Throughput Maximization Based Spectrum Sensing in Cognitive Radio Network Using Differential Evolution Scheme

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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 is provide 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 a optimization problem is formulated to maximize the throughput of SUs. The designed optimization problem is jointly optimized using Differential Evolution (DE) 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 and optimization algorithm system parameters to validate robustness of the proposed optimization technique. From the simulated results it is inferred that proposed DE method outperforms traditional optimization technique PSO (Particle Swarm Optimization) and Genetic algorithm (GA) in terms of achievable throughput. The proposed system is achieved about 2.1 (bits/Hz/Sec) of achievable throughput with saving sensing time with good probability of detection P_d is about 90%.**

I.INTRODUCTION

The wireless services such as 5G and IOT (Internet of Things) are 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 gets affected by the spectrum shortage. A survey conducted by Federal Commission for Communication (FCC) for analyzing the usage of spectrum in time domain. These surveys inferred that the spectrum which is allocated for certain wireless services not well utilized its 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 using wireless spectrum in dynamically 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 users (SUs) are coexist with each other. The SUs uses the PU channel or band in temporary manner when PU activity not present in the channel. The SUs which are deployed around PU network environment uses spectrum sensing technique 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 addressed, 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 is provide 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 is depends on the sensing time and fusion scheme is used.

In cooperative spectrum sensing, high energy consumptions, reduced throughput, interferences and security threats are major existing issues. Most of research work is not given more importance to throughput of the SUs which gives way for efficient utilization of the channel. In the paper [8] author studied impact of k- parameter of the fusion rule and no 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 no of secondary user and way of improves the achievable throughput using joint iterative optimization algorithm. [9] Rozeha A. Rashid et al proposed concept of tradeoff between sensing and throughput under in 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 of fusion rule on the throughput of secondary user (SUs). [10] author proposed a method of maximizing throughput of SUs by optimizing K-parameter of fusion rule without analyzed the influence of sensing time. The optimization problem is formulated and solved by using joint iterative algorithms, they produce good optimal solutions initially but the when the problems become complex they stuck into local optimum. In the paper [11] , author formulated optimization model based on sensing alone, then the optimization problems is 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 condition when primary transmission is present and absent in cognitive radio (CR) network. The optimization problem is solved by using PSO technique, after optimization of the problem the algorithm 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 parameter like fusion scheme parameter on SUs throughput. So in this work, a special focus for influences of sensing time and K-parameter of fusion rule on throughput of SUs is analyzed and optimization problem is formulated based on this parameter for maximizing the secondary user throughput.

Contribution of this work

- Derived the expression for throughput for SUs based on, when the primary user are present and absent. And achievable throughput of the secondary user is formulated from adding these two conditions.
- Proved that the sensing time and K-parameter of fusion rule is a unimodal function of the throughput of SUs. From these relation it is conclude that the two parameter on influence on secondary user throughput.
- The optimization problem is formulated by two separate steps: In first step optimization model for sensing time is framed while keeping K-parameter as a constant and second step followed by optimization model for K-parameter in fusion rule while keeping sensing time as a constant.
- Then the formulated optimization problem is solved by using DE (Differential Evolution) and then the optimal value of sensing time and K-parameter of fusion rule is obtained which will maximizes the secondary user throughput, when both the sensing time and fusion scheme parameter is jointly optimized.

II. System Model

Let us consider the cognitive radio, with one PU and N number of SU users is deployed and SUs are monitoring the transmission activity of PU. The energy detector is an 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 $V_i = \left(\frac{1}{M}\right)\sum_{n=1}^{M}|y_i(n)|^2 \, for \; i = 1, \ldots\ldots N$,Where M represents number of signal sample.

The probability of detection and the probability of false alarm of every energy detector is calculated as.

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

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

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 channel with primary user are present and if the $D_i = 0$ its indicate no primary user are absent. Then, the obtained decision results is 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 sensing phase and transmitting phase, and it will uses a channel over two conditions. In first condition, if the FC find 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 permitted to work in the absence and the presence of the PU, correspondingly, then 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 is absence and PU is 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 pointing that, average throughput over Cooperative spectrum detection is relies on the parameter of the fusion rule K, so in this work, inclusion K parameter as an optimization variable for study its influence on throughput under collaborative spectrum sensing.

A. Formulation of the optimization problem

In this work, tradeoff between sensing and throughput is considered and by using collaborative detection to maximizing the average achievable throughput of the CR network by optimizing sensing time, k parameters of Fusion scheme with enough guarding offered to primary User. Then the optimization model maximization of SUs throughput is given by

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

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

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

$$1 \leq k \leq N$$

Where, $\overline{P_d}$ is the minimum probability of detection that the fusion center needs to give for safeguarding to PU. By help of proof obtained [ ], 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

$$\underset{\tau, k}{max} : \widehat{R_0}(\tau, k) \qquad (8)$$
$$s.t: \; 0 \leq \boldsymbol{\tau} \leq T$$
$$1 \leq k \leq N$$

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

B.Proposed iterative optimization algorithm

In spite of solving the two variables optimized problems in directly, a idea of splitting the problems into two single variable optimization problems.

B.1.1First sub- optimization problem

Here finding the optimum range of τ that maximizes the achievable throughput of the CR network with strict condition to net Pd. Then the first optimization problem is formulated as

$$\underset{\tau}{max} : \widehat{R_0(\tau)} \overset{\Delta}{=} \widehat{R_0}(\tau, k)/_{k=\bar{k}} \quad (9)$$
$$= C_0 P(H_0) \left(1 - \frac{\tau}{T}\right)\left(1 - \widehat{P_f}\,(\tau)\right)$$
$$s.t : 0 \leq \tau \leq T$$

The function of $\widetilde{R}\,(T_s)$ is rises with monotonic if the T_s is small and monotonic decreases if T_s reaches T_f. Therefore, there is condition for maximum point of $\widetilde{R}\,(T_s)$ in the region of $(0, T_f)$.This condition clearly indicates that the optimization function as this range is the global maximum. And finally it is concludes that the solution for optimization problem also converges to the same maximum point.

B.1.2 Sub optimization Problem Two

The second sub optimization problem is decoupled from the optimization problem (9) by treating τ to be a constant. Removing all constant terms, the optimization problem reduces to

$$\underset{k}{min} : P_f(k) \overset{\Delta}{=} \check{P}_f(\tau, k)/_{\tau=\bar{\tau}}$$
$$P_f(\tau, k) = \sum_{i=k}^{N} \binom{N}{i} \widehat{P_f}\,(k)^i (1 - \widehat{P_f}(k))^{N-i} \quad (10)$$
$$s.t : 0 \leq k \leq N$$

Where for a given τ = ˇτ. No closed-form solution for *k* is available for this sub problem, so search over all possible *k* values is required. However, since *k* is an integer and ranges from 1 to *N*, it is not computationally expensive to search for the optimal *k*. Combining the step for solving the two sub optimization problems, the proposed optimization algorithm. The objective function of the optimization problem, i.e., ˆ R_0 (τ, *k*), is non-decreasing at the every iteration, it indicates that optimization problem also converges to the same maximum point.

III.THE HYBRID DIFFERENTIAL EVOLUTION

The differential evolution algorithm is propounded by Kenneth price and Rainer strorn, and it is regarded as an influential optimization techniques and it is effectively used in numerous real time implementation. The nature of simple to 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 an familiar optimization technique.
In this work, the nature of the objective function is multi-objective and unimodal in nature, which is indicated from optimization problem formulation. And it can be solved by using evolutionary algorithm such as genetic algorithm, PSO and DE. Many previous work related to this, considered only single optimization variable to maximize or minimize the optimize the optimization problem. But in this work, two sub optimization problem is required to the solve the optimization problem .Then the joint optimization of two sub-optimization problem i.e., sensing time τ and K parameter of fusion scheme is done 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 less no of control values will have capability to solve the complex problem easily. The algorithm having improves the candidate solution in intermediate operation like mutation technique may the candidate solution avoid from stuck into local optimum. Base on these scenarios, hybrid differential evolution is chosen as a proposed optimization technique to optimize the problem in this work. It is a straight forward searching method and it has capability to increases the fitness values at each iteration effectively. The basic step involved in differential evolution optimization scheme is discussed in elaborated manner.

Major Steps Involved in hybrid 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 there are 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.

A.Initialization

The initialization of population is carried out as a first step in DE before transferring the objective vector to the mutation technique. The parameter are rule the system are denoted in a vector form as given in equ 1 and equ 2 as

$$X_r = [X_1, X_2 X_3, \dots \dots X_D]^T \quad (10)$$

$$f(X) = f(X_0, X_1, \dots \dots . X_{D-1})$$

From equation, X represents sampling vector of given population, r is the total samples vector and D denotes dimension of the objective function. If the D dimensional problem is govern, then DE find and searching for global minimum in the population provided.

B.Mutation

The random selection of population in the three vectors is carried out in initialization process and then it is sent to mutation process, which would make unpredicted changes in the vector values randomly. A mutation vector is generated by deducting two randomly generated vector forms the three vectors; then obtained disparity range will be measured by scalar value F before adding to the third vector as shown in

$$\overrightarrow{v_{t,G}} = \overrightarrow{X_{r_{2,}^{t}G}} + F.\left(\overrightarrow{X_{r_{2G}^{t}}} - \overrightarrow{X_{r_{3G}^{t}}}\right) \quad (11)$$

Where *G* represents total number of generation, F represents scale factor and V is called as mutation vector.

C.Crossover

The diversity of population is increased by the crossover operation. Basically two types of crossover technique are available exponential and binomial. In this work based on nature of optimization problem, the binomial crossover will be utilized. The binomial crossover is done on the every D variable by contrasting the component vector in the population from the random numbers 0 and 1 considering with fixed crossover range.

The (4) represents obtained trail vector after the crossover.

$$u_{j,i,G} = \begin{cases} v_{j,i,G} & if(rand_{i,j}\,[0,1] \le C_r \; or \; j = j_{rand} \\ x_{j,i,G} & otherwise \end{cases} \quad (12)$$

Where $u_{j,i,G}$ the resultant trial is vector and Cr is the crossover value.

D.Selection

Selection is a method to comparing the two vectors; the final test vector and the best vector from the current generation. Then vector that provide finest value when compared to other will be selected and sent to the subsequent generation for comparison.

This iterative method will carry on till the preferred optimization value is reached.

The Equation 5 shows the selection process.

$$\overrightarrow{X_{\iota,G+1}} = \overrightarrow{U_{\iota,G}} \; if \; f\left(\overrightarrow{U_{\iota,G}}\right) \le f(\overrightarrow{X_{\iota,G}}) \quad (13)$$

$$= \overrightarrow{X_{\iota,G}} \; if \; f\left(\overrightarrow{U_{\iota,G}}\right) \le f(\overrightarrow{X_{\iota,G}})$$

From equation, f(X) represents objective function to be minimized or maximized.

E.Hybrid Differential Evolution Algorithm

The two sub optimization problem is solved by using proposed differential evolution algorithm as follows .From the derived mathematical expression , it is found that the objective function of the optimization problem, i.e., $\hat{R}_0(\tau, k)$ is an non–decreasing function at each iterations , then it is given by

$$\widehat{R_0}(\tau_i\,, k_i) \leq \widehat{R_0}(\tau_m, k_m) \quad \forall\, i.$$

Initialization

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} with uniform probability distribution

While *$G \leq G_{max}$* ***or*** *{optimal value is not sufficiently improved}* ***do***
$G \leftarrow G+1$;
for all *$i \in \{1, 2, ..., N_p\}$* ***do***
Randomly pick a, b and c $\in \{1, 2, ..., N_p\} - \{i\}$;
$(\tau_m, k_m) \leftarrow (\tau_a, k_a) + F((\tau_b, \ ) - (\tau_c, k_c))$;
Randomly pick k_1 and $k_2 \in [0, 1]$;
if *$k_1 > C_r$* ***then*** *$\tau_t \leftarrow \tau_i$;*
else *$\tau_t \leftarrow \tau_m$;*
end if
if *$k_2 > C_r$* ***then*** *$k_t \leftarrow k_i$;*
else *$k_t \leftarrow k_m$;*
end if
if *$R_0(\tau_t, k_t) < R_0(\tau_i, k_i)$* ***then***
$(\tau_i, k_i) \leftarrow (\tau_t, k_t)$;
end if
end for
end while
$(\tau^*, k^*) = \text{argmin}\{R_0(\tau_i, k_i), i = 1, ... N_p\}$;
Output*: $R_0(\tau_i, k_i)$*

The proposed DE algorithm iterates until $R_0(\tau, k)$ converges to a maximum point and algorithm may converge to a solution of a possible local maximum point, this point is actually the global maximum point. Finally optimal sensing time and k-parameter of fusion scheme is obtained which will maximizes achievable throughput of SUs, when both the sensing time and k-parameter fusion scheme are jointly optimized.

IV.SIMULATION AND RESULTS

In order to simulate the CR system for achieving maximized throughput, the following system parameter has to be carried out the probability of detection is set as 90%, and the primary transmitted signal is a BPSK (Binary Phase shift keying) .The sensing time for spectrum detection is 15ms and the data transmission time is 50ms respectively . .The channel bandwidth and sampling frequency (f_s) is 3 MHz and 5MHz respectively and SNR of a detection signal in the ranges of -20 db to 5 db.

Table 1.Simulation parameters for spectrum sensing

Parameters	**Value**
Target detection probability Pd	0.9
Primary signal	BPSK
Sensing time T	15 ms
Data transmission time	40 ms
Frame time	50 ms
Number of channels *L*	6
Channel bandwidth	3 MHZ
Sampling frequency *fs*	5 MHZ
Noise variance	2
SNR	15 db

Tabel .2 The system parameters for optimization algorthim

Parameters	**DE**	**PSO**	**GA**
Population size	50	50	50
Maximum number of iterations	100	100	100
Mutation rate	3	3	2
Cross over rate	[0.55, 0.4]	[0.75, 0.3]	-
Inertia weight range	-	0.8	-

The system parameter for optimization algorthim is set as follows: population size and maximum number of iteration of each algorthim is 50 and 100 repsectively. The Mutation rate of DE and PSO is 3 and GA is 2 and cross over rate for DE and PSO is [0.55, 0.4] and [0.75, 0.3] and the inertia weight range for PSO is about 0.8.

Table 3.Performance of different optimization schemes

Optimization algorithm	HDE	PSO	GA
Pd	91	89	88
Achievable throughput (R) (bits/Hz/sec)	1.544	1.755	**2.001**
Sensing time Ts (msec)	27.250	27.333	27.654
Convergence rate(No of iterations)	32	42	**50**

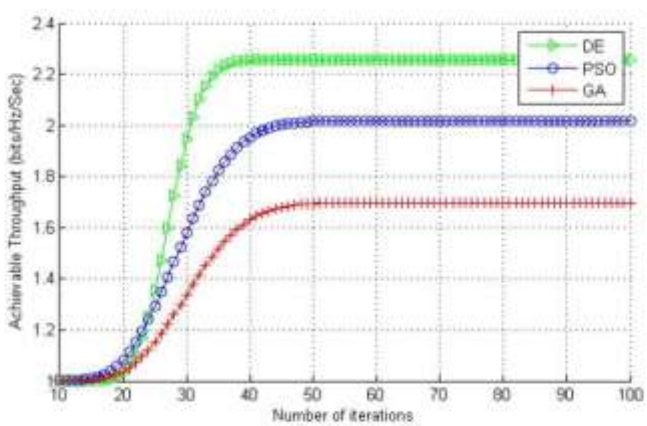

Fig1.1 Convergence curve for DE, PSO and GA optimization algorithms

Fig1.1 shows the convergence curve for different optimization algorithm is simulated in MATLAB for DE, PSO and GA. The Curve plotted for fitness function as achievable throughput against number of iterations. From simulated graph it is noticed that DE converged at 35th iteration which is less when compared to other two optimization technique and achieved highest achievable throughput 2.2(bits/Hz/Sec) at converging point.

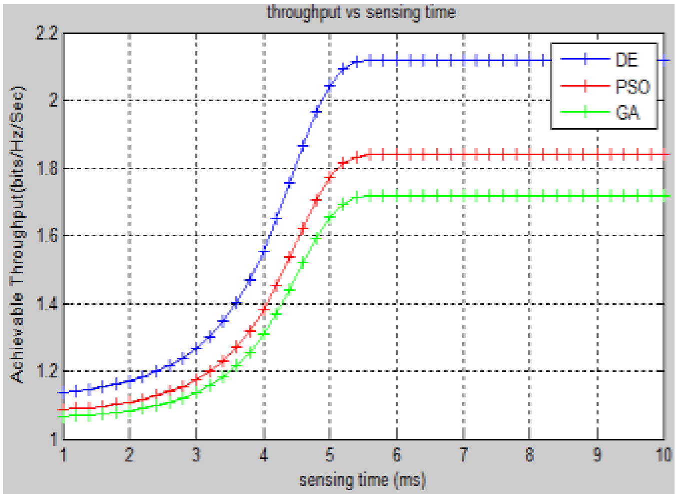

Fig1.2 Simulated results of optimization schemes for sensing time Vs throughput

Fig 1.2 shows simulated plot of sensing time against achievable throughput, from simulated graph it is inferred that DE is achieved maximum throughput of 2.1(bits/Hz/Sec) at optimal sensing time 5.5 ms and PSO and GA achieved throughput of 1.8(bits/Hz/Sec) and 1.7 (bits/Hz/Sec) at optimal sensing time ms. From above results it is conclude that DE optimization technique outperform other two optimization technique when sensing time is optimized.

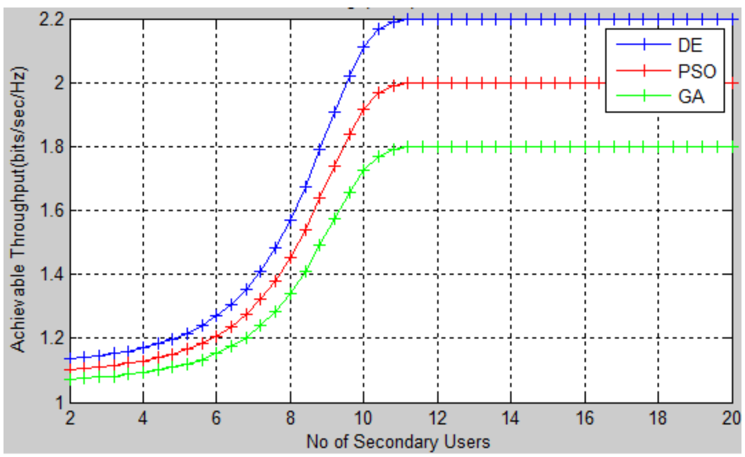

Fig 1.3 Simulated results of optimization schemes for No of secondary users Vs throughput

Fig 1.3 shows simulated plot of sensing time against achievable throughput, from simulated graph it is inferred that DE is achieved maximum throughput of 2.1(bits/Hz/Sec) at optimal sensing time 5.5 ms and PSO and GA achieved throughput of 1.8(bits/Hz/Sec) and 1.7 (bits/Hz/Sec) at optimal sensing time ms. From above results it is conclude that DE optimization technique outperform other two optimization technique when sensing time is optimize

V.CONCLUSIONS

In this paper, proposed a hybrid differential evolution algorithm to obtain the sensing time and the K parameter of the fusion scheme that maximizes the throughput of the secondary users, with consideration of enough protection to the primary user. The MATLAB generated simulation results of proposed optimization algorithm are compared with other exhaustive search traditional algorithm. From the simulated results proposed new hybrid differential evolution schemes outperforms all other traditional optimization schemes. It is noted that a good improvement in the throughput of the secondary users has been obtained when the both the parameters of fusion scheme and the sensing time are jointly optimized. The shortcoming of traditional optimization techniques i.e. premature convergence has been neglected by introducing the new hybrid evolution optimization technique.

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