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Spectrum Management Strategy for Cognitive Radio Networks

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Abstract

Cognitive radio network is emerged to solve spectrum shortage and scarcities caused by the greatest demand of spectrum radio. This network is based on the exploitation of the licensed spectrum bands during the absence of their owners. It brings new secondary users that should observe the environment to identify the spectrum holes and exploit them as long as they don't interfere with the owners. These capabilities are realized based on cognitive cycle that enables observing the environment, analysing the observations, learning, deciding and acting to improve the performance. Hence, spectrum management solutions for cognitive radio networks are essential for efficient utilization of the radio resources, and they are decisive to allow spectrum sharing between different radio communication systems. In this paper, spectrum management strategy is proposed to carry out an autonomous cognitive management system. The proposed system relies on the execution of an iterative cognitive cycle. The cycle executes four management functionalities, including cooperative spectrum sensing and sharing, spectrum allocation and spectrum handoff, respectively. The proposed system is able to autonomously adapt to different wireless environment implementation and improve its performance. The performance of the proposed system is studied in terms of total reward achieved and the average handoff delay. The simulation result is carried out in Matlab platform.

Keywords: Cognitive radio network; Spectrum management; Cognitive management system

1. INTRODUCTION

The continuous growth of wireless communication systems led to an increase in spectral resources demand. However, the current static spectrum allocation policy [1] is seriously challenged by spectrum underutilization and scarcity problems. Cognitive radio (CR) paradigm was proposed to solve this spectrum shortage by enabling Dynamic Spectrum Access (DSA) [2]. The main goal of DSA is to provide efficient solutions that allow sharing the spectrum radio resource between different communication systems by optimizing the total spectrum usage.

With the appearance of CR technology as a key enabler of DSA, various researches revealed the need for Cognitive Radio Networks (CRNs), which allow wireless communication systems rely on the so-called cognitive cycle. The cognitive cycle enables secondary users (SUs) observing the environment, analysing these observations, make autonomous decision to dynamically reconfigure the radio parameters to the environment's changes and finally execute these decisions through actions [3] to improve the network performance.

Subsequently, various research works have presented the main benefits of developing cognitive management systems by exploiting the CR capabilities in several scenarios. In [4], cognitive management system is proposed for planning heterogeneous small cells in 5G mobile networks. The authors proposed two planning approaches. First planning approach without CRN result in worse performance in terms of SINR and throughput. The second planning approach with CRN based genetic algorithm. The authors showed that the later approach yields the best SINR and throughput compared to others. In [5], the authors used cognitive management radio to deliver green communications. The authors adjusted the modulation strategy by cognitively determining the assignment and use of the available spectrum, taking into account the channel occupancy probability. In [6], the cognitive management framework is proposed to efficiently improve the medical applications. The authors defined new health cognitive architecture as Co-health architecture to exploit available information and previous experience in emergency situations. In [7], cognitive management systems are proposed in the context of internet of things (IoT). The authors presented the main applications, architectures and designs of integrating cognitive radio paradigm into IoT technology. In [8], cognitive management functionalities is considered to develop new future internet architecture called NovaGenesis. They are considered the embedded and low cost cooperative spectrum sensing solution.

In other hand, various papers have addressed the usage of intelligent analytical approaches to improve the cognition capability in cognitive management systems. The most popular intelligent techniques considered in the literature in the field of CRNs are, but not limited to, artificial neural networks, game theory, fuzzy logic, genetic algorithm, Markov model, etc. The integration of the intelligent techniques to the core of cognitive management functionalities assist to enhance the spectrum management decision making process and therefore increase the overall system performance. In [9], the authors proposed cooperative game theory to address spectrum sensing and access in CRNs. The proposed game is modelled in partition form where SUs make individual distributed decisions to join or leave a coalition, while maximizing their utilities captured by the average time spent for sensing and the achieved capacity during accessing the spectrum. In [10-12], cooperative games have been well applied in decision making process for spectrum sharing. In [13], the authors proposed auction theory for developing solutions for secondary users to successfully compete with each other in limited and time-varying spectrum opportunities. In [14], the authors proposed genetic algorithm (GA) to address the spectrum allocation in CRN. The activity history patterns generated from four ON/OFF primary user activity models is combined with the GA as sensing vector to select the best available channel in terms of quality and least PU arrivals. The random appearance of PUs on a specific channel can significantly degrade the secondary ongoing transmissions due to the various interruptions. For this effect, several works have proposed different intelligent techniques to manage spectrum handoff. In [15], a hidden Markov model (HMM) has proposed to optimize handoff decision. The model is used to check the channel state and correct spectrum sensing decisions. In [16], authors presented fuzzy logic analytic hierarchy process for the handoff decision. This strategy reserves a number of backup channels characterized on the basis of quality of service required by SUs.

In the literature, the proposed spectrum management strategies maintained by cognitive management systems usually rely on intelligent learning approaches. The use of such algorithm is selected depending on the research problem, the accuracy, the available prior knowledge and the hardware capabilities. The employ of these tools is convenient for achieving best performance results. However, innovative solutions integrating autonomous decision-making and self-adaptation mechanisms supplied by cognitive management systems for efficient utilization of the radio resources are deemed crucial.

Based on this motivation, this paper proposes spectrum management strategy to carry out an autonomous cognitive management system. The proposed system is able to autonomously adapt in different wireless communication environments implementation and improve its performance. In detail, the proposed spectrum management strategy relies on the execution of an iterative cognitive cycle. The cycle executes the four management functions, including cooperative spectrum sensing and sharing, spectrum allocation and spectrum handoff, respectively. The cycle starts with the execution of spectrum sensing. The spectrum sensing enables SUs to observe the environment to identify the spectrum holes. The observation data gathered by SUs are reported to the entity in charge of analysing and processing them to decide the unoccupied channels. The quality of every available channel is then estimated. The channel with longer available duration is considered of better quality. The cycle executes then spectrum sharing. To ensure equitable and fair sharing of available channels among different SUs we apply game theory [10, 11]. The game theory assigns to each SU a reward according to his effort done during sensing the environment. The cycle runs then the next function which is spectrum allocation. To develop a priority-based channel allocation scheme we consider the auction theory because it is an extreme tool that can be used with game theory [17]. The auction mechanism considered is called a VCG (Vickrey Clarke Groves) auction [18]. In the auction scheme, SBS acts as the auctioneer and SUs as bidders. Each SU sends his bid according to his needs for transmission and his reward obtained, to the auctioneer which analysing and ranking them to assign SUs available channels according to their merits. Because of the temporary nature of available channels in CRNs and the highly dynamic nature of the environment, the cycle executes the spectrum handoff function. This function is triggered if the state of channel is changed during the secondary transmission or the time of availability of channel is exhausted. We consider proactive-reactive handoff approach [19]. Based on this approach, the system performs the spectrum sensing proactively to cope with the changing environment and update available channel list then reactively switch to other channel selected from the list of available channels upon the handoff is requested. Thus, faster spectrum handoff delay can be achieved. The handoff delay is the time spent to switch from one channel to another. The management strategy proposed achieved significant performance in terms of total reward achieved and the average handoff delay.

This paper is organized as follows. In section II, we present the proposed cognitive management system. In section III, simulation results and discussion are presented. And finally we conclude our work in section IV.

2. PROBLEM FORMULATION

The proposed cognitive system is considered of N secondary users (SUs) and an secondary base station (SBS) coordinating the N distributed SUs. We suppose implementing the cognitive system in a wireless environment of M licensed channels. Each channel is divided to X time slots (t_S). Let $S^k(t_S)$ denote the state busy (ON) or idle (OFF) of a channel k at time slot t_s and a sample on/off period correspond to the value 1/0. During every t_S, the cognitive cycle is executed to observe and sense the licensed environment to detect the opportunities and exploit them as long as the channels still available or a t_S is not yet finished. The sensing process produces a binary random state for each channel (Fig. 1) during each t_S. We are not interested in a particular band (GSM or TV for example), nor in a particular system. The objective is to propose spectrum management solution that autonomously adapt into wireless environment implementation, make decisions and improve its performance with low complexity and low processing time. Decisions are made in terms of the overall cognitive cycle capabilities.

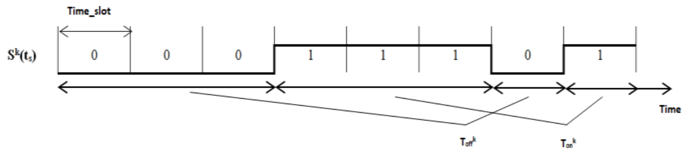

Fig 1. Example of time slotted channel

2.1. Proposed spectrum management strategy

The proposed spectrum management strategy relies on the execution of an iterative cognitive cycle at the beginning of each time slot. The execution of the cycle implicitly executes the spectrum management functions one after another. The output of one function is considered as the input of the next one. The processing time of each function depends on the reliability of the results provided by the preceding function. The cycle starts with the execution of cooperative sensing to jointly observe the environment and identify spectrum holes, then cooperative sharing is executed to coordinate access between the cooperative SUs, then spectrum allocation is runs to carry out the transmission and finally spectral handoff is triggered if the state of channel is changed during the secondary transmission or the time of availability of channel is exhausted. In this case, SU must stop its current data transmission and switch to another available channel. The fig. 1 shows the workflow of the proposed spectrum management strategy.

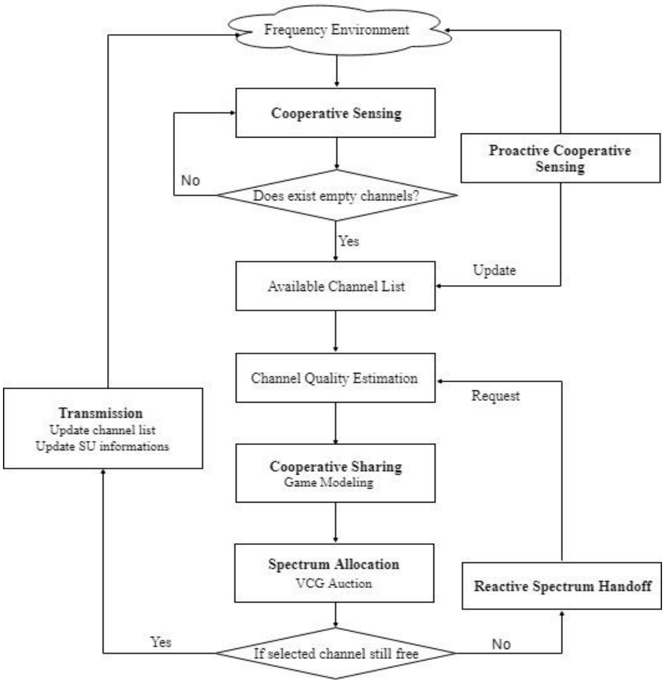

Fig 2. Flowchart of spectrum management strategy

2.1.1. Sensing scheme

This functionality allows the cognitive management system to obtain the requisite awareness amount in its environment to identify spectrum availability and to make the suitable decisions during the decision-making spectrum allocation. Awareness of the radio environment is achieved through implementing spectrum opportunity identification strategy in SUs to give the signal energy of each channel. Spectrum sensing can be formulated as a binary hypothesis testing problem as follows:

$$\begin{cases} H_0\text{: the frequency is idle, there is no primary user signal} \\ H_1\text{: the frequency is occupied, there is primary user signal} \end{cases} \tag{1}$$

In this study, the cognitive network considered consists of an SBS coordinating N distributed SUs, which cooperatively detect the PU signal in the frequency band of interest. The received signal at each SU is given by:

$$\begin{cases} H_0\text{:} & x(t) = w(t) \\ H_1\text{:} & x(t) = s(t) + w(t) \end{cases} \tag{2}$$

Where x(t) is the received signal, s(t) is the signal transmitted by the primary user (PU) and w(t) is the additive white gaussian noise.

The sensing is based on a certain function of samples received and then compared to a threshold. If the threshold is exceeded, it is decided that H_1 is true, otherwise we decide H_0. The false alarm probability P_{fa} and probability detection P_d are given as considered in [20]:

$$P_{fa} = P(\rho > \eta_l | H_0) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{M}\,\eta_l\right) \tag{3}$$

Thus the threshold at the local detector can be calculated as:

$$\eta_l = \frac{1}{\sqrt{M}}\mathrm{erfc}^{-1}(2P_{fa}) \tag{4}$$

Similarly, the probability of detection P_d is given by:

$$P_d = P(\rho > \eta_l |\, H_1) = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{M}\frac{\eta_l - \rho_1}{1-\rho_1^2}\right)$$
$$\text{where } \rho_1 = \frac{N_c}{N_d + N_c}\frac{\sigma_s^2}{\sigma_s^2 + \sigma_w^2} = \frac{N_c}{N_d + N_c}\frac{SNR}{1 + SNR} \tag{5}$$

The SNR is a power ratio. N_d, N_c and M denote the number of symbols in data block, the number of symbols in the Cyclic Prefix (CP) and the number of samples respectively.

The decision making about the available channels is done by SBS entity by combining the P_d values at each SU based OR rule.

Once the available channels have been identified, we estimate the quality of each one based on channel quality estimation scheme considered in [21]. In [21], the authors considered two parameters, spectrum sensing accuracy of SU on primary channel and the expected idle state duration to estimate the quality of channel as follows:

$$CH_q = (1 + \log_{\epsilon} S_A)E[T_{off}] \tag{6}$$

Where S_A is the accuracy of spectrum sensing and $E[T_{off}]$ is the expected idle state duration. The accuracy of spectrum sensing is calculated based on false-alarm probability and detection probability as follows:

$$S_A = P_d(1 - P_{fa}) \tag{7}$$

The channel usage is modeled as on/off source alternating model, where on means busy period and off means idle period. The PU arrival process follows a Poisson arrival distribution with arrival rate of μ and exponential service distribution [22]. The on and off periods are independent identically distributed (i.i.d.) and exponentially distributed, with probability distribution functions given as:

$$\begin{cases} f(T_{on}) = \alpha e^{-\alpha T_{on}} \\ f(T_{off}) = \beta e^{-\beta T_{off}} \end{cases} \tag{8}$$

Where (α, β) are the mean parameters for the exponential distributions for busy and idle periods. $E[T_{on}]$ and $E[T_{off}]$ are the vectors related to the mean quantities of the on and off states with T_{on} and T_{off} are durations of on and off states. The expected durations of on and off states are then:

$$\begin{cases} E[T_{on}] = 1/\alpha \\ E[T_{off}] = 1/\beta \end{cases} \tag{9}$$

In Eq. (6), $\epsilon > 1$ indicates the preference of the system when estimating the channel quality. The authors in [21] jugged that the scheme could give more importance to the idle duration by choosing higher ϵ or more preference to the sensing accuracy by choosing smaller ϵ. In our study, we interest to the channel with longer available duration as best channel because the sensing function is not always precise and can be limited in terms of the observation quantity and noise. So we take $\epsilon = 8$ to promote the expected idle duration of channel.

Thus our proposed management system maintains the pre-ranked list of available channel quality in advance that help to quickly assign best channel to SUs during the allocation process or if the handoff is triggered.

2.1.2. Sharing scheme

This functionality allows making coordination among different SUs to access radio resources. Once the list of idle channels has been identified, SBS entity computes the reward of each user and coalition. To ensure equitable and fair sharing of available channels among different SUs we apply cooperative game theory. The proposed spectrum sharing strategy jointly assigns to each SU a reward according to his effort done during sensing the environment. The reward presents the total gain created by cooperative sensing process how is shared between SUs. The reward of SU *i* is calculated as considered in [10]:

$$w(i) = \sum_{j=1}^{M} \frac{1-H(P_{ij})}{c_i(j)} \qquad (10)$$

Where P_{ij} is probability of detecting PU by SU i on channel j, $c_i(j)$ is total number of users sensing channel j, M number of channels sensed, and H(.) entropy function. The binary entropy function H measures the amount of reduction in uncertainty associated with detection probabilities P_d about PU activity as given in fig. 3. It serves as a parameter to quantify the quality of work done by SUs from spectrum sensing. The maximum value of H(0.5) is 1 before sensing the channel.

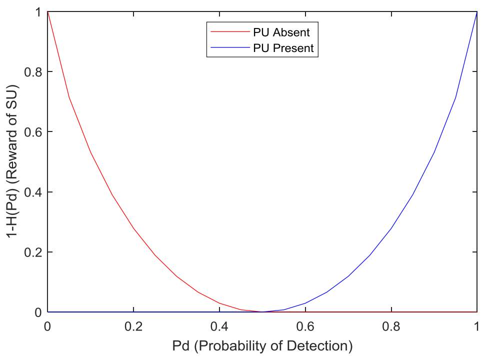

Fig 3. Reward of secondary user based reduction of uncertainty about primary user

The coalition is treated as a single user. The P_d value for a coalition is chosen from one of different detection probabilities of SUs that form it. Since the coalition is bound by the decision of SBS on spectrum occupancy, the P_d for the coalition is chosen as the closest one to the decision of SBS.

The game theory defines the characteristic function that measures the entire effort done by SUs in terms of quality and quantity. If two SUs form a coalition, the first SU definitely benefits from the reduction in uncertainty about PU activity carried by the second one and vice versa. Thus, the worth of the coalition is better than the individual one due to sharing of increased awareness about spectrum availability and improved decision making performance amongst themselves. This mechanism captures the importance of cooperative spectrum sensing in cognitive radio networks. Mathematically the characteristic function is given as:

$$w(S) = |S| \sum_{j=1}^{M} \frac{1-H(|\max_{\forall i \in S}(P_{ij} D_j)|)}{c_S(j)} \qquad (11)$$

Where S is any coalition in {1, 2… |N|}, |S| represents cardinality of set S, M is the number of channels, H(.) is the binary entropy function, P_{ij} is the probability of detecting PU by SU i on channel j, D_j is the spectrum decision (1 when PU is present and 0 when PU is absent) on channel j, $|\max \forall i \in S(P_{ij} D_j)|$ is detection probability for a coalition and $c_S(j)$ is the total number of entities sensing channel j including coalition S.

The worth of the coalition is equally devised amongst its players. When this criterion is satisfied, the cooperative game is considered to have transferable utility (TU-game). A TU-game is characterized by that the benefits awarded to the players are not unique to a specific player. Hence it is possible to freely distribute the utility among all players [22].

It is proven that games modeled in this fashion are totally balanced and convex in nature. Thus, the core is non-empty and the one-point solutions lie within the core, especially the Shapley value, which lies in the center of gravity of the core [19]. When there are many players in a game, it becomes complex and tedious to solve the system of inequalities and then to find a singleton solution by bargaining. Hence, one-point solutions such as the Shapley values, Tau values, Nucleolus, etc were developed to calculate the allocation ratio directly without the need to solve the core [6]. Singleton solutions provide payoffs to SUs which are not directly used to assign idle channels, but is instead used as currency in allocation process to access unoccupied channels. The Shapley value for each player i is the expected marginal contribution when it joins the coalition. In other words, the Shapley value is an average measure of fairness, it calculates as follows [10]:

$$Sh(i) = \sum_{S \subset N\{i\}} \frac{|S|!(N-|S|-1)!}{N!} (w(S \cup \{i\}) - w(S) \qquad (12)$$

2.1.3. Allocation scheme

This functionality executes the selection of the most prioritized SU to access the most appropriate available channel. To this aim we consider the auction theory because it is an extreme tool that can be employed with game theory [17]. The auction mechanism considered is called a Vickrey

Clarke Groves (VCG) auction [19]. The proposed spectrum allocation strategy implements the decision-making that maximizes the average reward by selecting the most qualified channel from the pre-estimated list of available channel quality. In the VCG auction scheme, SBS entity acts as the VCG auctioneer and the SUs are the bidders. Each SU sends his bid according to his requirements for transmission and his payoff obtained from sharing process, to the auctioneer. SBS ranks the SU's bids and the high bidder is allocated a high priority channel. The winner SU is paid a price equal to the second high bid plus a bid increment 1. The bid increment satisfies that winner of the auction pays a higher price than the second high bidder. This price is then subtracted from the bid of SU who was just allocated the channel. The SU's bids are rearranged to allocate remaining idle channels in a similar way. This procedure repeats until there is no available channel. After the auction mechanism, payoffs of SUs are normalized again and are averaged with normalized ones obtained in previous time slots.

Mathematically, the VCG mechanism can be expressed as given in [10]. Denoting the idle channel by g and $b_i(g_i)$ the SU i's value for any vector gi. Each SU sends a bi value to SBS which calculates a value-maximizing allocation given by:

$$g^* \in \arg\max \sum_i b_i(g_i) \qquad \text{subject to } \sum_i g_i \leq g \qquad (13)$$

The price paid by SU i is then given by:

$$p_i = \alpha_i - \sum_{m \neq i} b_m(g_m^*) \quad \text{where}$$
$$\alpha_i = \max\{\sum_{m \neq i} b_m(g_m^*) \mid \sum_{m \neq i} g_m \leq g\} \qquad (14)$$

The parameter α_i depends only on the value reports of other SUs and not on what SU i reports.

2.1.4. Handoff scheme

The CRNs is known by the temporary nature of available channels and the highly dynamic nature of the environment. In order to complete the above process successfully, the proposed cognitive management system must have the ability of executing spectrum handoff. This functionality is triggered if the state of channel is changed during the secondary transmission or the time of availability of channel is exhausted. In this case, SU must stop its current data transmission and switch to another unoccupied channel to resume its transmission.

In general, in CRNs, spectrum handoff mechanism can be categorized into proactive or reactive handoff based on the target channel selection methods. In proactive-handoff (fig. 4(a)), SUs periodically observe the environment to obtain the channel usage statistics, and determine the set of target channels for spectrum handoff according to the succession observation measurements. SUs make the target channels for spectrum handoff ready before its transmission is started. In reactive-handoff (fig. 4(b)), the target channels are sought based the on-demand way. In this case, the instantaneous measurements from wideband sensing will be used to determine the target channel selection for spectrum handoff when spectrum handoff is requested [23].

The proposed spectrum management handoff strategy proactively perform the sensing to stay in every instant aware of the environment changes, monitor and update instantaneously the availability of channel that being used for data transmission. And reactively switch to other available channel selected from the pre-ranked list of available channels upon the spectrum handoff is requested. Thus, faster spectrum handoff delay can be achieved. The handoff delay is the time spent to switch from one channel to another. Consequently, the hybrid scheme of proactive-reactive handoffs is considered in our cognitive management strategy.

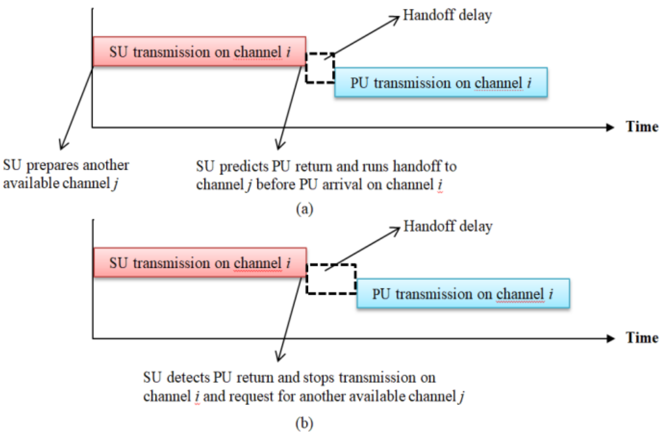

Fig 4. Spectrum handoff schemes inspired from [23] (a) proactive handoff and (b) reactive handoff

3. SIMULATION RESULTS AND DISCUSSION

A set of 3 SUs, one SBS and 5 channels of equal bandwidth of 7 MHz are considered. Two different states are considered for each *i-th* channel during every time slot (t_s). $S^i(t_S)=0$ when channel is inactive during t_s and $S^i(t_S)=1$ when channel is active during t_s. The durations of the on and off states are exponentially distributed with the average times of t_s=50ms. The number of symbols in data block N_d, the number of symbols in the Cyclic Prefix N_c and the number of samples M are considered of 32, 8, 4000, respectively. SNR values are uniformly distributed between [-25dB, -5 dB]. The proposed strategy is executed to analyse the performance in terms of the average handoff delay and the average reward achieved. The random strategy is also considered as a baseline strategy for comparison.

The proposed spectrum management strategy starts by executing spectrum sensing functionality that enables SUs to sense channels to find radio spectrum opportunities. Each SU chooses channels to sense and then SNR values are randomly generated for each sensed channel. The generated SNR values are translated to probability of detection P_d values using eq. 5 with constant value of false alarm probability (P_{fa}=0.05). The SBS entity combines P_d values to decide about the idle channels. Once free channels are identified, the strategy estimates their quality using Eq. 6 with ϵ =8. The scheme provides the quality index for each channel, and then it ranks them in descending order in the list of available channel quality. The characteristic function of cooperative game theory based on the reduction of uncertainty (fig. 3) about the PU activity is then calculated using Eq. 11. Each SU and coalition receives a reward for its effort done in the sensing process. SU1 has the high reward because he is the only one that detected CH4 and his information accorded with the SBS decision about the status of CH2. SU2 has the second high reward because he detected CH1. SU3 has lower reward because his information doesn't accord with the SBS decision about CH2 status. The rewards obtained used to compute the payoffs using Eq. 12. The payoffs are used as currency during the decision-making spectrum selection. The strategy provides then SUs to bid for access channels according to their needs in transmission. The SU2 has great bid which reflect his high need to transmission, despite the SU1 has the high payoff which reflect the cooperation incentive. The CH3 is assigned to SU2, because it is assumed as the best channel in the list of available channels. CH5 is allocated to the second high bidder SU1. The simulation example is shown in Table 1.

Table 1. Simulation example.

	Users	**Channels**				
		1	2	3	4	5
SNR Values	1	-	-6.4846	-12.3883	-5.3829	-
	2	-7.1753	-12.5015	-	-	-
	3	-	-19.3400	-12.9396	-	-12.4537
Pd Values	1	0.5	0.98	0.25	0.99	0.5
	2	0.95	0.24	0.5	0.5	0.5
	3	0.5	0.08	0.22	0.5	0.24
SBS decision		1	1	0	1	0
E[Toff]		-	-	20	-	5.88
SA		-	-	0.21	-	0.23
Quality index		0	0	1	0	2
				SUs		
				1	2	3
Rewards				1.9665	0.7136	0.4448
Reward of the coalition				5.4360		
Normalized payoffs				47.6803	33.4897	18.83
Bids				20.5833	23.6802	7.5981
Best bidder					✓	
Best channel					3	
Price paid					20.5834	
Remaining bids				20.5833	3.0968	7.5981
Best bidder				✓		
Best channel				5		
Price paid				7.5982		
Remaining bids				12.9851	3.0968	7.5981
Normalized payoffs				55.8104	17.9707	26.2190

Figure 5 shows the evolution of the simulation during the first time slot of channel 5. From the figure it can be noticed that after 20ms the proposed strategy detect the changing state of the current channel then request for spectrum handoff, whereas the random strategy request for spectrum handoff after 50ms.

Figure 6 illustrates the activity states of channel 5 during the 3rd first time slots. From the figure it can be noticed that the decision making of the proposed strategy accorded with the changing state of channel 5 after the instant 20ms by triggering the handoff process at this time which avoids the interference. Contrariwise, the random strategy is affected by the interference at the decision-making time instant.

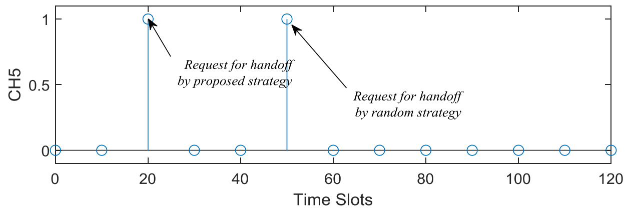

Fig 5. Channel 5 handoff request

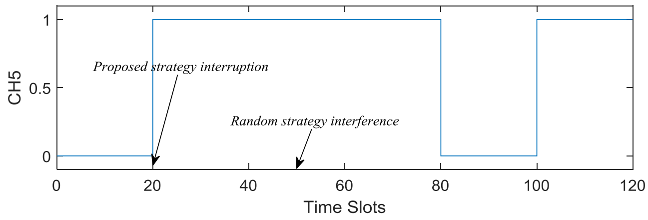

Fig 6. Channel 5 activity states

To evaluate the average handoff delay, figure 7 compares the handoff delay of our proposed strategy with pure proactive and pure reactive methods and the random strategy. From the result it shown that our strategy minimizes the spectrum handoff delay better than other methods, because our strategy relies on the proactive sensing that sense the environment instantaneously before the arrival of the owner as well as relies on the reactive switching to another available channel that is already builded with better quality upon detecting the arrival of PU and doesn't need to spent time by evaluating the quality of available channels.

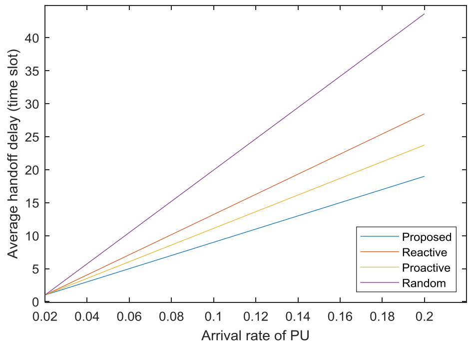

Fig 7. Average handoff delay

To evaluate the average reward achieved by the proposed management system, we provide a comparison of our proposed strategy with round robin strategy and random strategy. In round robin access, SUs allocate channels in sequence, and all SUs have equal opportunity to access available channels. The data rates are estimated using Shannon's capacity and randomly generated. Figure 9, shows that our strategy performs the two other methods because it relies on selecting channels that are already evaluated and qualified i.e. our scheme selects only the best channels. Figure 8, illustrates the total throughput achieved by each SU, the result shows clearly the fairness of the proposed strategy.

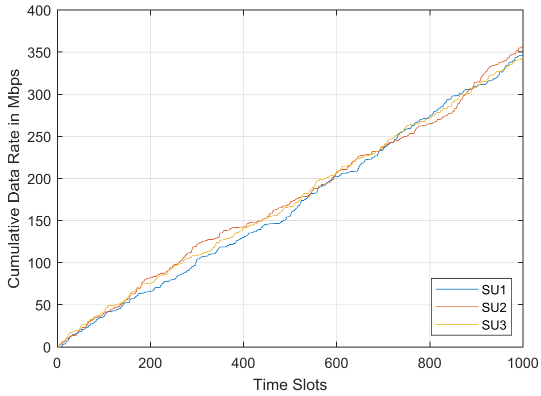

Fig 8. Total throughput achieved by each SU

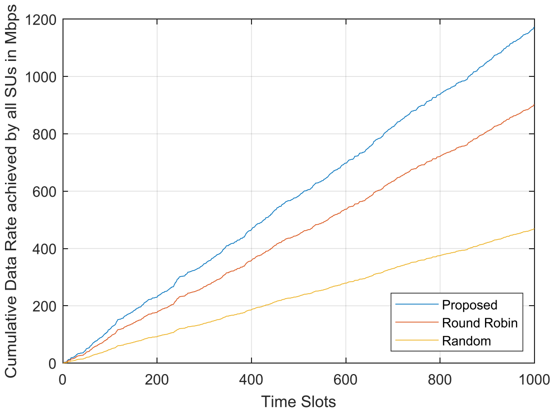

Fig 9. Total throughput achieved

4. CONCLUSION

This paper has presented spectrum management strategy in the context of cognitive radio networks. The aim was to propose a cognitive management system that is able to autonomously adapt to different wireless environment implementation and improve its performance. This paper has described the management functionalities that make up the proposed system. The proposed strategy has provided consistency among different management functions. The system has been successfully minimized the average handoff delay and maximized the expected reward.

As future work, implementing the proposed spectrum management strategy in real-time emulation platform can be considered. Proposing more complex spectrum management systems, when more parameters like interference probability management, transmission in real time, dynamic slot length structures, can be addressed.

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