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Time triggered handoff schemes in cognitive radio networks: A survey

Usama Mir[a,*], Zeeshan Ahmed Bhatti[b]

[a] Saudi Electronic University (SEU), Saudi Arabia
[b] King AbdulAziz University, Saudi Arabia

A R T I C L E I N F O

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A B S T R A C T

Rapid development in wireless networks has largely raised the demand for spectrum bandwidth. However, current static spectrum allocation policy is unable to meet this ever-growing requirement which causes the spectrum scarcity problem. Cognitive radio network (CRN) has emerged as a grasping solution to scarcity problem where the secondary or unlicensed users are allowed to access the temporary free channels owned by the licensed or primary users. Among other important steps involved in a spectrum management process, handoff plays an essential role since it requires shifting the on-going transmission of a secondary user (SU) to a free channel without degrading the quality of service. An extensive work has been done in the field of spectrum handoff for CRNs. This work is mostly classified in timing, probability, and operating mode based handoff schemes. In this paper, we present a detailed classification and a compressive survey for time triggered handoff schemes. This topic is chosen because in time triggered handoff process, the handoff decision needs to be performed based on continuously sensing the arrival and departure patterns of licensed users, thus making it an important area of research. Therefore, we discuss the pros and cons for time triggered handoff schemes in detail.

1. Introduction

With rapid development of wireless networks, the demand for spectrum bandwidth has raised largely (Akyildiz et al., 2006). Number of devices utilizing the spectrum (licensed or unlicensed) is growing very fast in contrast to the availability of bandwidth. This spectrum scarcity problem occurred because the current spectrum allocation policy is static which is unable to accommodate the increasing bandwidth demands. In fact, the static allocation policy causes the licensed spectrum bands to be underutilized (FCC, 2003; Akyildiz et al., 2008).

Cognitive radio network (CRN) comes as an efficient solution to spectrum underutilization (Wang et al., 2011). A CRN enables a secondary, an unlicensed or a cognitive radio (CR) user, to utilize the temporarily unoccupied licensed bandwidth of a primary or licensed user in order to enhance the utilization of limited spectrum resources. CR maximizes channel utilization without effecting the well-established spectrum allocation regulation (Christian et al., 2012).

The main goal of cognitive radio (CR) technology is to allow unlicensed users to opportunistically utilize the spectrum holes (or white spaces) without disrupting communication of primary users (PUs). This opportunistic spectrum usage requires us to develop protocols and algorithms which can adapt to this highly changing environment. Moreover, due to the randomness in PU's behavior with unpredicted arrival and departure timings, it is very difficult to achieve smooth spectrum usage to secondary users (SUs) and limited interference to PUs (Song and Xie, 2012).

Spectrum management process in CRNs usually consists of three different steps: firstly, since CR gets temporary access to available spectrum; therefore, it monitors the available channel and detects the spectrum holes by continuously examining the PU activities known as *spectrum sensing* (Sun et al., 2013; Akyildiz et al., 2011; Althunibat et al., 2015). Next up, there can be multiple SUs accessing specific channels; this access should be coordinated to avoid collisions among users known as *spectrum sharing* (Ahmad et al., 2015; Akyildiz et al., 2006; Mir et al., 2011). The third step is *spectrum mobility/handoff* (Wang et al., 2010; Christian et al., 2012) where an SU should continue its access on a vacant channel in case of arrival of the corresponding PU. Spectrum handoff is an important step in spectrum management process as it requires shifting the on-going transmission of an SU to another free channel without degrading the QoS (quality of service) of licensed users (Tayel et al., 2016).

As defined in Kumar et al. (2016), the triggering event is considered to be the main cause of handoff initiation. This triggering can be timing, CR user's mobility, probability, or operating mode based. In CR user's mobility based strategy, spectrum handoff can occur due to SUs mobility. This CR movement can be within the same cellular region without changing the current BS (base station) or to another cell,

* Corresponding author.
E-mail addresses: u.mir@seu.edu.sa (U. Mir), zbhatti@kau.edu.sa (Z.A. Bhatti).

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connecting to a new BS (Sun et al., 2016; Lee et al., 2012). In probability based handoff, the channel prediction probability is chosen to be the main factor for handoff decision (Tayel et al., 2015; Sheikholeslami et al., 2015; Yang et al., 2008). Thus, algorithms in these types of schemes are designed to predict the probability of future channel being idle or busy. With probabilistic estimates, sensing results are also used to make handoff decisions (Christian et al., 2012; Yang et al., 2008). Next is the operating mode based handoff process (Zhang et al., 2013; Feng et al., 2011). As mentioned in (Kumar et al., 2016), this handoff is divided in non-hopping and hopping categories. In the former, an SU does not perform a handoff in case of PU arrival and quietly stays on the current channel. In latter, the arrival of a PU may result in triggering of a handoff process and the affected SU may move to another channel. However, an SU may also decide not to perform handoff and stay idle on current channel. In timing based handoff schemes, both the effects of sensing decision and PU arrival rate are considered to trigger a handoff process. This type of handoff requires the movement patterns of PUs to be sensed and monitored carefully since the channel selection and handoff processes are to be performed based on the timing events triggered by a PU entering or leaving a channel. As per our knowledge and highlighted in (Kumar et al., 2016), time triggered handoff is very important in CR networks because it is based on the timing of spectrum sensing (Liang et al., 2008) and actual handoff process. Time triggered handoff can further be divided in four types (depending on sensing and handoff triggering time) such as non-handoff, proactive handoff, reactive handoff and hybrid handoff/adaptive handoff, respectively (Kumar et al., 2016). An extensive work has been done in recent literature in field of spectrum handoff in CRNs. To the best of our knowledge, at present, there is no detailed classification and comprehensive survey dealing with time triggered handoff schemes.

Moreover, we strongly believe that a handoff strategy should be developed by keeping in view the movements of PUs as an important design factor (Fahimi et al., 2016; Huang et al., 2015). Therefore, in this paper, we address the aforementioned in detail.

The main contributions of our paper are as follows:

- Spectrum handoff strategies based on time triggering are discussed individually in terms of features and limitations.
- Various figures and tables are drawn to present a comparative analysis.
- We present different performance criteria which are important in designing an efficient handoff strategy. We also highlight important papers addressing each of the mentioned criteria.

A list of all acronyms/abbreviations with their full form is provided in Table 1.

The rest of the paper is organized as follows. In the following section, we give a general overview of cognitive radio technology and the handoff process. Existing surveys addressing spectrum handoff process are summarized in Section 3. Time triggered handoff schemes are discussed in Section 4. In Section 5, important criteria for handoff strategies are detailed. Section 6 highlights the current and future research issues and challenges for time triggered and other handoff schemes in general. Our work is concluded in Section 7.

2. Overview of cognitive radio and handoff process

2.1. Cognitive radio: basic concept and importance

Currently, spectrum in wireless networks is governed by government agencies through a static assignment policy. Spectrum is assigned to licensed users usually for a longer period of time in large geographical areas. Spectrum is fully utilized in certain portions while a sufficient amount of licensed spectrum remains underutilized due to recently deployed static spectrum access policies (FCC, 2003; Akyildiz et al., 2008; Mitola, 2000). According to FCC (Federal Communication Commission) (FCC, 2003), at some point of a day, up to 85% of spectrum assigned to a licensed user may remain idle, showing a huge wastage.

Table 1
List of acronyms used throughout the paper.

Acronym/Abbreviation	Full form
AHP	Analytical Hierarchy Process
BS	Base Station
CCC	Common Control Channel
CDMA	Code Division Multiple Access
CRN	Cognitive Radio Network
CTMC	Continuous Time Markov Chain
CUWBIN	Cognitive Ultra-Wide Band Industrial Network
DFHC	Dynamic Frequency Hopping Communities
DSA	Dynamic Spectrum Access
FAHP	Fuzzy Analytical Hierarchy Process
FCC	Federal Communications Commission
FLB	Fuzzy Logic Based
FLC	Fuzzy Logic Controller
HMM	Hidden Markov Model
ISM	Industrial Scientific Medical
LTE	Long Term Evolution
MAC	Medium Access Control
MOTCSD	Modified Optimal Target Channel Sequence Design
NPRP	Non-Preemptive Resume Priority
PRP	Preemptive Resume Priority
PU	Primary User
QoS	Quality of Service
RF	Radio Frequency
SA	Spectrum Aggregation
SHCP	Spectrum Handoff based on Commutative Probability
SNR	Signal Noise Ratio
STBC	Short Time Backup Channel
SU	Secondary User
UWB	Ultra Wide Band
VoD	Video on Demand
WLAN	Wireless Local Area Network
WRAN	Wireless Regional Area Network

As a result of above, modern-day wireless networks are moving from static and centralized control to distributed and autonomous networks (Khan et al., 2017; Clark et al., 2016), where the devices may work more dynamically and can opportunistically select the available spectrum by having frequent interactions and information exchanges with their neighboring devices. By autonomous networks, we mean that the control and information are fully distributed and wireless devices have the capabilities of self-organization and adaptability to cope with frequent network changes. Most commonly, the devices are meant to be infrastructure independent and are designed to enable inter-device interactions over single and multi-hop networks.

These autonomous as well as opportunistic behaviors are now becoming both possible and necessary by the introduction of cognitive radio technology in wireless networks. A cognitive radio (designed to follow a dynamic access policy) comes as an efficient solution to spectrum underutilization issue. Joseph Mitola defined cognitive radio in Mitola (2000) as "*a radio that employs model based reasoning to achieve a specified level of competence in radio-related domains.*" Generally, a CR (or a secondary user), considered to be an intelligent wireless network component that is aware of its surroundings through its sensing part, may adapt to the present environment by examining the radio frequency (RF) signals and can learn by interacting with its neighbors. Fig. 1 shows that a CR is basically aware of its radio environment, having the capabilities of adapting to these surroundings according to the changes it perceives. To adapt, a CR continuously senses or monitors its environment. It contains the knowledge of the priorities, procedures and needs of its users by learning over time and finally can generate the possible solutions in order to facilitate the necessary communications with its neighbors.