive radio technology. In cognitive radio technology, the unused licensed spectrum is exploited by means of spectrum sensing. In spectrum sensing process, the longer sensing time provides good detection rate, but it will reduce the amount of time for data transmission and hence affects the achievable throughput of a SUs(Secondary Users). Based on sensing time and fusion scheme parameter an optimization problem is formulated to maximize the throughput of SUs. The designed optimization problem is jointly optimized using Hybrid Differential Evolution (HDE) to generate the optimal value of both sensing time and k-parameter of fusion scheme that maximize achievable throughput. The MATLAB based simulation is carried out based on Cognitive Radio (CR) system parameters to validate the robustness of the proposed optimization technique. From the simulated results, it is inferred that proposed HDE method outperforms traditional optimization techniques like Differential Evolution (DE) and Genetic algorithm (GA) in terms of achievable throughput.

Keywords: cognitive radio network, cooperative spectrum sensing, throughput optimization, Hybrid Differential Evolution (HDE).

1. Introduction

The wireless services such as 5G and IOT (Internet of Things) shows the development of wireless communication in current scenario. The wireless communication is fully depending on the spectrum as a medium for communication. Being limited nature of the wireless spectrum, the new wireless services are affected by the spectrum shortage. A survey was conducted by Federal

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Commission for Communication (FCC) for analyzing the usage of spectrum in time domain. The survey inferred that the spectrum which is allocated for certain wireless services are not well utilized remains unused with respect to time. The idea of using underutilized spectrum for new wireless services will mitigate the problem of spectrum shortage [1, 2]. The method of using wireless spectrum in dynamic manner instead of static manner is known as dynamic spectrum access. The dynamic usage of the spectrum is achieved by Cognitive Radio (CR) technology. In CR technology, the licensed user is called as Primary User (PU) and unlicensed user is called secondary user (SU) are coexist with each other. The SU uses the PU channel or band in temporary manner when the PU activity not present in the channel. The SUs which are deployed around PU network environment uses spectrum sensing technique to find the PU activity in that channel [3, 4]. The well known spectrum sensing method like energy detection, matched filter detection and cyclosationary detection are utilized for finding the activity of PU. Among these techniques, the energy detection is mostly preferred detection method for its easy implementation. When channel is become fading and shadowing, the performance of the energy detection is limited [5,6]. To improve the performance in fading channel, the Cooperative Spectrum Sensing (CSS) is used, instead of single SU , a idea of many SUs are engaged to perform sensing is said to be CSS. In spectrum sensing process, generally longer sensing time provides good detection rate, but the longer sensing time will reduce the amount of time for data transmission and hence affects the achievable throughput of a Cognitive User (CU). And also the performance of cooperative spectrum sensing depends on the sensing time and fusion scheme used.

In cooperative spectrum sensing, high energy consumption, reduced throughput, interferences and security threats are major existing issues. Most of research work has not given more importance to the throughput of the SUs which gives way for efficient utilization of the channel. In the paper [8] author studied the impact of k- parameter of the fusion rule and number of secondary user on the system throughput of SUs without considering influences on sensing time. Further author proposed a concept of optimizing the k- parameter of the fusion rule and number of secondary user and way of improve the achievable throughput using joint iterative optimization algorithm. [9] Rozeha A. Rashid *et.al*proposed concept of tradeoff between sensing and throughput under band sensing. In this work, the Fast Convergence–PSO is used as an optimizing technique to optimize sensing time alone without considering impact of k- parameter

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of fusion rule on the throughput of Secondary User (SUs).[10] Author proposed a method of maximizing the throughput of SUs by optimizing K-parameter of fusion rule without analyzing the influence of sensing time. The optimization problem is formulated and solved by using joint iterative algorithms.They produce good optimal solutions initially but when the problems become complex they stuck into local optimum. In [11], author formulated the optimization model based on sensing alone and solved by using genetic algorithm. The less control over operator used in genetic algorithm results in premature convergence. And also author doesn't give much importance to fusion schemes and its influence on system throughput [12].In this work author proposed the concept for possible way maximize the throughput of SUs. The optimization problem is formulated based on the condition when primary transmission is present and absent in cognitive radio (CR) network. The optimization problem solved by using PSO technique, produce only near optimal value of throughput only and problem of premature convergence. And also author addressed the optimization problem by optimizing sensing time alone and neglected the influence of other parameters like fusion scheme parameter on SUs throughput. So in this work, a special focus for influence of sensing time and K-parameter of fusion rule on throughput of SUs is studied and optimization problem is formulated based on this parameter for maximizing the secondary user throughput.

2. System Model

Let us consider the cognitive radio, with one PU and Nnumber of SU users is deployed and SUs are monitoring the transmission activity of PU. The energy detector is employed for detecting the primary user activity. Let H_0 and H_1 represents hypothetical notations of the absence and the presence of PU respectively. The signal received at the i_{th}SU detector at the given detection time is put forward as $y_i(n) = u_i(n)$and $y_i(n) = h_i s(n) + u_i(n)$ for hypothesis H_0 and H_1,where $s(n)$ represents PU signal, h_i is represents channel gain,$u_i(n)$ is denotes noise variances. The measured received PU signal power is given as $V_i = \left(\frac{1}{M}\right)\sum_{n=1}^{M}|y_i(n)|^2 \; for \; i = 1, \dots\dots N$,Where M represents number of signal sample. The probability of detection and the probability of false alarm of every energy detector is calculated as.

$$P_{d_i} = Q\left(\left(\frac{\varepsilon_i}{\sigma_u^2(\Upsilon+1)} - 1\right)\sqrt{\tau\, f_s}\right), \qquad i = 1, \dots\dots, N \qquad (1)$$

$$P_{f_i} = Q\left(\left(\frac{\varepsilon_i}{\sigma_u^2} - 1\right)\sqrt{\tau\, f_s}\right), \qquad i = 1, \dots\dots, N \qquad (2)$$

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Where $Q(.)$represents the right-tail probabilities of a normal Gaussian distributed function. Each secondary users carry out their own decision D_i , if $D_i = 1$ is indicated then it shows the channel with primary user is presentand ifthe$D_i = 0$ it indicate no primary user is absent. Then, theobtained decision results are sent to the SUs base station's common Fusion Centre (FC) for making final conclusion regarding the activity of PU.The FC uses combining rule for processing the decision result sent by every SU users. In this work, k-out-of-*N* fusion rule is established as a fusion rule for combining the decision results.Based on k-out-of–N fusion scheme, the net probability of detection (P_d) and probability of false alarm (P_f) of the CR network is given by

$$P_d(\tau, k, \varepsilon) = \sum_{i=k}^{N} \binom{N}{i} P_d(\tau, \varepsilon)^i (1 - P_d(\tau, \varepsilon))^{N-i} \quad (3)$$

$$P_f(\tau, k, \varepsilon) = \sum_{i=k}^{N} \binom{N}{i} P_f(\tau, \varepsilon)^i (1 - P_f(\tau, \varepsilon))^{N-i} \quad (4)$$

The Frame structure of CR network is comprised of sensing phase and transmitting phase, and it will uses a channel over two conditions. In first condition, if the FC finds the absence of primary User and in second condition, if the FC not able to find the PU occurrences. Let R_0 and R_1 represent the SUs throughput, when they are permitted to work in the absence and the presence of the PU, correspondingly, then the throughput of SUs is given by

$$R_0(\tau, k, \varepsilon) = C_0 P(H_0)\left(1 - \frac{\tau}{T}\right)\left(1 - P_f(\tau, k, \varepsilon)\right) \quad (5)$$

$$R_1(\tau, k, \varepsilon) = C_1 P(H_0)\left(1 - \frac{\tau}{T}\right)\left(1 - P_d(\tau, k, \varepsilon)\right) \quad (6)$$

Let $P(H_0)$ and $P(H_1)$ are the probability of PU absence and PU in presence in the band, correspondingly. The net achievable throughput at the SUs is represented as $R(\tau, k, \varepsilon) = R_0(\tau, k, \varepsilon) + R_1(\tau, k, \varepsilon)$.From above equation it is influenced, the average throughput over Cooperative spectrum detection relies on the parameter of the fusion rule K. So in this work, inclusion of K parameter as an optimization variable for the study of its influence on throughput under collaborative spectrum sensing is done.

2.1Formulation of the optimization problem

In this work, tradeoff between sensing and throughput is considered and by using collaborative detection to maximize the average achievable throughput of the CR network by optimizing

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sensing time, k parameters of Fusion scheme with enough guarding is offered to primary User. Then the optimization model maximization of SUs throughput is given by

$$\max_{\tau, k, \varepsilon} : R(\tau, k, \varepsilon) \qquad (7)$$

$$s.t: P_d(\tau, k, \varepsilon) \geq \overline{P_d}$$

$$0 \leq \boldsymbol{\tau} \leq T$$

$$1 \leq k \leq N$$

Where,$\overline{P_d}$is the minimum probability of detection that the fusion center needs to give for safeguarding thePU.The fusion scheme, k-out-of-N rule has a condition of $P_d(\tau, k, \varepsilon)/P_f(\tau, k, \varepsilon)$ property of monotonic increase in $P_d(\tau, \varepsilon)/P_f(\tau, \varepsilon)$for a stable K.The relation of $P_d(\tau, k, \varepsilon) = \overline{P_d}$is satisfied, then the optimization problem is formulated as

$$\max_{\tau, k} : \widehat{R_0}(\tau, k) \qquad (8)$$

$$s.t: \ 0 \leq \boldsymbol{\tau} \leq T$$

$$1 \leq k \leq N$$

Where $\widehat{R_0}(\tau, k)$represent the value of $R_0(\tau, k, \varepsilon\,)$by adapting predefined threshold ε selected in (8).

3. The Differential Evolution

The differential evolution algorithm is propounded by Kenneth price and Rainer store, and it is regarded as an influential optimization techniques and it is effectively used in numerous real time implementation. The nature of simple rule with less control parameter involved and efficiency of handling many optimizing problem like multi-objective nature, unimodal and multimodal and dynamic nature problem had made DE as a familiar optimization technique. Manyprevious works related to this, only single optimization variable is considered to maximize or minimize the optimization problem. But in this work, two sub optimization problems is required to the solve the optimization problem.The joint optimization of two sub-optimization problem i.e., sensing time τ and K parameter of fusion scheme is to maximize the achievable throughput of the SUs. Therefore for the optimization algorithm that solve joint optimization problem easily with near optimal will be a good choice. An algorithm also possessing the best converging property, simple to implement and has less no of control values will have capability to solve the complex problem easily. The algorithm improves the candidate solution in intermediate operation like mutation technique may avoid the candidate solution from stuck into local optimum.

3.1Major Steps involved in Differential Evolution Scheme

DE is belonging to evolutionary algorithm, population based one and that solve the given problem by sampling the objective function from random selected position. In DE, four steps are required to make the algorithm such as, at the first initialization of parameter, then mutation operation is done and followed by crossover operation for better generation finally algorithm end with selection mechanism. However, when the nature of the optimization problem is multi-objective in nature the traditional DE shows sign of premature convergence.

3.2 PROPOSED HDE

The major operator in HDE is the migration operator, and it hybridizes the DE operator. The system of suggesting the migration operator is based on two interpretations. First, good solutions would be less destroyed, while reduced solutions can differentiate a lot of novel features from good solutions. In this sense, the current population can be exploited adequately. Second, the mutation operator of DE can find out the new search space and construct the algorithm further robust. The algorithm for HDE is as follows

Step-1: Set up the control parameters of the HDE optimization method such as population dimension, scaling factor, crossover probability, and convergence condition, lower and upper limits of variables. Then the maximum number of iterations are carried out. And make an initial population of individuals with random positions are

$$X_i^0 = X_{min} + (X_{max} - X_{min}) * rand \quad (9)$$

Step-2: Compute the rate of the fitness function for each particle.

Step-3: Compare the fitness of every particle with personal best P_{best} .If the existing solution is superior to P_{best} , and then P_{best} is replaced by the current solution.

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Step-4: Compare the fitness of all particles with global best G_{best} .If the fitness of any particle is better than G_{best} and then replace G_{best} .

Step-5(**Mutation**): HDE produces a novel parameter by adding the weighted difference between two vectors to a third Vector. Mutant vector is produced based on the present individuals

$$Y_i^{G+1} = X_i^G + F\Big((X_{r1}^G - X_{r2}^G) + (X_{r3}^G - X_{r4}^G)\Big) \tag{10}$$

Where, F is called scaling factor or mutant factor which amplifies the differential variation. The range of mutation factors is among zero and one. r_1,r_2, r_3 and r_4 are mutually different points taken randomly from population not coinciding with the current control parameter.

Step-6(**Crossover**): The mutant vectors are mixed with the vector called target vector to form a new vector called a trial vector. The parameter mixing is called crossover. Every generation of i_{th} individual is replicated from a mutant vector.

Step-7(**Selection**): The parent is substituted by its offspring if the fitness of the offspring is superior to that of the parent.

Step-8(**Migration**): Migration operation is utilized to renew a new varied population of individuals. The new Population is supported on the best individuals (XbG+1). The h_{th} generation of i_{th} individual is given as

$$X_{hi}^{G+1} = \begin{cases} round\left(X_{hb}^{G+1} + \rho_1(X_{h\ min} - X_{hb}^{G+1})\right), if\ \rho_2 < \dfrac{X_{hi}^{G+1} - X_{h\ min}}{X_{h\ max} - X_{h\ min}} \\ round\left(X_{hb}^{G+1} + \rho_1(X_{h\ min} - X_{hb}^{G+1})\right), \quad otherwise \end{cases} \tag{11}$$

Step-9: Repeat steps 2 to 8 until desired fitness is reached.

Hybrid Differential Evolution (HDE) Algorithm implementation for obtaining the optimal sensing time and K-parameter.

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Set G = 0: Randomly select N_p vectors of (τ_i, k_i) ; (i= 1, 2, , ...N_p) from τ ∈[0, 1] and k ∈{1, 2, ...,N} withuniform probability distribution.

While *$G \leq G_{max}$* ***or*** *{optimal value is not sufficiently improved}* ***do***
G ←G+ 1;
for all *i∈{1, 2, ...,N_p}* ***do***
Randomly pick a, b and c ∈{1, 2, ...,N_p} − {i};
(τ_m,k_m) ← (τ_a, k_a) + F((τ_b,) − (τ_c, k_c));
Randomly pick k_1 and k_2∈[0, 1];
if *k_1>C_r* ***then*** *τ_t←τ_i;*
else *τ_t←τ_m;*
end if
if *k_2>C_r* ***then*** *k_t← k_i;*
else *k_t←k_m;*
end if
if *R_0(τ_t, k_t)<R_0(τ_i, k_i)* ***then***
(τ_i, k_i)←(τ_t, k_t);
end if
end for
end while
(τ, k*) = argmin {R_0(τ_i, k_i),i= 1, ... N_p};*
Output:*R_0(τ_i,k_i)*

4.SIMULATION AND RESULTS

In order to simulate the CRN system to achieve the maximum throughput for SU the following system parameter has to be initialized as tabulated in Table.1. The probability of detection is set as 0.9 and the primary transmitted signal is BPSK (Binary Phase shift keying) .The sensing time for spectrum detection is 10 ms and data transmission time is 25ms. The channel bandwidth and sampling frequency (f_s) are 3 MHz and 5MHz respectively and the Signal-to-Noise Ratio (SNR) of the detection signal ranges from -20 dB to 15 db. The above mentioned parameter is simulated up to 1000 Monte Carlo simulations for 20 SUs.The simulation parameter for the optimization algorthim used are as follows: the population size and the maximum number of iteration of each algorthim is 50. The Mutation rate of HDE and DE is 3 and for GA is 2 .The cross over rate for HDE and DE is [0.55, 0.4] and [0.75, 0.3] respectively.

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Tabel.1 simulation parameter for CRN systems

S.No	PARAMETERS	VALUE
1	Probability of false alarm(P_f)	0.1
2	No of secondary user	20
3	Primary signal	BPSK
4	Sensing time	10ms
5	Data transmission time	25ms
6	Frame time	35ms
7	Number of channels L	6
8	Channel bandwidth	3 MHZ
9	SNR of PU signal	-20 to 15 dB
10	Number of Monte Carlo simulations	1000

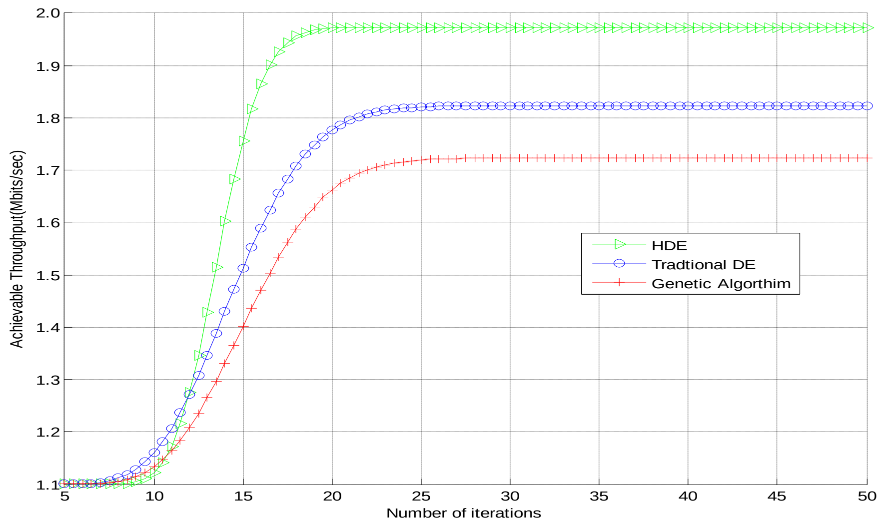

Figure.1 Plot of Fitness Function in terms of Achievable throughput versus number of iterations for HDE, DE and GA based schemes for 50 iterations

Figure.1 shows the simulated results of the convergence curve of HDE, DE and GA based optimization methods. From the simulated results, it is inferred that the proposed HDE based scheme offers a rapid convergence for reaching the maximum fitness value of achievable throughput, when compared to the other traditional optimization DE and GA based schemes.

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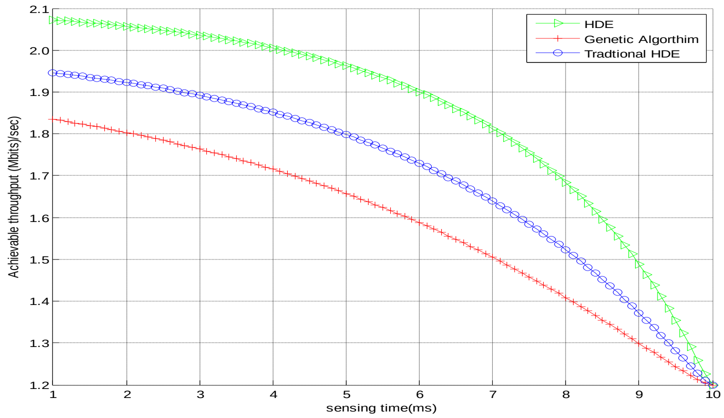

Figure.2 Performance assessment for HDE, DE and GA based schemes in terms of Achievable Throughput versus sensing time for M=20 SUs

Figure.2, shows the simulated results of achievable throughput against the different sensing time for M=20 SUs. From the simulated results, it is inferred that the proposed HDE based optimization scheme outperforms the traditional based DE and GA schemes in terms of achievable throughput for different sensing time. When M=20 SUs and sensing time τ = 1ms, the proposed HDE has achievable throughput of 2.1 (Mbits/Hz/Sec). For the same above parameters, the DE and GA based optimization schemes has achieved achievable throughput of 1.95 (Mbits/Hz/Sec) and 1.85 (Mbits/Hz/Sec) respectively.

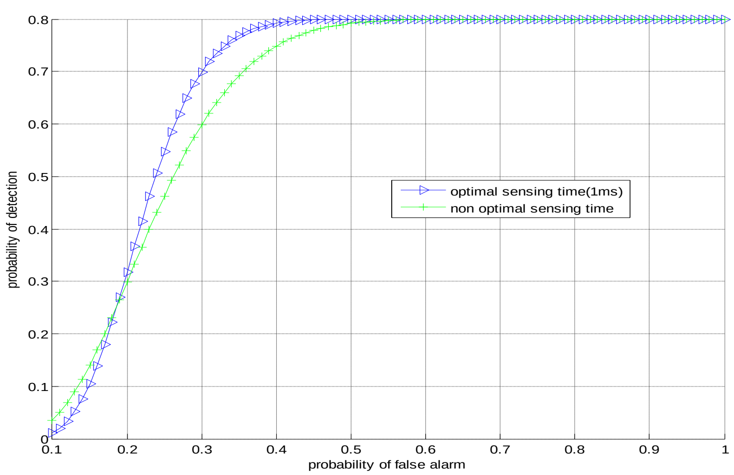

Figure.3 ROC Curve for Optimal Sensing Time at τ* =1 ms VS. Non Optimal Sensing

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Figure.3 shows the ROC curve for the optimal sensing time versus non optimal sensing time based sensing. From the figure, it is inferred that the optimized sensing and non-optimized sensing has shown the same detection performance.

5. Conclusion

The CSS based method addresses for improving detection performance in fading channels, but it has the drawback of reduced throughput due to the longer sensing time. In this work, optimizing sensing time and k-parameter of K-out-N fusion scheme rule to maximize the throughput of SU is addressed. Based on the sensing time and throughput tradeoff, an optimization problem is formulated for maximizing the throughput of SU in CRN. The theoretical analysis of the optimization problem shows that the nature of the objective function is multi-objective in nature. When optimizing this multi-objective problem, by using traditional DE based optimization technique it shows the drawback of premature convergence. Therefore, Hybrid Differential Evolution (HDE) based optimization is proposed to optimize the sensing time and K-parameter of the fusion scheme, which is based on a novel migration operator. The proposed system is simulated in MATLAB.From the simulated results, it is inferred that the proposed HDE based optimization scheme outperforms in terms of achievable throughput and convergence rate, when compared to other traditional optimization schemes DE and GA.

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