Spectrum Handoff Schemes in Cognitive Radio Network Using Particle Swarm Optimization

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Abstract**-- In this paper, we focus on spectrum mobility (or called spectrum handoff) that occurs when the primary users (PUs) appear to occupy its licensed band that used by secondary users (SUs). We discuss the three spectrum handoff mechanisms that used to reduce the handoff delay (proactive, reactive and hybrid). We implement particle swarm optimization (PSO) to minimize the total service time of spectrum handoff to the optimal value. Numerical results show that PSO is significantly minimizing the total service time compared to other spectrum handoff schemes.**

Index Term**-- Particle swarm optimization; Cognitive radio; spectrum handoff**

I. INTRODUCTION

Theoretically, the radio frequency spectrum becomes very valuable due to the increasing in number of mobile devices and different types of wireless services. Each wireless service has its own spectrum in which the users operate on the listened spectrum. However, some of the wireless services have a (not fully utilized) wide spectrum with small number of users like TVWS. Unlike, other services whose spectrum is fully utilized by the users. Moreover, the bandwidth becomes very expensive due to the shortage of frequency. Thus, cognitive radio was suggested to manage and utilize the usage of available spectrums. The cognitive radio was introduced by [1] to improve the spectrum efficiency of radio bands. Recently, a new communication technology uses Dynamic Spectrum Access (DSA) which is mainly based on cognitive radio technique [2]. The technology of cognitive radio has a great potential to overcome the lack of spectrum smoothly. It allows secondary users (SUs) to opportunistically access unused licensed spectrum of primary user (PU) while avoiding the interference with PU. The cognitive radio consists of four main functions: spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. The SU starts to sense the radio environment and detects the available spectrum holes. Then, it makes a decision to select the best spectrum band from sensed spectrum based on its requirements. Next, the selected used spectrum band can be shared with other existing users. Lastly, spectrum mobility (spectrum handoff) is very important for SUs to avoid the interference with licenced users [3]. In other words, the SU should have the ability to change its current operating frequency on licensed band once the PU is detected. In addition, the SU mobility becomes a substantial issue in recent research and not sufficiently studied in order to obtain an optimal quality of services [4].

Handoff spectrum schemes are essential issue to maintain the data transmission when unlicensed spectrum bands are used. The handoff strategy mainly depends on the spectrum sensing to find the idle channel in order to perform handoff process. The spectrum sensing can be performed either before or after spectrum handoff triggering events happen~~s~~ [5]. There are three types of handoff schemes triggering time based on spectrum handoff namely: proactive handoff scheme, reactive handoff scheme and hybrid handoff scheme. The main role of these spectrum handoff schemes is to make a decision to select the idle channels. In the proactive handoff decision, the SUs sense the activities of PUs periodically before making the decision to start transmission data on idle channel [6]. Then, the SUs select the channel that has the highest probability idle for certain of time. Thus, this handoff scheme has a small spectrum handoff delay which depends on the PU traffic model. In the reactive handoff decision scheme, the SU is sensing the idle channel after arrival of the PU [7]. Although this scheme can obtain the idle channel for handoff, but it still suffers from the handoff delay during the spectrum sensing. The Hybrid handoff scheme combines the pervious handoff schemes (proactive and reactive) by applying proactive spectrum sensing and reactive handoff action [3][7]. In other words, it takes the advantages of fast response and accurate target selection in proactive and reactive handoff scheme, respectively. Thus, it can achieve a fast spectrum handoff with a very low latency since spectrum sensing is not performed during the handoff process.

In this paper, we propose particle swarm optimization (PSO) to minimize the total service time of spectrum handoff. The rest of this paper is organized as follows. In Section 2, we provide the related works that have been done in spectrum mobility in the past years. Section 3 describes the system model based on Preemptive Resume Priority (PRP) M/G/1 queuing network model. Section 4, describes the total service time of the spectrum handoff. Section 5, we describe the obtained simulation results from the proposed algorithm. Finally, Section 6 concludes the paper and provides recommendations for future work.

II. RELATED WORK

Some works like [3, 7] used reactive handoff scheme which found has less waiting latency compare to non-handoff scheme. The spectrum handoff scheme improves the channel utilization with considering the transmission latency due to the multiple spectrum handoffs. The reactive spectrum handoff scheme is capable of obtaining the accurate target channel in CR. The analytical framework was introduced by [7] to evaluate the effects of reactive spectrum handoff scheme on channel utilization and latency performances in CRN. This work proposed a Preemptive Resume Priority (PRP) M/G/1 queuing network model to characterize the channel usage behaviors of CR networks. It evaluates channel utilization under various traffic arrival rates and service time distributions. Besides, investigates the transmission latency of the secondary users due to multiple handoffs.

The reactive spectrum handoff scheme has an advantage of obtaining the accurate target channel. However, it has larger handoff delay compared to proactive scheme when the sensing time is longer. Hence, for short sensing time, reactive scheme outperforms the proactive spectrum handoff scheme in terms of total service time [8, 9].

In proactive spectrum handoff scheme, spectrum handoff depends on the PU traffic where the CR predicts PU arrival to occupy the used channel by SU. The prediction of PU arrival happens before the spectrum handoff takes place to continue the transmission on other ideal channel. Hence, proactive spectrum handoff scheme is significantly reduced the handoff latency compared to reactive spectrum handoff scheme. However, its performance depends on the traffic model of PUs in CR. In other words, if the traffic model fails to predict PU arrival correctly, it leads to poor spectrum handoff due to interference [3, 6]. For long sensing time, proactive spectrum handoff performs better than reactive spectrum handoff. CR has enough time for the spectrum sensing for free channel in CR networks. Hence, proactive spectrum handoff scheme performs better than reactive spectrum handoff scheme in terms of handoff delay when the sensing time is longer.

The hybrid spectrum handoff scheme consists of the two or more different spectrum handoff schemes. It takes the advantages of the combined spectrum handoff schemes in order to obtain minimal handoff delay. The hybrid spectrum scheme was introduced by [3, 7] which combines two spectrum handoff schemes together. It uses the sensing technique of proactive spectrum scheme to prepare the idle channel before the handoff takes place. Thus, the handoff delay is reduced in proactive spectrum handoff scheme compared to the reactive spectrum handoff scheme.

III. SYSTEM MODEL

For our subsequent treatments of priority queueing systems, there are different priorities classes depend on the arriving customers: small priory class and high priority class. The smaller the priority class number (Class 1 for primary users), the higher the priority, and Class 2 has the second highest (secondary users). There are two types of queueing disciplines for priority systems~~,~~ namely: pre-emptive and non-pre-emptive. In the pre-emptive priority queueing system, the service of a secondary customer is interrupted when a primary customer of a higher priority class arrives. However, the secondary customer whose service was interrupted, it resumes service from the point of interruption once all customers of higher priority have been served; this system is called pre-emptive resume system. In the case of the non-pre-emptive priority system, a customer service is never interrupted, even if a customer of higher priority arrives in the meantime.

We use the analysis of an M/G/1 non-preemptive system [6]. In this model, primary users of each priority class i (i = 1, 2,.. n) arrive according to a Poisson process with rate λ. If we define $P(t)_k$ to be the probability of having k arrivals in a time interval *t*. Figure 1 shows a sample family of Poisson distributions for $k = 0, 1, 2$ *and* 3. It can be seen that the probability changes over a time interval.

$$P_0(0) = e^{-\lambda t} \tag{1}$$

$$P_k(t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t} \tag{2}$$

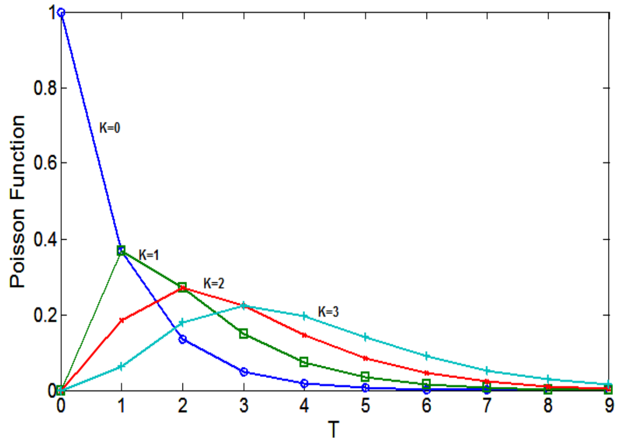

Fig. 1. Poisson distributions for $k = 0, 1, 2$ *and* 3.

IV. TOTAL SERVICE TIME

The model introduced by [6] to characterize the spectrum usage interactions between primary users (PUs) and secondary users (SUs). In this model, PUs have a high priority to interrupt the transmission of SUs where the interrupted secondary user is resumed the unfinished transmission in another idle channel. Figure 2 shows the PRP M/G/1 queueing network with two channels, in which PUs are placed into the high-priority queue, and SUs are placed into the low-priority queue. We assume that the arrivals of primary and whose default channels are channel k follow the Poisson processes with rates $\lambda(k)_p$ (arrivals/slot) and $\lambda(k)_s$ (arrivals/slot), respectively. $E(X_p)$ (slots/arrival) and $E(X_s)$ (slots/arrival) are their corresponding average service time, respectively, where X_p and X_s are assumed exponentially distributed with rates μ_p and μ_s.

$$E(X_S) = \frac{1}{\mu_s} \qquad , E(X_p) = \frac{1}{\mu_p}$$

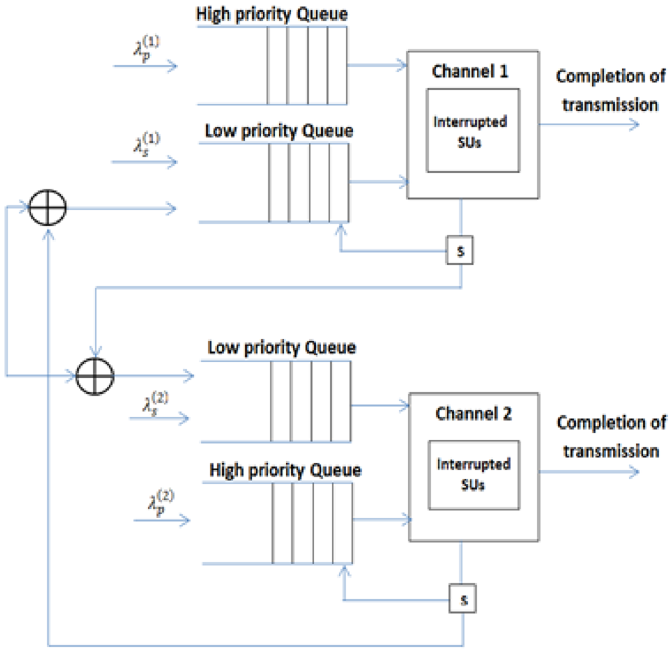

Fig. 2. PRP M/G/1 queueing network for two-channel system where n ≥ 1.

When secondary users are interrupted by primary users, they have two options to perform:

- Stay strategy: SUs stay on the current channel and the unfinished transmission can be placed into the head of the low-priority queue of the current channel.
- Change strategy: SUs change their operating channels to another channel and the unfinished transmission will be placed into the tail of the low-priority queue of another channel.

In both strategies, the SUs can be immediately continued unfinished packet transmission once the channel becomes idle. The total service time of the secondary users is given as follows:

$$E\left(T^{(k)}\right) = E\left(X_s^{(k)}\right) + E(N)E\left(D^{(k)}\right) \qquad (3)$$

$$E(N) = \lambda_P E(X_S) \qquad (4)$$

where $E(D)$is the average handoff delay of secondary users and $E(N)$ is the average number of interruptions.

In case of stay strategy, the average handoff delay of secondary users represents the average of busy period $B_p$caused by primary users and it can be expressed as follows:

$$E\left(T_{stay}\right) = E(X_S) + E(N)B_p \qquad (5)$$

where $B_p = \frac{E(X_p)}{1-\lambda_P E(X_p)}$

In case of change strategy, the average handoff delay of secondary users represents the sum of waiting time and channel switch time of the secondary users $(W_s + t_s)$.

$$E\left(T_{stay}\right) = E(X_S) + E(N)(W_s + t_s) \qquad (6)$$

Based on [6] the total service time can be minimized when both strategies considering the activity of busy period result from the primary users. On the other hand, the interrupted secondary user prefers to stay on the current channel when the busy period $B_p$is less than the sum of waiting time and channel switch time. By contrast, the larger value of busy period B_p the interrupted secondary user prefers to change the current operating channel.

$$E(T) = \begin{cases} E\left(T_{stay}\right) & , B_p \leq W_s + t_s \\ E\left(T_{change}\right) & , B_p \geq W_s + t_s \end{cases} \qquad (7)$$

In addition, the baseline case that the interrupted secondary user randomly selects a target channel from all available channels can be expressed as follows:

$$E(T_r) = E(X_S) + \frac{E(N)B_p}{2} + \frac{E(N)(W_s + t_s)}{2} \qquad (8)$$

According to [7] the total service time of the proactive spectrum handoff scheme is given as follows:

$$E\left(T_{proactive}\right) = E(X_S) + E(N)\left(W_{s,proactive} + t_s\right) \qquad (9)$$

where the waiting time of secondary users $W_{s,proactive}$ is given by:

$$W_{s,proactive} = \left(\frac{0.5\lambda_p (E[X_p])^2 + \frac{\lambda_s}{(\lambda_p + \lambda_s)\mu_s} + \frac{\lambda_p{}^2 (E[X_p])^2}{2(1-\rho_p)} E[X_p]}{1 - \rho_p - \rho_s} \right) \qquad (10)$$

The total service time of the reactive spectrum handoff scheme is given as follows:

$$E(T_{reactive}) = E(X_S) + \left(W_{s,reactive}\right) \qquad (11)$$

where the waiting time of secondary users $W_{s,proactive}$ is given by:

$$W_{s,reactive} = \left(\frac{\lambda_p (t_P \mu_s + \lambda_p \mu_s E[X_p])^2 + (\lambda_s - \lambda_p t_P \mu_s) E[X_p]}{\mu_s{}^2 (1 - \lambda_p E[X_p])} \right) \qquad (12)$$

where t_P is the processing time which is the sum of channel switch time t_s and channel sensing time t_P .

V. OPTIMIZATION PROBLEM FORMULATION

In this section, the formulation of the optimization problems using particle swarm optimization is introduced. The main objective of using optimization is to minimize the total service time of secondary users with low-complexity algorithm.

$$\min\{E(T^{(k)})\}$$

The objective function is

$$E(T^{(k)}) = E(X_s^{(k)}) + E(D^{(k)})$$

The PSO algorithm is explained in the following steps:

STEP 1: Define the parameters of $N, t_s, t_P, \lambda_p, \lambda_s$

STEP 2: Define the number of dimensions: μ_p, μ_s

STEP 3: Generate initial positions and velocities of particles

STEP 4: Determine the service time with different PU arrival rate. Then select the minimum total service time

STEP 5: For i=1:*N*.

STEP 6: Generate the positions of *N* particles and define them as X and set Pbest =X and V=0

STEP 7: For t=1:T.

STEP 8: Calculate the latency from related to the position of the particle (x_i).

STEP 9: If $f(x_i) < f(Pbest_i)$ then do

$Pbest_i = x_i$

End

STEP 10: Calculate the latency related to the position of the particle using $Pbest_i$

STEP 11: Record the gbest which is the best particle that achieves $\min D[X]$

STEP 12: Update the velocity of the particle using Equation 13.

STEP 13: Update the position of the particle using Equation 14.

STEP 14: Next t

STEP 15: Next i

STEP 14: Stop when all the *N* particles have been generated.

STEP 15: For each generated particle

STEP 16: Find the particle that satisfies all minimum service time

STEP 17: End for loop.

PSO uses position and velocity update equations which can be written as follows:

$$v_{id} = w * v_{id}(t) + c_1 r_1 (Pbest_{id}(t) - x_{id}(t)) + c_2 r_2 (gbest_{id}(t) - x_{id}(t)) \quad (13)$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \quad (14)$$

where c_1 and c_2 indicate~~s~~ to the acceleration constants, *w* is the inertia weight, r_1, r_2, are uniformly distributed random numbers between 0 and 1.

VI. ANALYSIS OF STIMULATION RESULT

In this paper, the simulation platform is Matlab with using simulation parameters as listed in Table 1. We compare the three different of spectrum handoff schemes (proactive, reactive and hybrid) with the proposed PSO algorithm.

Table I
Simulation Parameters

Parameter	**Setting**
Number of iterations	100
Swarm size	30
Number of runs	10
$\boldsymbol{c_1, c_2, w}$	2,2,0.9
$\boldsymbol{t_p, t_s}$	0

Figure 3 shows the three different types of the spectrum handoff schemes. The total service time of spectrum handoff changes with the variety of PU arrivals λ_p for each spectrum handoff scheme. Clearly, with the increase of PU arrivals λ_p, the total service time of the three spectrum handoff schemes is gradually increasing. However, the proactive spectrum handoff scheme has short and long service time of 1 and 1.4 at PU arrival rate of 0.1 and 0.27, receptively. Similarly, the reactive spectrum handoff scheme obtains short and long service time of 1.4 and 1.75 at PU arrival rate of 0.27 and 0.35, receptively. In other words, the proactive spectrum handoff scheme has minimized the spectrum handoff when $\lambda_p \leq 0.27$ while the reactive spectrum handoff scheme has effectively minimized the spectrum handoff $\lambda_p \geq 0.27$. Thus, hybrid spectrum handoff scheme combined the pervious schemes together to improve the efficiency of the spectrum handoff. However, the random spectrum handoff obtained the longest service time compared to the pervious schemes. It is shown that the total service time of the hybrid scheme can be shortened about 25% comparing to the random scheme. The proposed algorithm is significantly improved the total service time by 35% comparing to other spectrum handoff schemes.

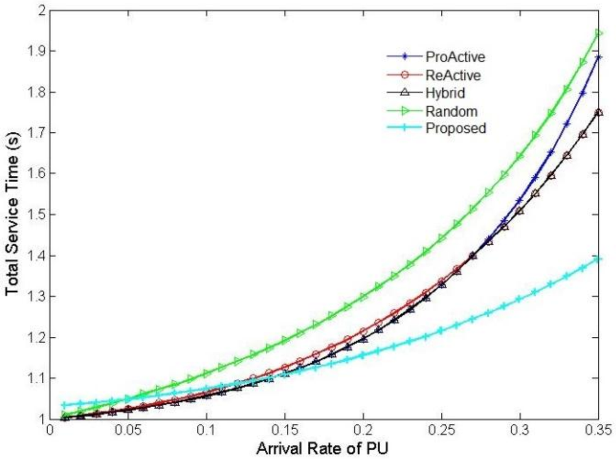

Fig. 3. Comparison of total service time in proactive, reactive and hybrid, random and proposed

Figure 4 shows the effects of μ_p and λ_p on the total service time. It can be seen that the service time of spectrum handoff increases as μ_p and λ_p increase. Increasing λ_p leads to higher interruption probability for the secondary user connection. Similarly, increasing μ_p leads to longer handoff delay when the interrupted secondary user prefers to stay on its current channel.

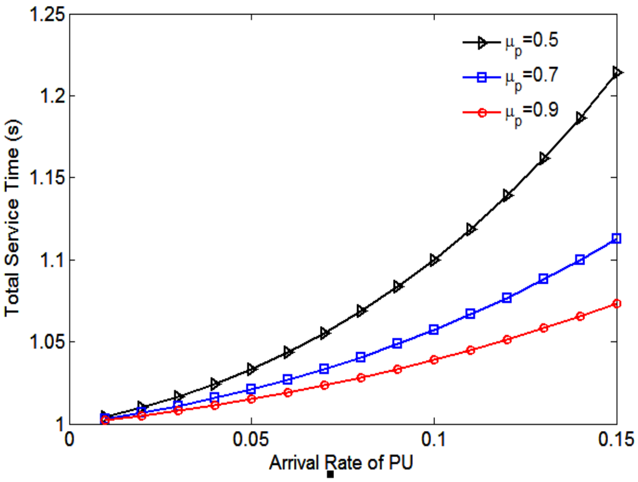

Fig. 4. Effects of μ_p and λ_p on the total service time

Figure 5 shows the effects of μ_s on the service time at different rate of μ_s = 0.5, 0.7 and 0.9. It can be seen that larger value of μ_s makes the interrupted secondary user to change its current operating channel because the service time is very short. By contrast, a small value of μ_s makes the interrupted secondary user to stay on the current channel due to longer waiting time if decides to change to another channel.

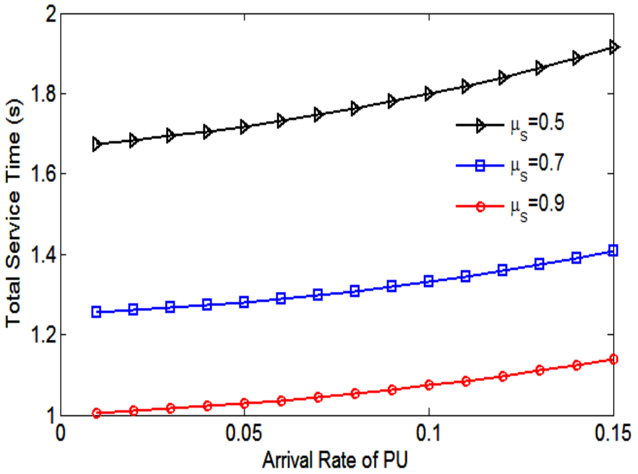

Fig. 5. Effects of μ_s and λ_p on the total service time

VII. CONCLUSION

Spectrum handoff in cognitive radio is an essential mechanism to avoid interference with licenced users in CR. In this paper, we have investigated the three different types of spectrum handoff schemes which are: proactive, reactive and hybrid schemes. We proposed PSO to minimize the service time of spectrum handoff compare to spectrum handoff schemes. The proposed algorithm has shortened the service time by 35% which results in reducing the handoff delay. In the future work, we will consider other variants of the PSO and other optimization algorithms such as genetic algorithm and Lagrangian method.

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