

# Spectrum Handoff in Cognitive Radio Network

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**Abstract:** Rapid development of wireless networking technology has raised a large demand for spectrum band. Cognitive radio networks (CRNs) offer a solution for spectrum scarcity problem by means of dynamic spectrum access. Cognitive radio technology is an emerging technology which would enable a set of secondary users (SU) to opportunistically use the spectrum allocated to a primary user (PU) and has potential to serve as a solution to spectrum inefficiency and spectrum shortage problems. However, SUs face number of challenges based on the fluctuating nature of the available spectrum. When PU arrives on a specific frequency band, any SU occupying this band should free the channel for PUs which is referred as Spectrum handoff. It is an important but unexplored event in cognitive radio network. This paper is a brief overview on the reason, mechanism, challenges and their solutions in spectrum handoff.

**Keywords:** cognitive radio, spectrum handoff, spectrum mobility queuing theory, PRP M/G/1 queueing model.

## I. INTRODUCTION

The demand for new wireless application and services are growing very rapidly, but the spectrum resources are non-renewable. It has led to new research toward finding an efficient way to improve the spectrum utilization to satisfy this growing demand. According to the report given by Federal Communications Commission (FCC), allocated spectrum is under-utilized due to the inefficient fixed spectrum allocation policy. This limited available spectrum and the inefficiency in the spectrum usage necessitates a new communication technology to exploit the existing wireless spectrum opportunistically by access to the licensed bands without interfering with the primary user. The licensed user referred as primary user and the unlicensed user are referred as secondary user and this new networking paradigm is referred as Dynamic Spectrum Access (DSA) or cognitive radio networks (CRN).

Cognitive radio is a new approach to reduce the spectrum scarcity by allowing the secondary users or cognitive user too temporarily utilize the licensed spectrum unoccupied by the primary user. The cognitive radio technology will enable the secondary users to determine which portions of the spectrum is available and detect the presence of primary user when a user operates in a licensed band known as spectrum sensing. And selecting the best available channel through spectrum management. Co-ordination of the access to this channel with other users known as spectrum sharing, and if band is found to be occupied by a primary user, the CR user moves to another channel or spectrum hole to avoid interference known as spectrum handoff. Through cognitive capability and re-configurability prime objective of cognitive radio network to obtain best available channel is achieved which is discussed in [2].

Cognitive radio (CR) can improve spectrum efficiency by allowing secondary users or cognitive users to temporarily

access primary users' unused licensed spectrum [1]. Cognitive radio (CR) system requires four important functionalities [2]:

- (1) Spectrum sensing
- (2) Spectrum management
- (3) Spectrum sharing
- (4) Spectrum handoff

In this paper, we focus on the spectrum handoff issue, which is discussed less often in the literature than other spectrum issues of CR networks. Spectrum handoff occurs when the high-priority primary user appear at its licensed channel and that channel is occupied by secondary users [3]. In this case, secondary users are forced to vacate the occupied licensed spectrum. Spectrum handoff procedures aim to help secondary users find suitable target channels to resume the unfinished transmission.

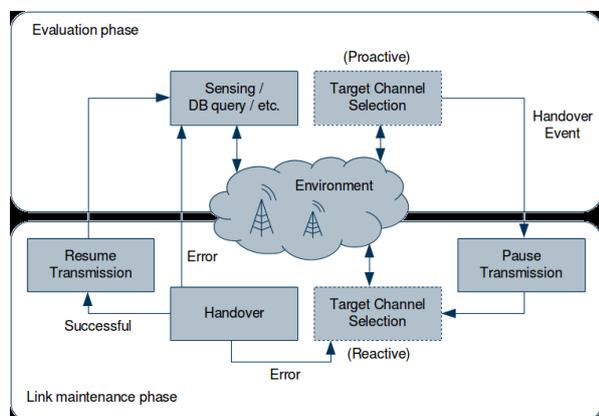
## II. SPECTRUM HANDOFF

Cognitive radio technology allows a cognitive user to use the idle spectrum resources temporarily on the condition that it does not interfere with the communication of the licensed user during this process. In order to complete the above process successfully, the cognitive user must have the ability of spectrum sensing, spectrum access and spectrum handoff. When the licensed users appear in the licensed band which is occupied by the cognitive user or secondary user [1], in order to avoid interfering with the primary users, the cognitive user has to vacate the spectrum and re-establish a communication link on some other vacant channel or spectrum to avoid interrupting the transmission of the primary user, this process is known as spectrum handoff.

Spectrum handoff is the process of transferring ongoing communication of the secondary user from the current channel to another free channel. This causes latency to SU

communication that eventually affects the SU performance. There are two PU related events which can trigger the spectrum handoff in CRNs. First, PU arrival in the licensed channel which is used by secondary user and necessarily forces SU to perform spectrum handoff. Second, spectrum handoff occurs because of cognitive user mobility. As CR users moves spatially, there is a chance that transmission coverage of the secondary user overlaps with a primary user currently using the same channel band. Being opportunistic users in licensed bands, secondary users activity in legacy networks shall conform to the ground rule: PUs always has higher priority in using the licensed band than secondary user. As a consequence, if secondary user arrival causes the interference to primary user data transmission, the SU shall leave the licensed channel immediately. SUs in addition, can also perform spectrum handoff because of degradation in link quality. Since the radio spectrum of cognitive radio network is occupied by primary user outside the control of SUs, the quality of service of the communication channel in CRNs may vary dynamically over time and space.

Thus, it is very important for secondary users to monitor and analyse periodically the quality of the channel being used for the communication or data transmission. In the future if channel quality tends to degrade, spectrum handoff is required to maintain the quality of service level of the secondary user. Spectrum handoff can be described as the cyclic process. It consists of two phases: evaluation phase and link maintenance phase. In evaluation phase, secondary user observes the environment and analyses whether handoff triggering events occur or not. Once SU decides to perform spectrum handoff, it goes into link maintenance phase. In this phase, Secondary user first pause the ongoing transmission. Then secondary user hands over the reclaimed channel to primary user and resumes data transmission over another free channel. Finally, SU leaves link maintenance phase and resumes the cycle. Spectrum handoff is considered as the main issue in spectrum mobility. Spectrum handoff procedures aim to help secondary users to find suitable target channels to resume the unfinished transmission.



In general, spectrum handoff mechanism can be categorized into two types based on the target channel selection methods:

- (i) proactive-sensing spectrum handoff
- (ii) reactive-sensing spectrum handoff

For the proactive-sensing spectrum handoff, secondary users periodically observe all channels to obtain the channel usage statistics, and determines the set of target channels for spectrum handoff according to the long-term observation outcomes. Secondary users make the target channels for spectrum handoff ready before its transmission is started.

For the reactive-sensing spectrum handoff, the target channels are searched by the on-demand manner. And in this case, the instantaneous outcomes from wideband sensing will be used to determine the target channel selection for spectrum handoff when spectrum handoff is requested.

**(i) Reactive Handoff:** In reactive handoff, secondary user applies reactive spectrum sensing and reactive handoff action approach. Once a handoff triggering event occurs, secondary user performs spectrum sensing to find target backup channel. And then link communication is transferred to the new target channel. Both target channel selection and handoff action are performed after a triggering event happens.

The advantage of this approach is that secondary user can get an accurate target channel since spectrum sensing is performed in the most relevant spectrum environment. Nevertheless, the accuracy comes at a cost of longer handoff latency due to on demand spectrum sensing. Since secondary user performs spectrum sensing after detecting the handoff event, spectrum sensing becomes the major delay in the handoff process.

**(ii) Proactive Handoff:** In proactive handoff, secondary user uses proactive spectrum sensing and proactive handoff action approach. Secondary user performs spectrum sensing to find a backup target channel before actual handoff take place. Based on the knowledge of primary user traffic model, secondary user is able to predict primary user arrival so that secondary user vacate the channel before primary user arrives. Both target channel selection and handoff is performed proactively before the handoff triggering process take place.

There are certain advantages in using proactive spectrum handoff. First, handoff latency is very short because everything is planned in advance. Second, possibility of the multiple spectrum handoff can be minimized by considering the future target channel usage when selecting the backup target channel sequence. However, the drawback of this handoff scheme is that backup target channel can remain obsolete. There is a chance that prepared backup channel is already occupied by other users i.e primary user or another secondary user at handoff time. In addition, accurate primary user traffic model becomes a key feature in this handoff. Poor prediction caused by inaccurate primary user traffic model may degrade the overall spectrum mobility performance.

### III. STEPS OF SPECTRUM HANDOFF

In CR systems, the sudden appearance of a PU on a band occupied by a SU triggers the cognitive user to leave this band as soon as possible. The SU would then try to regain the medium through one of the following three actions:

- (i) Until the PU finishes its transmission SU will stay in the original channel and postpones its transmission,
- (ii) Select a channel from a list of previously sensed channels (predetermined spectrum handoff)
- (iii) Switching to a certain channel after immediate sensing (sensing-based spectrum handoff) and if SU fails in regaining the spectrum it is compelled to terminate its session.

In fig 1(a) secondary users SU1 and SU2 communicate on channel Ch1. When primary user appears on Ch1 SUs pause its current communication as in fig 1(b). Now SU1 has two options i) SU1 and SU2 can resume its transmission on the selected target channel as in fig 1(c) or ii) it can also remain on the same channel and resume the transmission after the PU activity is over as in fig 1(d) this case is preferred if PU activity is small as it will reduce the number of handoff. A frame may be interrupted many times during its transmission hence spectrum handoff procedure may be executed many times.

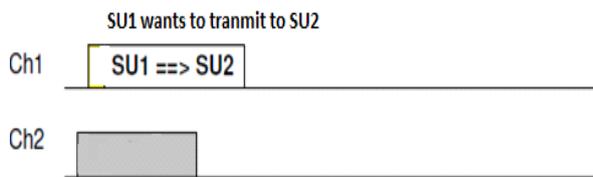


Fig 1(a): Transmission between SUs

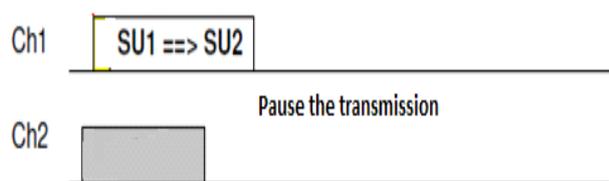


Fig 1(b): PU appears

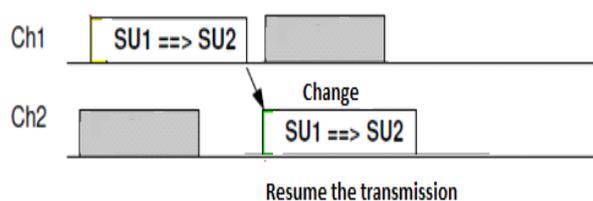


Fig 1(c): Resume transmission on selected channel

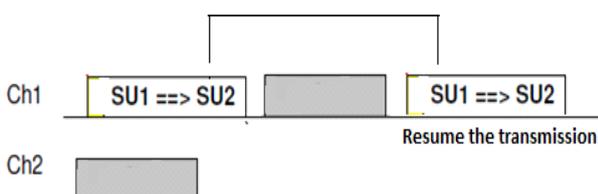


Fig 1(d): Resume transmission on the same channel

### IV. DESIGNING STRATEGY OF SPECTRUM HANDOFF

Design, analysis and optimization of DSA require versatile awareness. This includes knowledge of wireless communication and networking, signal processing techniques (to estimate parameters), filtering and prediction (to gain knowledge of radio environment), machine learning techniques (to learn, plan and optimize the decision of DSA), optimization techniques (to obtain the optimal dynamic spectrum management scheme). It also includes intelligent techniques based on fuzzy logic and decision theory.

In the process of spectrum handoff decisions are made based on incomplete and vague information available at the secondary user as a result of the spectrum sensing. An approach based on fuzzy logic has potential to make effective spectrum handoff decisions which is characterized by incomplete, uncertain and heterogeneous information. In [4] an approach using Fuzzy Logic System (FLS) to control the spectrum access is proposed which detects the effective spectrum access for cognitive users via cognitive radio (CR). In [5] a decentralized architecture was considered, as solution to problem of the spectrum handoff decision, channel selection and channel estimation on the way how a secondary user makes this decision based on the information available from the spectrum sensing done by the secondary user. To trigger spectrum handoff a simple and less complex fuzzy-based approach is suggested, which guarantees quick decisions so that secondary user can automatically make the decision to change its frequency channel. Fuzzy Logic is a simple way to arrive at a conclusion based upon ambiguous and missing input information but it is expensive as it requires extensive testing and system that use fuzzy logic do not have ability to learn and adapt after solving a problem as some expert system can.

Spectrum handoff helps secondary users to find appropriate target channels to resume the unfinished transmission. According to the target channel selection methods, spectrum handoff mechanisms can be classified into two types: (i) proactive-sensing spectrum handoff; and (ii) reactive-sensing spectrum handoff. In proactive-sensing spectrum handoff, before transmission, secondary users select the target channels for spectrum handoff. Periodically secondary users observe all channels and channel usage statistics are obtained to find the candidate set of target channels for spectrum handoff. In reactive-sensing spectrum handoff, the target channels are searched by the on-demand strategy. In this case, the result from wideband sensing will be used to determine the target channel selection for spectrum handoff. In comparison to reactive-decision spectrum handoff, the proactive-decision spectrum handoff has less handoff delay because the wideband sensing is not required here but the target channel which is pre-determined may be unavailable. The advantage of the reactive spectrum handoff is selecting the target channel with the accuracy, but requires extra sensing time.

In CRN channel is allocated on the basis of priority to primary and secondary user, for modelling and analysis pre-emptive resume priority (PRP) M/G/1 queue model can be used. In [6] a comparison of reactive and proactive is done with the help of proposed PRP M/G/1 queue network model. A relationship between model and spectrum handoff is established and the transmission time for a frame in single and multiple handoffs is calculated, this transmission time is further used to calculate the latency in transmission for reactive and proactive mechanism. The same author has provided a modelling and analysis of proactive and reactive spectrum handoff separately in [7] and [8] respectively. For proactive in [7] a pre-emptive resume priority (PRP) M/G/1 queuing network model is proposed. Based on this model, the total service time for various target channel sequence can be evaluated, and we can find the optimal target channels sequences. As mentioned above proactive handoff is having limitation of predetermined channel unavailability. A suboptimal greedy target channel selection scheme is proposed to find the optimal target channels and reduce the complexity for the finding target channel. While in reactive decision spectrum handoff, handoff delay may be shorter because it can accurately find an idle channel through spectrum sensing but requires extra sensing time. In [8] the secondary user can reactively decide the target channel for spectrum handoff to resume its unfinished data transmission. A Markov transition model is integrated with the pre-emptive resume priority (PRP) M/G/1 queuing network to characterize the effects of the sensing time, the channel switching time, the handshaking time on the handoff delay in CR networks is proposed.

In comparison to reactive, proactive has advantage of avoiding collision between the primary users and secondary users, it increases the throughput of the primary and secondary users, but requires complex algorithm to implement. In [9] a proactive spectrum handoff protocol based on the Greedy Channel Selection (GCS) which avoids collision between secondary users, also between primary and secondary users is proposed. Furthermore, the channel selection is distributed which results in higher throughput, and lower average service time. Random appearance of licensed users may lead to low throughput in communication of both licensed and unlicensed users. In [10] a proactive spectrum handoff framework for CR ad hoc networks is proposed. Channel switching policies and a proactive spectrum handoff protocol are suggested so that unlicensed users vacate a channel before a licensed user appears, to avoid unwanted interference. Cognitive user who are equipped with the prediction capability can proactively predict the idleness probability of the spectrum band in the near future. Hence harmful interference between SUs and PUs can be avoided and SU throughput is increased.

Spectrum handoff procedure help the secondary users to free or vacate the occupied licensed band and find the suitable target channel to resume the unfinished transmission and in proactive the decision is made on past

usage of channel, future prediction of channel usage and on probability of idleness of channel. However there exists the instability due to prediction and probabilistic approach here.

## V. CHALLENGES AND SOLUTIONS IN SPECTRUM HANDOFF

Spectrum handoff is indispensable event of transmission in cognitive environment and it should be handled properly. Reduce the handoff latency, find a proper set of channels to complete the unfinished transmission and to maintain the required quality of service are important challenges in spectrum handoff, discussed in [11] also there are several others challenges which are discussed in this section.

If presence of primary users is detected through collaborative effort of secondary users, this will hit on the power consumption of secondary users. Managing power is a critical factor in CR network and to identify the exact transition time when a secondary user needs to hand over the spectrum to the primary user is difficult. The broad range of available spectrum, undulating nature of the available spectrum, heterogeneous mobility events makes it more difficult to support seamless communications.

Evaluating the suitability of a new available spectrum band for usage and selecting the best channel among available channels could also be very tough job to do. The channel's parameters in terms of channel width, bandwidth, rate, etc. need to be evaluated before taking a decision and this could be a complex process. In [12] a cellular architecture is assumed for CR and a spectrum aware mobility management scheme is proposed. Network architecture is introduced based on the spectrum pooling to mitigate heterogeneous spectrum availability. Another challenge is transport layer protocols' performance of a SU which could be degraded significantly as on PU arrival it tries to give up channel. The primary reason for most of packet losses is route failure due to mobility but TCP assumes that packet loss occurs because of congestion, so TCP will invoke congestion control mechanisms for packet loss which is actually caused by route failures, resulting in low throughput. In [13] a solution to the above problem is given by identifying the problems which make TCP implementation in CR different from that of conventional wireless network. A TCP rate adapting algorithm which ensures seamless spectrum handoff as PU appears is proposed.

New mobility and connection management approaches need to be designed to reduce delay and loss of data during spectrum handoff. A new algorithms is required to ensure that applications do not suffer from severe degradation in performance when they have to be transferred to another available frequency band due to the appearance of a primary user. This performance degradation could be due to link destruction and to preserve the quality of transmission, link maintenance is important. In [14] we can see the link maintenance probability can be achieved

better if radio sensing time, erroneous channel selection probability and the number of handoff are reduced. If SU didn't get the channel for transmission it leads to forced termination of the session. To avoid this problem of forced termination in [15] virtual reservation is introduced as a new link maintenance strategy which reduces the forced termination probability of SU. It is a novel link maintenance strategy that aims to maximize the throughput of the cognitive network by utilizing the spectrum at most. Multiple handoffs for a user may reduce the quality of service for an interrupted user. An interrupted user is referred to that SU which has been interrupted by PU user, when it is utilizing a licensed band, and due to appearance of PU it has to pause its transmission and has to change their operating channel.

To maintain a required level of quality of service (QoS) for SUs, an effective spectrum handoff procedure should be initiated. In [16] a priority based model is proposed where priority is given to interrupted user over new uninterrupted user. In this model the interrupted user are required to maintain a queue and wait until all other primary and secondary users receive their services. This wait will add extra time in their delay and hence increase handoff delay and service time. By maintaining a queue we can easily identify the interrupted user, so we can give them priority over uninterrupted user. This will reduce the handoff delay and maintain the required level of quality of service (QoS). To model the proposed work a pre-emptive resume priority (PRP) M/G/1 queue model is used. Spectrum handoff is time consuming process as SUs need to search for the available spectrum and reconfigure their operating frequency at the RF front-ends dynamically and abruptly whenever spectrum availability changes, due to which a significant switching latency also called spectrum handoff delay is introduced. It includes time taken in spectrum sensing, analysis, decision and spectrum switching. Hence it is better to reduce unnecessary spectrum handoffs. In [17] the SU decides to wait silently in their current channel until the PU departs, instead of immediately switching to another idle channel. This option would be favourable to the secondary user if the returned primary user stays at the channel only for a very short interval of time. An expression for maximum waiting time for which the secondary users should wait is derived in two cases when primary user distribution is known and when it is unknown. Spectrum handoff may cause service interruptions or significant delay leading to the degradation in the quality of service of the secondary user.

A novel technique that aims at reducing spectrum handoff delays while keeping the quality of the transmission acceptable is suggested. The significant step in attaining a good level of SU's service is to know how to select best channels. In the beginning the expected delay of application packets is computed as the function of the queue associated with a channel. The calculated delay reflects the status of the channel and its usability for transmitting packets, then this delay is used to calculate delay violation ratio that guides the spectrum handoff and selection decisions.

To reduce the handoff latency a list of backup channel is maintained so that SU can switch to one of the channels among the list quickly whenever handoff took place. In the first standard for CR networks IEEE 802.22, a backup channel list is maintained to provide the maximum probability of finding an available spectrum band within the shortest time. The backup channels list attempt to minimize the switching delay which can be reduced if there are more idle channels in the backup channels list. A study on the utility of using additional backup channels at the time of handoff to alleviate the problem of fast successive handoffs is done but maintaining a backup channel list is itself a problem.

## VI. CONCLUSION

With the increasing demand for radio spectrum for new wireless application on one hand and inefficient usage of the licensed spectrum band on the other hand, a reform of the spectrum access policy seems inevitable. Opportunistic spectrum access is envisioned to solve the problem of spectrum scarcity by allowing unlicensed users or secondary users to dynamically utilize spectrum hole or white space across the licensed spectrum on a non-interfering basis. Cognitive radio (CR) has the potential for resolving the problem of spectrum scarcity issue in wireless communications. Spectrum handoff is very important but is the least explored area in Cognitive radio network. The research which has been done and explained in spectrum handoff area is based on prediction and probabilistic approach which in a way is unavoidable because of uncertain behaviour of Primary users. The prime objective of handoff is to provide smooth and fast transmission to secondary users. New mobility and connection management approaches need to be designed to reduce delay and loss of data or information during spectrum handoff. A mechanism has to be there to reduce spectrum handoff latency, a list of backup channel is maintained for this purpose but maintaining and updating that is itself a challenge. Future work includes to design a framework for spectrum handoff which is less probability and prediction based and to understand the mechanism of backup channel list and how we can utilize this list at most to provide a smooth and fast transmission

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