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SURVEY ON SPECTRUM MOBILITY IN COGNITIVE RADIO NETWORKS

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Abstract: Cognitive radio (CR) networks have been proposed as a solution to both spectrum inefficiency and spectrum scarcity problems. However, they face several challenges based on the fluctuating nature of the available spectrum, making it more difficult to support seamless communications, especially in CR cellular networks. Dynamic Spectrum Access (DSA) is a new spectrum sharing paradigm in cognitive radio that allows secondary users to access the abundant spectrum holes in the licensed spectrum bands. During the detection of primary user or spectrum conditions becomes worse than spectrum handoff occurs. In this paper survey on spectrum mobility is presented.

Index Terms: Cognitive Radio Network, Dynamic Spectrum Access, Spectrum Mobility and Spectrum Handoff.

I. INTRODUCTION

In the past few years, we have attested an impressive growth in wireless communication due to the popularity of smart phones and other mobile devices. Due to the emergence of application domains, such as sensor networks, smart grid control, medical wearable and embedded wireless devices, we are seeing increasing demand for unlicensed bandwidth. A study carried out by the Federal Communications Commission (FCC) has shown that some frequency bands are overloaded at the rush hours. However, the use of the frequency spectrum is not uniform according to the hours of day and to the geographical position, a frequency band can be overloaded while another remains unused [8]. The idea to develop tools to better use the spectrum has naturally emerged.

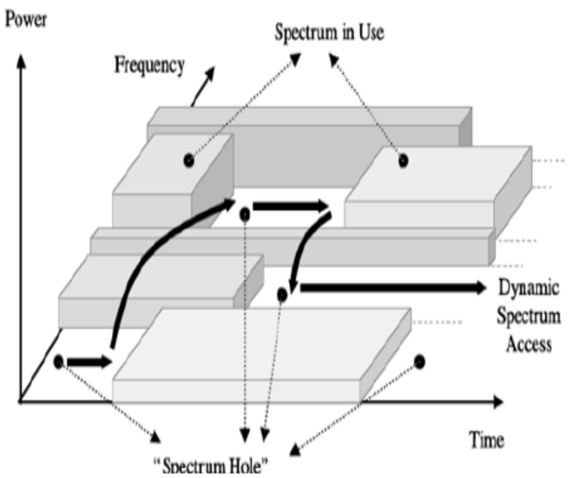
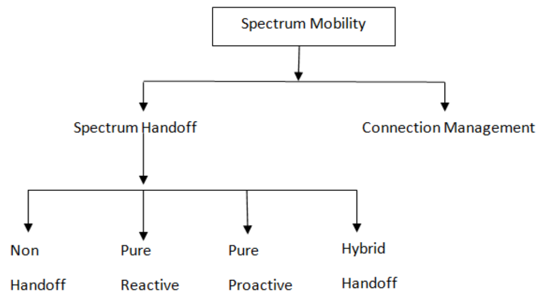


Fig 1: Spectrum hole

A "Cognitive Radio" is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. The above fig 1 shows the spectrum hole, as shown in the figure in between the spectrums there is available of free spectrums s[14]. Cognitive radio network system executes four interrelated functions: those are spectrum sensing, spectrum decision, spectrum management and spectrum mobility. In spectrum sensing, CR nodes search for spectrum holes in licensed spectrum bands that can be used for SU communication. Based on spectrum sensing results, CR nodes decide on the best available communication channel. Spectrum sharing coordinates channel access among the CR nodes. Finally, when a PU reclaims a licensed channel temporarily occupied by a SU, spectrum mobility suspends the transmission, vacates the channel, and resumes ongoing communication using another vacant channel. Here we have surveyed, spectrum mobility in CRNs is examined with respect to spectrum handoff. Various spectrum handoff strategies are reviewed and compared qualitatively. Self coexistence, accurate sensing, signaling, optimized spectrum decision, seamless spectrum handover, cross layer design and energy efficiency are the main issues occurred in cognitive radio network. This paper is organized as follows, classifications of spectrum mobility techniques in section II, followed by spectrum handoff in section III, design issues in spectrum mobility in section IV, open challenges in section V, comparisons of the spectrum handoffs are discussed in section VI and lastly we have discussed conclusion.

II. CLASSIFICATION OF SPECTRUM MOBILITY TECHNIQUES



The primary intention of spectrum mobility in CRNs is to perform seamless channel switch over while sustaining performance of ongoing SU communication. To this end, spectrum mobility is divided into two processes, spectrum handoff and connection management.

A. Spectrum Handoff

Spectrum handoff is the process of transferring ongoing data transmission from the current channel to another free channel. This naturally causes additional latency to SU communication that eventually affects SU performance. To compensate the unavoidable handoff delay. There are two PU related events that can trigger spectrum handoff in CRNs. First, PU arrival in the licensed channel necessarily forces SU to perform spectrum handoff. Second, spectrum handoff can occur because of CR user mobility. As CR users moves spatially, there is a chance that transmission coverage of the SU overlaps with a PU currently using the same channel band. Being opportunistic users in licensed spectrum bands, SUs activity in legacy networks shall obey the basic rule: PUs always have higher priority in using licensed spectrum than SUs. As a consequence, if SU arrival causes interference to PU data transmission, the SU shall leave the licensed channel immediately[12]. In addition, SUs can also perform spectrum handoff because of link quality degradation. Since the radio spectrum of CRNs is predominantly occupied by users outside the control of SUs, the quality of the communication channel in CRNs may in particular vary dynamically over time and space.

B. Connection Management

Connection management process manages and adjusts protocol stack parameters depending on current situation.

III. SPECTRUM HANDOFF

Spectrum hand off can be distinguished as non handoff, pure reactive handoff, pure proactive handoff and hybrid handoff. In general, spectrum mobility techniques with higher link maintenance probability and lower handoff latency give better spectrum agility to CRNs. In order to achieve high performance in spectrum mobility, multiple spectrum handoffs should be avoided if possible.

A. Non Handoff

In non-handoff strategy, SU keeps staying in original channel and being idle until the channel becomes free again. In other words, SU selects the current licensed channel as the next target channel. After PU leaves the licensed channel, SU resumes the data transmission again. The major disadvantage of this approach is that it causes high waiting latency to SU because the delay is as long as PU is active in the corresponding channel. In delay sensitive applications, this method would fail to meet QoS requirements. Also, it is obvious that time is badly wasted during SU waiting period.

B. Pure Reactive Handoff

In pure reactive handoff strategy, SU applies reactive spectrum sensing and reactive handoff action approach. Once a handoff triggering event occurs, SU performs spectrum sensing to find target backup channel. Afterward, link communication is transferred to the new target channel. In other words, both target channel selection and handoff action are performed reactively after a triggering event happens. The advantage of this approach is that SU can get an accurate target channel since spectrum sensing is performed in the most relevant spectrum environment. Nevertheless, it comes at a cost of longer handoff latency due to on demand spectrum sensing. Since SU performs spectrum sensing after detecting the handoff event, spectrum sensing becomes the major delay in the handoff process.

C. Pure Proactive Handoff

In pure proactive handoff strategy, SU uses proactive spectrum sensing and proactive handoff action approach. SU performs spectrum sensing to find a backup target channel before a handoff triggering event happens. Based on the knowledge of PU traffic model, SU is able to predict PU arrival so that SU evacuates the channel beforehand. In other words, both target channel selection and handoff actions are performed proactively before the triggering event happens.

There are several advantages in using pure proactive strategy. First, handoff latency can be very short because everything can be planned in advance. Second, the possibility of multiple spectrum handoffs can be minimized by considering future target channel usage when selecting backup target channel. However, the drawback of this strategy is that backup target channel can remain obsolete. There is a chance that prepared backup channel is already occupied by other users at handoff time. In addition, accurate PU traffic model also becomes a key factor in this strategy. Poor prediction caused by inaccurate PU traffic model may badly degrade the overall spectrum mobility performance.

D. Hybrid Handoff

Hybrid handoff strategy combines pure reactive and pure proactive strategy by applying proactive spectrum sensing and reactive handoff action. Target channel selection is prepared beforehand or during SU data transmission while spectrum handoff is performed after a handoff triggering event happens. In other words, target channel selection is performed proactively and handoff action is performed reactively [13]. Hybrid handoff strategy is a reasonable compromise between pure reactive and pure proactive strategy. Faster spectrum handoff time can be achieved as spectrum sensing time is not performed during the handoff process. However, target channel can stay obsolescent as it does in pure proactive approach. Yuh-Shyan Chen et.al [2] proposed a relay-assisted protocol for spectrum mobility and handover with minimum expected transmission times in cognitive long-term evolution networks, which allows unlicensed users access to not only the previous base stations but also the next base station, with the assistance of relay nodes. Xiaoshaung Xing et.al [3] proposed that, to alleviate the processing delays involved in the four functions of CRN and to improve the efficiency of spectrum utilization, spectrum prediction for cognitive radio networks has been extensively used. Adisorn Lertsinsrubtavee et.al [4] proposed A heuristic for dynamic spectrum sharing in cognitive radio networks. The concept of rate compensation is introduced so that cognitive radio users are able to achieve their rate requirement by performing adequately spectrum handoffs. Sarika M. Potdar et.al [5] proposed algorithm uses fuzzy logic and neural network for efficient handoff decision. Spectrum handoff is taken place based on mobility, quality of service (QoS) and priority. Spectrum Handoff Algorithm for Mobile Cognitive Radio Users based on agents Negotiation. Emna Trigui et.al [6] proposed multi-agent negotiation to enable cognitive radio terminals switching towards the best available spectrum band, while respecting users applications requirements and environmental conditions. Hailan Peng et.al [7] propsed a resource allocation scheme for mobile secondary users (SU) in a cellular cognitive radio network. Yeqing Wu et.al [1] proposed a mixed pre-emptive and non-pre-emptive resume priority (PRP/NPRP) M/G/1 queuing model for the modelling of the traffic in Cognitive Radio (CR) Networks with prioritized transmissions. A traffic-adaptive spectrum handoff scheme is then developed based on the proposed queuing model for delay sensitive applications. This spectrum handoff scheme reduces the delivery time of the delay-sensitive applications for secondary users [1].

IV. DESIGN ISSUES IN SPECTRUM MOBILITY

In this section, we briefly discusses on the issues of the spectrum mobility.

A. PU Detection

Sensing speed and accuracy in spectrum sensing are two important factors for efficient spectrum mobility. In fact, there is a trade-off between the two. Fast sensing speed would lead to less accurate sensing output. In addition, recent spectrum sensing techniques are also prone to imperfect sensing results due to radio propagation effects, such as channel fading or shadowing [12]. To increase sensing speed and accuracy, CR nodes can select other idle CR nodes as partners to perform cooperative spectrum sensing instead of local sensing. A cross-layer protocol called ESCAPE (Embedded Spectrally Agile Radio Protocol for Evacuation) using cooperative spectrum sensing in CRAHNs was suggested. Specifically, CR nodes are divided into evacuation groups and each group shares the same CDMA spreading code. If PU arrival is detected, warning messages are spread periodically to the entire group.

B. Handoff Decision

Generally SUs use spectrum overlay technique where radio signals are transmitted with a power above PU noise level. In contrast, SUs with underlay technique transmit radio signals with a power below PU noise level so that both SU and PU can use the same licensed band at the same time. Nevertheless, if the aggregate interference to the PU exceeds a certain threshold, SU should leave the licensed band. Therefore, spectrum handoff decision is an important issue even in CRNs with spectrum underlay technique.

C. Target Channel Selection

Finding a suitable target channel over which a SU can continue data transmission session is the most pressing issue In fact, target channel selection for spectrum handoff is a non-trivial task, because it depends on many factors, such as channel capacity, channel availability at the time of handoff, and probability of channel being available in the future. Poor target channel selection can cause multiple spectrum handoffs in a single data transmission session that degrades overall performance. The most common approach to this issue is using backup channel list (BCL). SU anticipates spectrum handoff by listing potential target channels into BCL and maintaining it periodically between communicating peers. A proactive channel access algorithm using both spectrum sensing results and spectrum statistics to determine a handoff target channel I suggested. Assuming that PU arrival pattern is not statistically random (because it depends on human behaviour) PU traffic can be modelled so that SU can estimate both channel availability and the length of time that channels will be available. As a result, intelligent target channel selection can be performed.

D. Routing Recovery

Routing recovery is another important issue in spectrum handoff that requires careful planning. Spectrum handoff is likely to cause route breaking. Accordingly, SU is required to recover the routing table to maintain network connectivity. In fact, routing recalculation is a costly process in terms of time and resource consumption. Therefore, routing recovery process should be integrated in spectrum handoff schemes. A few works in CR routing have been proposed to anticipate spectrum handoff, all of which attempt to keep network connectivity. One approach is to recalculate a new route and to perform spectrum handoff once a new routing table is ready. SU maintains the backup channel periodically so that the communication link can be immediately transferred to the backup channel upon spectrum handoff event.

V. OPEN CHALLENGES

A. Adaptive Spectrum Handoff Strategy

Current works are mostly focused on single spectrum handoff strategy. Since each spectrum handoff strategy is best suited for different PU networks, a new adaptive spectrum handoff algorithm with multiple spectrum handoff strategies is required. Ideally a SU should know the PU traffic pattern and apply the most suitable handoff strategy. When PU traffic pattern changes, SU would notice the change and adapt its handoff strategy accordingly. Therefore, future spectrum handoff strategy should consider spectrum learning factor in the design process.

B. Cross-Layer Link Maintenance Protocols

Link maintenance is at the heart of spectrum mobility. The related design issues are spread over physical, MAC and network layers. Therefore, cross layer approach between the three layers is required to address this issue efficiently.

C. Energy Efficiency

In CRAHN, energy efficiency becomes a major constraint due to the limited resources of CR nodes. On the other hand, spectrum mobility methods usually rely on frequent spectrum information update and spectrum sensing that take significant power. Therefore, energy efficient spectrum mobility is still a challenge.

VI. COMPARISON OF SPECTRUM HANDOFF STRATEGIES

Strategy	Non-Handoff	Pure Reactive	Pure Proactive	Hybrid
Main idea	Stay and wait	Reactive sensing Reactive action	Proactive sensing Proactive action	Proactive sensing Reactive action
Advantages	Very low PU interference	Accurate target channel seection	Fastest response Smart target channel selection	Fast response
Disadvantage	Very high SU interference	Slow respose	Outdated target channel selection High computational requirement	Outdated target channel selection
Handoff Latency	Unpredictably high latency	Medium latency	Very low latency	Low latency
Dependency	PU activity	Spectrum Sensing	Backup channel relevancy Accurate PU traffic model	Backup channel relevancy
Best suited environment	Short data transmission PU network	General PU network	Well modelled PU network	General PU Network

In terms of handoff latency, pure proactive handoff strategy has superior performance, followed by hybrid handoff, pure reactive handoff, and non-handoff strategy, respectively. The delays are accumulated together and become handoff latency. Therefore, more tasks performed by SU in handoff phase lead to longer handoff latency to the SU and in turn greater interference to PU. In non-handoff strategy, PU data transmission becomes a major delay source to SU. While handoff decision task completion can be estimated, it is not the case for PU activity where its completion tends to be random in nature. Therefore, non-handoff strategy suffers from unpredictable waiting latency. For other spectrum handoff models, major delay sources to SU come from spectrum sensing, handoff decision, and channel switching task. In pure reactive handoff strategy all three tasks are performed during the handoff phase. On the contrary, in pure proactive handoff strategy spectrum sensing and handoff decision task are excluded from handoff phase. In hybrid handoff strategy spectrum decision and channel switching tasks are performed during handoff phase, while spectrum sensing is excluded from handoff phase. As a result, pure proactive handoff strategy features the fastest response in spectrum mobility, while pure reactive handoff strategy exhibits relatively slow response and hybrid handoff strategy has moderate response. It is important to note that the application of spectrum handoff strategy depends on unique characteristics of the PU network. Non-handoff strategy can be suitable for the PU network with short data transmission pattern and in the situation where other licensed spectrum bands are highly congested. In the case of well-modeled PU networks, pure proactive strategy would be the best. On the other hand, pure reactive handoff strategy and hybrid handoff strategy are good for CRNs in general PU networks where PU arrival is considered to be random, such as in battlefield and natural disaster evacuation

VII. CONCLUSION

Spectrum mobility is one of main functionalities in CRNs that gives agility to CR nodes. We have discussed the spectrum mobility issues. Among these issues, spectrum handoff strategy plays an important role in spectrum mobility performance. Various handoff strategies are classified into four models Qualitative comparison between the four models is made in terms of handoff latency performance metric. In addition, reducing spectrum handoff effect using parallel multichannel transmission and mitigating channel contention between multiple SUs during spectrum handoff remain open issues in spectrum mobility.

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