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An Optimized Queuing Model to Improve Spectrum Utilisation in Cognitive Radio Network

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Abstract: Allocated Spectrum band has always been a limited resource; being later a more challenging issue due to the growth of user demands. The past decade is marked by important changes in spectrum access through especially cognitive radio technology. Here, spectrum access issue can be studied in all the different aspects of cognitive capabilities. This paper focuses on spectrum handoff in spectrum mobility. We will then study secondary connections behaviours after multiple interruptions providing from multiple secondary connections. In the IEEE 802.22 standards [1], two Spectrum Handoff Sequences have been defined to characterize Secondary Connections behaviours after each Primary Connections interruption. These sequences are known as always-leaving and always-staying sequences. A recent analysis uses the extended data delivery time metric to analyse these Spectrum Handoff Sequences. It shows the exponential value of connections service time in the first sequence (always-leaving sequence) and in the other (always-staying sequence), the lack of fairness due to the acquisition of channel's low-priority queue by the ongoing secondary connection (i.e. the secondary connection actually being served in the low-priority queue. We propose the pre-emptive resume priority (PRP) M/G/1 queuing network model to characterize the spectrum usage behaviours with all the three design features. This model aims to analyse the extended data delivery time of the secondary connections with proactively designed target channel sequences under various traffic arrival rates and service time distributions. These analytical results are applied to evaluate the latency performance of the connection-based spectrum handoff based on the target channel sequences mentioned in the IEEE 802.22 wireless regional area networks standard. Then, to reduce the extended data delivery time, a traffic-adaptive spectrum handoff is proposed, which changes the target channel sequence of spectrum handoffs based on traffic conditions. Compared to the existing target channel selection methods, this traffic-adaptive target channel selection approach can reduce the extended data transmission time by 35 percent, especially for the heavy traffic loads of the primary users.

Keywords: Cognitive Radio; Spectrum Handoff; Lifetime of Secondary Connection; PRP M/G/1 Queuing Theory.

I. INTRODUCTION

In Cognitive Radio system, Primary Connections have the pre-emptive right to use a specific spectrum while Secondary Connections have a lower priority on the use of the spectrum. So they are needed to use the spectrum without causing harmful interference. If the current spectrum band in use becomes unavailable, the spectrum mobility function is performed to provide a seamless transmission.

Any environmental change during the transmission such as Primary Connections appearance, user movement, or traffic variation can trigger this adjustment. Efficient utilization can be improved by allowing a Secondary Connections to utilize a licensed band when primary user Primary Connections are absent [2]. The efficiency also guarantees that the coming back of a Primary Connections will not interfere with the running Cognitive Radio system. One of the most efficient queuing model that helps analyse secondary and primary connections is the PRP M/G.1 queuing network model because it considers general service time distribution of the primary and secondary connections; different operating channels in multiple handoffs; and queuing delay due to channel contention from multiple interrupted secondary connections [3]. The PRP M/G/1 queuing model organizes channels in queues; Secondary Connections are arranged in low priority queues when Primary Connections are in high priority queues. The Primary Connections have the pre-emptive right to access and transmit in the channel. Meanwhile Secondary Connections use the idleness of the channel to transmit.

During their transmission, Secondary Connections endure multiple Primary Connections interruptions and Spectrum Handoff Sequences are defined according to Secondary Connections behaviour towards those interruptions. In this paper we propose a novel Spectrum Handoff Sequence. Next, to show the efficiency of our novel Spectrum Handoff Sequence, we propose a novel performance metric that we call Lifetime of Secondary Connections instead of the Extended Data Delivery Time of Secondary Connections and we use it to compare the IEEE 802.22 Spectrum Handoff Sequences standards with our propose Spectrum Handoff Sequence. In our analysis, to prove the importance of the Lifetime metric, we will take the first four Secondary Connections present in a low-priority

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queue, analyse the first Secondary Connection Extended Data Delivery Time and deduce the effect on the Lifetime of the other three Secondary Connections. We will see that our proposed sequence is a better Spectrum Handoff Sequence, and that the Lifetime of Secondary Connections brings new system analysis that improves considerably the cognitive radio handoff performance.

II. IEEE 802.22 STANDARDS FOR SPECTRUM HANDOFF SEQUENCES

Spectrum handoff in cognitive wireless networks impacts directly on software and hardware costs of system resources, and it is critical to design and evaluate the strategy of wireless resources management [4]. When a Primary Connection appears, current channel condition becomes worse causing spectrum mobility to arise. Due to this a chain reaction is triggered and spectrum mobility also causes spectrum handoff to arise. Figure 1 shows spectrum mobility and spectrum handoff processes. From what precedes, it appears that it is important to describe efficient spectrum handoff sequences. These will follow the analysing network model to create policy that will be applied to coexisting Secondary Connections. Here, we will briefly introduce spectrum handoff sequences provided by the IEEE 802.22 standards, while give the main limitation of each one.

The always-staying sequence: Here a Secondary Connection always stays on its default channel η at every interruption. That is, the other Secondary Connections in low-priority queues will have to wait an infinite time before transmitting. Though the lack of fairness.

The always-leaving sequence: Here, a Secondary Connection will switch to a different channel at each interruption. With the channel switching delay and the residual service time to consider, this sequence shows an enormous effective service time.

III. EXTENDED DATA DELIVERY TIME OF OUR PROPOSED SEQUENCE

In our proposed sequence, a Secondary Connection will endure a predefined number (Ni) of interruptions on a channel k, and then switches to another target channel where it will occupy the head of the low priority queue after the ongoing connection terminates. We assume the expression of the Average Extended Data Delivery Time defined in [3] as the basis of our analysis. In table (1) there is a resume of important notations that we will use in what will follow. In general, a Secondary Connection that encounters N interruptions has an average Extended Data Delivery Time of:

$$E[T]=\sum_{n=1}^{n_{\max}} E(T\mid N=n)\Pr(N=n)$$

By definition, the Extended Data Delivery Time is the original service time added to the cumulative handoff delay of the Secondary Connection. Here, a Secondary Connection can eventually endure Ni+1 interruptions, in which case we will consider the handoff delay for the case it will stay Ni times on a channel, and the one when it will switch to another channel at the Ni+1 interruption. We can then write the Extended Data Delivery Time of the considered Secondary Connection as:

$$E(T\mid N=n)=E[Xs^{(k)}]+E[T_1]+E[T_2]$$

Where E[T1] and E[T2] represent the staying (Ni times) part and switching part successively. With the general form of:

$$E[T_{1/2}]=\sum_{i=1}^{n} E[D_{i(1/2)}]$$

We will consider two channels k and k'. Here k is the current channel in which the Secondary connection being served may endure Ni interruptions; and k' the channel where the Secondary Connection will switch at the (Ni+1) th interruption. Let's first derive $E[D_{i(1)}]$. When the considered Secondary Connection stays on the same channel, the handoff delay is the busy probability resulting from multiple Primary Connections of channel k denoted as $Y_p^{(k)}$ That is, $E[D_{i(1)}]=E[Y_p^{(k)}]$. The Secondary Connection using the idleness of the channel to transmit, its Extended Data Delivery Time can be expressed from the memory less property applied to the idle period as:

$$E[I_p^{(k)}]=\frac{1}{\lambda_p^{(k)}}$$

From the utilization factor of channel k we have:

$$\rho_i^{(k)}=\lambda_p^{(k)}E[(X_p^{(k)})]$$

$\rho_i^{(k)}$ Being the channel busy probability from the Primary Connections, we have:

$$\rho_i^{(k)}=\frac{E[Y_p^{(k)}]}{E[Y_p^{(k)}]+E[I_p^{(k)}]}$$

$$E[Y_p^{(k)}]=\frac{E[X_s^{(k)}]}{1-\rho_p^{(k)}}=\frac{E[X_s^{(k)}}{1-\lambda_p^{(k)}E[X_p^{(k)}]}$$

Next, the Secondary Connection will switch to a different channel and wait only until the current connection finishes. Its handoff delay will then be the channel switching delay time added to the average effective residual time of channel k'.

If we note $E[W_p^{(k)}]$ as the waiting time in channel k' we have $E[W_p^{(k)}]=E[R_s^{(k')}]$. $E[R_s^{(k')}]$ Serves as the remaining time to complete the service of the connection being served at channel k'[6]. Considering the channel switching delay, we can have the final expression of the handoff delay as:

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$$E[D_{i(2)}] = E[R_s^{(k)}] + t_s$$

With the definition of the residual time in [3], we have

$$E[R_s^{(k')}] = \tfrac{1}{2}\lambda_p^{(k')} E[(X_p^{(k')})^2] + W_i^{(k')} E[(\phi_i^{(k')})^2]$$

Note that the ongoing connection can be either from Secondary Connections or Primary Connections. Then comes the derivation of $P_r(N = n)$. In any case (staying or leaving), here we consider the channel sequence (S1, η, S2, η, S3, η, … , Si, η) with Si, η = η as the default channel. The probability that the Secondary Connection is interrupted again at the i interruption is defined as Pi(k).That gives us the general expression of $P_r(N = n)$ as:

$$P_r(N = n) = (1 - p_n^{(s_{n,n})}) \prod_{i=0}^{n-1} P_i^{(S_{i,n})}$$

We can then obtain the final expression of our proposed sequence Extended Data Delivery Time from:

$$E[T_f] = E[X_s^{(k)}] + \sum_{n=1}^{N_i} \left[(\sum_{i=1}^{n} E[Y_p^{(k)}])(1 - P_i^{(k)} \prod_{i=0}^{N_i - 1} P_i^{(k)} \right] +$$
$$\sum_{n=1}^{N} \left[(\sum_{i=1}^{n} (\tfrac{1}{2}\lambda_p^{(k')} E[(X_p^{(k')})^2 \right] + \tfrac{1}{2} \sum_{i=0}^{n_{\max}} W_i^{(k')} E[(\phi_i^{(k')})^2 + t_s)]$$

With

$$W_i E[(\phi_i)^2] = \lambda_s (\tfrac{\lambda_p}{\lambda_p + \mu_s})^i \tfrac{2}{(\lambda_p + \mu_s)^2}$$

The average extended data delivery time of the secondary connections for the always-staying sequence can be expressed as follows:

$$E[T_{stay}] = E[X_s^{(\eta)}] + \sum_{n=1}^{n_{\max}} (\sum_{i=1}^{n} E[Y_p^{(\eta)}])(1 - P_n^{(\eta)}) \prod_{i=0}^{n-1} p_i^{(\eta)}$$

The average extended data delivery time of the secondary connections for the always-changing sequence can be expressed as follows:

$$E[T_{change}] = E[X_s^{(\eta)}] + \sum_{n=1}^{n_{\max}} [(\sum_{i=1}^{n} (E[W_s^{(s_i,\eta)}] + t_s))(1 - P_n^{(s_{n,\eta})}) \prod_{i=0}^{n-1} p_i^{(s_{i,\eta})}]$$

Based on the analytical results, the secondary connection can adaptively adopt the better target channel sequence to reduce its extended data delivery time. Thus, the average extended data delivery time with this adaptive channel selection principle (denoted by E[T]) can be expressed as follows here, the adaptive sequence adopts the better channel sequence between the always-leaving and always-staying sequences, to reduce its Extended Data Delivery Time. It is expressed as:

$$E[T^*] = \min(E[T_{stay}], E[T_{change}])$$

The average extended data delivery time with our adaptive target channel selection approach can be expressed as follows:

$$E[T^*] = \begin{cases} (E[T_{stay}], E[Y_p] \le E[W_s] + t_s \\ (E[T_{change}], E[Y_p] \ge E[W_s] + t_s \end{cases}$$

Note that the always-staying and the always-changing sequences have the same extended data delivery time when $E[Y_p] = E[W_s] + t_s$

Table 1: Important Notations

$\lambda_p^{(\eta)}$	Traffic arrival rate of primary connection at channel η
$\lambda_s^{(\eta)}$	Initial traffic arrival rate of secondary connection at default channel η
$X_p^{(\eta)}$	Service time of the primary connection at channel η
$X_s^{(\eta)}$	Service time of the secondary connection at channel η
t_s	Channel switching time
D_i	Handoff delay for the ith interruption
$\eta_{\max}$	Maximum number of interruptions for the secondary connection
$S_{i,n}$	The target channel at the ith interruption
$p_i^{(S_{n,n})}$	Interrupted probability when the secondary connection has experienced i interruptions

Here, we have the simulation Comparison between our proposed sequence and the IEEE 802.22 Spectrum Handoff Sequence standards using the Extended Data Delivery Time metric with ts = 1, λs = 0.01, E [Xs] = 10, and E [Xp] = 20.

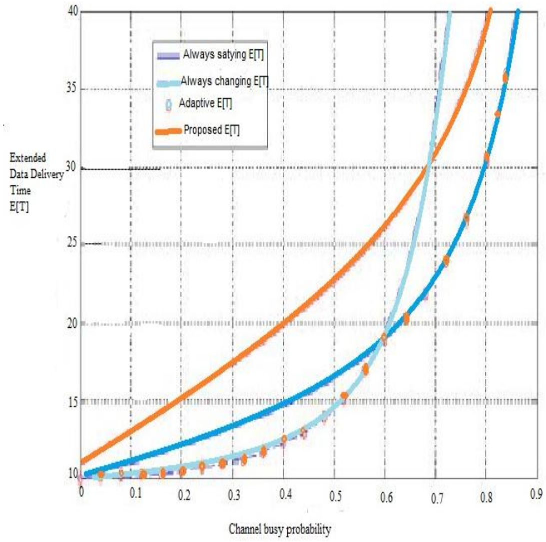

Figure1. Analysis of Spectrum Handoff Sequences using the Extended Data Delivery Time

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Figure 1 shows simulation results of the comparison between our proposed sequence and the IEEE 802.22 Spectrum Handoff Sequences standards using the Extended Data Delivery Time. Here, the adaptive sequence adopts the better channel sequence between the always-leaving and always-staying sequences, to reduce its Extended Data Delivery Time. It is expressed as:

$$E[T^*] = \min(E[T_{stay}], E[T_{change}])$$

IV. PERFORMANCE COMPARISON BETWEEN DIFFERENT CHANNEL SELECTION METHODS

Now, we compare the extended data delivery time of the following three schemes: 1) the slot-based target channel selection scheme; 2) the random-based target channel selection scheme; and 3) the traffic-adaptive target channel selection scheme. We consider a three-channel network with various traffic load $\lambda_s = 0.01(arrival/slot)$ and

$$(E[X_p^{(1)}], E[X_p^{(2)}], E[X_p^{(3)}]) = (5,15,25)(slots/arrival)$$

$$(E[X_s^{(1)}], E[X_s^{(2)}], E[X_s^{(3)}] = (15,15,15)(slots/arival)$$

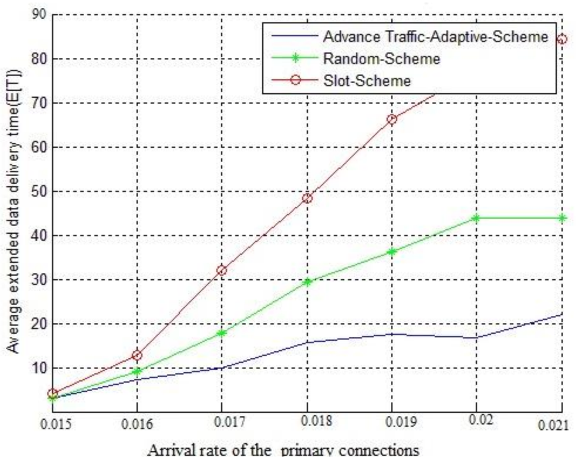

Figure2. Comparison of average extended data delivery time for different target channel selection sequences

The below graph shows comparison of the extended data bringing time of the following three schemes: 1) the slot-based direct channel selection scheme; 2) the random-based direct channel selection scheme; and 3) the traffic-adaptive direct channel selection scheme. For the slot-based scheme, the secondary connections prefer selecting the channel which has the least busy chance resulting from the primary connections in each time slot. That is, when handoff functions are started in the beginning of each time slot, all the secondary connections will select channel one to be their direct channels. Furthermore, the random-based scheme selects one channel out of all the three channels for the direct channel. Hence, every channel is selected with probability 1/3. Moreover, based on the considered traffic arguments, the traffic-adaptive outline will adopt the always-alerting sequence and the always-alerting sequence when ʎp <= 0:018 (arrivals/slot) and ʎp >=0:018 (arrivals/slot), respectively.

The three direct channel selection outlines result in various direct channel successions. Based on the proposed analytical model, we can evaluate the average extended data bringing time resulting from these direct channel successions ans compares the extended data bringing time of the three direct channel selection methods. We have the following three important observations.

First, we consider ʎp < 0:018 (arrivals/slot). Because the probability of changing operating channel is higher than that of staying on the current operating channel for the cut off secondary client in the random-based scheme, we can find that the average extended data bringing time for the random-based direct channel option scheme is similar to that for the traffic-adaptive direct channel selection scheme, which adopts the always-altering succession. Second, when ʎp > 0:018 (arrivals/slot), the traffic-adaptive scheme can shorten the average extended data bringing time because it adopts the always-staying sequence.

For a larger value of ʎp, the traffic-adaptive scheme can improve the extended data bringing time more significantly. Third, it is shown that the ergodic-based and traffic-adaptive schemes can result in shorter extended data bringing time compared to the slot-based scheme. For example, when ʎp=0:018, the random-based and traffic-adaptive schemes can improve the extended data bringing time by 35 percent compared to the slot-based scheme. This is because the slot-based scheme does not believe the queuing detain due to channel argument from multiple secondary connections. Here we compare the result obtained from the previous paper and the new result and conclude that the new result is much better than the previous result as in this we get lower value for the extended data bringing time for different channel. With simulation we have seen that the extended data bringing time is reduced by 35% by using the traffic adaptive scheme as compare to the other direct channel selective scheme for performing spectrum handoff.

V. CONCLUSION

In this paper PRP M/G/1 queuing network model is used to characterize the spectrum usage behaviours with multiple handoffs. We studied the latency performance of the secondary connection by considering the effect of 1) general service time distribution; 2) various operating channels; and 3) queuing delay due to channel disagreement from multiple secondary connections. The proposed model can precisely estimate the extended data delivery time of different proactively designed target channel sequences. On top of this model, we manifest that the extended data delivery time of the secondary connections with the always-staying and the always-changing order. If the secondary users can adaptively adopt the better target channel sequence according to traffic condition, the elongated data delivery time can be improved significantly compared to the existing target channel selection method, mainly for the heavy traffic loads of the primary users.

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We used the PRP M/G/1 queuing model, and designed a novel Spectrum Handoff Sequence to improve handoffs in cognitive radio networks. Additionally, we compare our proposed solution with the existing sequences using the extended data delivery time .From this method it is concluded that our proposed Spectrum Handoff Sequence provides a solution of both fairness and efficiency. Furthermore, the Lifetime of Secondary Connections allows us to predetermine our cognitive radio network system performance, while modelling novel Spectrum Handoff Sequences. In this paper Pre-emptive resume priority M/G/1 (PRP-M/G/1) model is used to investigate the issues involved in spectrum management. By using traffic acclimatize scheme spectrum handoff we have increase the spectrum efficiency in cognitive radio network and hence increases the quality of services of cognitive radio users using spectrum handoff.

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