Primary User Traffic Pattern Based Opportunistic Spectrum Handoff in Cognitive Radio Networks

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Abstract: Through the expeditious expansion of the wireless network, the unlicensed bandwidth-based devices are growing substantially as compared to the present vacant bandwidth. Cognitive radio networks present a proficient solution to the spectrum shortage diminution hitch by allowing the usage of the vacant part of the spectrum that is not currently in use of the Primary User licensed bandwidth to the secondary user or cognitive radio user. Spectrum management procedure in cognitive radio network comprises of spectrum sharing, sensing and handoff. Spectrum handoff plays a vital role in spectrum management and primarily focuses on single handoff strategies. This paper presents a primary user traffic pattern-based opportunistic spectrum handoff (PUTPOSH) approach to use in the cognitive radio networks. PUTPOSH permits a secondary user to sense the arrival of a primary user and use an opportunistic handoff scheme. The opportunistic handoff scheme firstly detects the arrival of the primary users by energy detection sensing and secondly, it allows a cognitive radio user to decide whether to do handoff or not contingent upon the overall service time to reduce the unused handoffs. The handoffs can either be reactive or proactive based on the arrival rate of the primary user. The simulation results show that the presented PUTPOSH approach (a) minimizes the number of handoffs and the overall service time, and (b) maintains the channel utilization and throughput of the system at a maximal point.

Keywords: spectrum handoff; spectrum sensing; cognitive radio networks; cognitive radio user; primary and secondary user

1. Introduction

The number of devices which make use of the licensed or unlicensed spectrum is growing swiftly, and a spectrum shortage problem arises due to the existing unproductive spectrum allocation strategies. The current approaches are static-based and not capable of adjusting to the increasing demand of the bandwidth requirements [1,2]. The cognitive radio network (CRN) provides a proficient solution to overcome the spectrum shortage problem. CRN permits a secondary user (SU) which is also known as a cognitive radio user (CRU) to utilize the provisionally unused bandwidth of the primary user (PU) to improve the narrow spectrum resources. CRU increases the utilization productivity of the channel
without resettling the predefined rules of spectrum allocation [3]. The spectrum management method in CRNs is mainly composed of three major steps. Firstly, spectrum sensing, where CRU or SU get provisional access to the vacant spectrum; spectrum sensing scans and detects the vacant spectrum bands constantly by probing the PU actions. Secondly, spectrum sharing, where many SUs access those vacant spectrums; spectrum sharing must be synchronized to avoid crash between various SUs. Finally, the spectrum handoff (SH)—in which an CRU ought to continue its spectrum access on an available channel (if the related PU originates).

Recent research on CRN focuses mainly on spectrum detection and exchange of information [4–8]. Spectrum transfer is becoming a challenging topic due to different research actions related to the heterogeneous network and also remains less studied [3,9]. Spectrum transfer is considered as a vigorous step in spectrum management due to its position for continuous switching from one available channel to another without compromise to its Quality of Service (QoS) [3]. There are two types of SH, proactive and reactive handoff [10–12]. In the proactive handoff, the target channel is selected with regard to the PU’s interarrival pattern. It is used for data transfer prior to any event of the actual handoff process. In the reactive handoff, to resumed the paused transmission a channel is selected by real-time sensing after the handoff event takes place. The CRU can maintain the paused transmission on the recently explored channel [10]. The prevailing work mainly focuses on the single handoff approach which may be proactive or reactive. The handoff method is preselected without considering the PU arrival rate and it can be the reason for channel underutilization and large handoff delay. The handoff approach between reactive or proactive is preselected without caring for the primary user traffic samples in the existing single handoff strategies. The research efforts described in [9–14] are focused on single SH approaches, where the handoff process is previously determined. The existing handoff approaches function in the theory of shifting the channel on PU’s arrival and no methods in these practices are to reside and wait until PU completes a successful transmission. Preferably, a CRU should be familiar with the PU traffic pattern using its sensing capabilities and the most appropriate handoff method wherever required.

In this paper, a primary user traffic pattern-based opportunistic spectrum handoff (PUTPOSH) scheme is presented. It permits a CRU to sense the PU’s traffic through energy-efficient sensing [15–17] and then adopt a proactive or reactive handoff strategy according to the interarrival rate. PUTPOSH is comprised of three modules: (1) spectrum sensing, (2) spectrum mobility management, and (3) spectrum handoff decision. In the spectrum sensing module, the energy detection technique is used due to its low computational features and working difficulty. The spectrum mobility management obtains the PU interarrival information by spectrum sensing and the dwelling period of a PU is forecasted with respect to the previous waiting behavior in its licensed band. The major contribution of this research is the spectrum handoff decision module. The spectrum handoff decision chooses on a suitable handoff class between reactive and proactive with regards to (w.r.t.) the overall service time of a CRU. The overall service time of a CRU comprises of sensing, processing, waiting and transmission times. Spectrum handoff takes place when the PU appears on its bandwidth which is temporarily engaged by the CRU. Apart from maintaining its transmission CRU must have to sense for a new free channel. When a free channel is sensed, the CRU can continue its transmission on the recently vacant spectrum, packet failure can occur throughout this handoff method [2,18]. Moreover, A preemptive resume priority (PRP) M/M/1 queuing model is used to manage the transmission and incorporated to differentiate the spectrum usage behavior of PUs and SUs. The research aims to develop a PUTPOSH algorithm with various handoff modules that permit a CRU to detect patterns of PU’s traffic and select a reactive or proactive scheme accordingly. On the arrival of PU, the CRU intelligently decides whether to do handoff or to wait for the on-going channel depending upon the overall service time (in both cases). A simulation which included PUTPOSH was setup in Matlab to validate and show the performance of the presented approach by comparing the results with some of the existing reactive, proactive, and hybrid schemes in terms of the overall service time, the number of handoffs and the channel utilization.
This paper is organized as follows: the literature review is presented in Section 2. The PUTPOSH approach is described in Section 3. It comprises of three sections (a) the presented approach, (b) the queuing model, and (c) the timing diagram of CRU transmission. Section 4 describes the simulation setup and some of the results. Finally, the conclusion is given in Section 5.

2. Literature Review

The literature presented in this section is generally absorbed on the spectrum sensing and handoff features.

2.1. Spectrum Sensing

Under channel shadowing and fading, the PU signal cannot be noticeable to the CRU. The detection capability of a single CRU is limited, which in turn strongly affects the PU transmission. A spectrum sensing scheme in CRNs with cooperative nature is presented in [19] and is based upon the Amplify and Forward (AF) protocol to reduce the sensing time of CRUs. Authors in [19] considered an infrastructure of the cognitive radio network where a band manager is responsible for communication between the cooperative CRUs. Authors defined two protocols to detect the PU arrival: (1) a non-cooperative protocol, and (2) a totally cooperative protocol. Another cooperative spectrum sensing framework is proposed by Won-Yoel Lee and Ian. F. Akyildiz in [20] which delivers solution for the sensing efficiency and interference avoidance problems. Sensing and transmission cannot be done concurrently in CRNs, therefore, it has to be bounded with the transmission. The basic concept of sensing in CRNs is to provide efficient and opportunistic communication to SUs. Data communication cannot be done which sufficiently reduces the transmission capabilities of SU.

In [21], authors presented a framework based on the theory of multiclass to exploit the attainable throughput in CRN. Through the absence of the PU in the two-class hypothesis, the energy range of sensing signal is separated into quantized areas while during the presence of the PU, the sensing signal is conserved. Authors claim that the obtainable approach increases the throughput by providing a higher amount of transmission actions. In [22], authors formulated and analyzed the amount of spectrum operation with different groups of channels and with different primary and secondary users in synchronized network structures. Authors considered realistic channels for the SUs and each channel is licensed to the PUs. The CRU is supported by the spectrum handoff and is authorized to utilize the channels by sensing outcomes and PU interruptions. In [23], authors studied resource sharing for chunk based multi-carrier with time varied spectrum resources and presented a novel opportunistic capacity model. Authors divided the novel opportunistic capacity model into two modules to reduce the computational complexity and solve them using the Lagrangian dual method. In [24], authors developed a supportive sensing method, which is based on the pairwise secondary user transmitter and receiver. Authors presented the detailed protocol description to illustrate the working of the projected framework. The main objective is to minimize the false alarm rate of the missed detection rate by adaptively correcting the discovered thresholds of every sensor.

Energy finding is a simple spectrum sensing method that can be depicted as a Neyman Pearson-like a binary hypothesis testing issue which is developed using the chi-square, gamma/normal statistical distributions [25–27]. Energy detection is usually used for the low computational features complexities [28,29]. Therefore, immense work can be found in the literature discussing energy detection in terms of fading channels, diversity systems, additive white Gaussian noise and collaborative detection [18,30–37]. However, the energy detector is not capable of differentiating between the PU signal and the noise with a lower value of Signal to Noise Ratio (SNR) [38]. The solution to this problem is presented in the sensing techniques that are based on Eigenvalue based methods [39–42]. Using Eigenvalue based method, an energy detection scheme is proposed in [43] that can efficiently perform under frequency selective channels and noise uncertainty. The method proposed in [44] is a low complexity spectrum sensing method that depends upon the exploitation of the sub-band energy variations. In [45], authors proposed a twofold threshold energy recognition scheme. Two
thresholds are used in double threshold schemes instead of one. The region between the two thresholds is considered as the uncertain region and CRU performs sensing again.

2.2. Spectrum Handoff

2.2.1. Proactive Handoff

In [46], authors anticipated a proactive handoff approach which considered Short Time Backup Channel (STBC), the BC for CRU communication is selected prior to the PU arrival. The handoff judgment in STBC is dependent upon the QoS of the ongoing channel. In this scheme, a backup channel achieves the usage of the bandwidth improvement for a short period whereas, in the complete backup approaches, the BC is reserved continually with the ongoing channel. In the STBC the lowest stage of the handoff wait can be attained as compared to without backup schemes. The STBC chooses the marked channel in the handoff prior to the occurrence of the trigger event. A proactive Fuzzy Logic (FL) based Spectrum Handoff approach is proposed in [47] and presented the major principles of FL to manage troubles professionally. Two FL controllers are used; first controller determines the space among CRU and PU. It examines the control of CRU communication (without causing any influence on the communication of the nearest PU). The second controller measures the waiting of the CRU in the ongoing channel. A handoff is started if the QoS of the CRU is not suitable and the high intervention caused by the CRU on the nearest PU’s communication. In [14], authors projected a methodology established upon an increased probability Spectrum Handoff having Cumulative Probability (SHCP) to decrease the handoffs to achieve an improved quality of service. In this method, the PU decides whether to wait or stay on its ongoing operating channel or do a handoff. It depends upon an algorithm of probability estimation however maintaining a backup reserve channel. In [48], authors anticipated a proactive handoff scheme based on a probabilistic and predictive approach. It is slightly mandatory due to the indefinite behavior of PUs. It was planned to decrease the latency and loss of facts, and figure out through spectrum handoff. Proactive handoff gives an excessive option to the SUs to continue their half-finished broadcast on the target station. In [49], authors presented a distributed CRN scheme based on the multi-armed bandit method. Authors examined the blind spectrum choice problem of SUs by considering a fixed handoff stay whose detecting aptitude of Cognitive Radio (CR) is inadequate and the channel statistics are not known in advance. In this scenario, SUs have made the choice of either (i) waiting at ongoing spectrum with low accessibility or (ii) handing off to another spectrum with higher accessibility.

2.2.2. Reactive Handoff

Authors in [18], projected a reactive handoff approach named as dynamic frequency hopping communities (DFHC). DFHC is believed to enhance QoS demands of CRUs while giving suitable and reliable sensing of the spectrum for assuring the PU defense. In this research, a wireless regional area network cell or a CRU examined the accessibility of the new objective channel while transmitting on an ongoing channel. To avoid intervention with the PUs, the CRU maintains its communication on the selected channel and opens sensing for other channels. Authors in [50], proposed a reactive handoff approach which uses an M/G/1 queuing model [18] to examine the channel utilization of CRN. In this approach, a user can concurrently use various vacant channels for transmitting CR. In [21], the authors proposed an M/G/1 queuing model to resolve the spectrum handoff problem. The interarrivals to the M/G/1 queue are modeled and shared various vacant channels, for instance, the overall interarrivals from all CRUs. The handoff delay occurs at the maximum level when the PU arrived, hence the handoff judgment is completed. In [51], author presented a framework comprises of probabilistic algorithms, and some other novel approaches including CRU clustering and PRP M/G/1 queuing to attain better competence in spectrum handoff in a CRN. Authors claim that the proposed strategy performs better than existing schemes in terms of accuracy in sensing the right channel, handoff latency, and energy consumption. The authors of [52] projected a reactive handoff scheme for Zigbee in which a CRU can
access various channels via incessantly sensing and spectrum handoff. The presented sensing and handoff technique provides better results in a situation where the noise is at a minimal level. However, as an energy detector, it cannot distinguish between noise and PU signal, hence a false alarm can be activated which produces the useless handoffs.

2.2.3. Hybrid Handoff

In order to assure the requirement of the wide bandwidth and to achieve the improved results in terms of QoS and spectrum aggregation (SA), an approach is required which permits a PU or a CRU to concurrently use various spectrum groups [33]. CRU is a clever user who can sense and use vacant spaces by probing the radio atmosphere. This class of sensing builds probably to join the free channels by spectrum aggregation. In [54], the author presented a scheme named hybrid handoff, which is founded on dynamic spectrum aggregation (DSA) to discover the manners of a CRU through handoff. Each time the CRU performs a handoff to BC when PU visits back to its certified channel. According to CRU, all the channels are BCs except the present channel (can be either utilized or idle). When PU arrives at the present channel; on the one hand, if the channel is free, the communication of CRU can be smoothly moved into it while on the other hand if all the channels are assessed to be busy, the CRU will wait till the completion of the PU communication. In [55], authors developed a spectrum-management scheme and estimated the performance in varied spectrum environment (opportunistic and centralized CRNs). Authors considered a determined threshold period for spectrum handoff delay to improve the performance for both opportunistic and negotiated situations with backup channels. In [54], authors describe that the CRU should select the probability of minimum handoff to reduce the handoff delay and the number of handoffs. The main application of this method makes it achievable to give superior QoS. The level of SH gap is minimized whenever the BCs are utilized; it guides towards the utilization of channels which are continuously vacant (most of the time).

Table 1 summarizes the handoff strategies in a comparative manner, which are also discussed in the above subsections. The strategies are compared on the basis of channel backup property, bandwidth utilization and handoff delay. The fuzzy-based analytic hierarchy process (FAHP) is a scheme with a full backup property in which BC is kept (all the time) with the ongoing operating channel. The bandwidth utilization becomes low whenever the handoff delay is at the minimal level. STBC and SHCP schemes have the middle course between full backup and no backup therefore the bandwidth utilization is at an average level while handoff delay is minimal. Since the fuzzy-based scheme has no BCs, the handoff delay can be maximized when the channel underutilization is at its minimal level. DFHC [18], M/G/1 [21] and Zigbee [52] are reactive handoff schemes with no channel backup facility, therefore, the handoff delay is at maximum level and the channel underutilization is at its minimal level. DSA [53] is a hybrid handoff scheme which is considered as a middle course between proactive and reactive handoff schemes. In DSA, the bandwidth utilization is at an average level, however, the handoff delay can be at its maximum level.
Table 1. Comparison of some of the existing handoff strategies with regards to the channel backup, bandwidth utilization and the handoff delay.

| Categories       | Handoff Approach | Backup Channel | Bandwidth Utilization | Delay of Handoff | Disadvantages                                      |
|------------------|------------------|----------------|-----------------------|------------------|----------------------------------------------------|
| Proactive Handoff Schemes | STBC [46]         | Compromise between no and full backup | Average          | Minimum          | - Bandwidth underutilization                      |
|                  | Fuzzy Based [47] | No backup       | Maximum              | Can be Maximum   | - No on-going sensing mechanism - Increased Handoff delay |
|                  | SHCP [14]        | Compromise between no and full backup | Average          | Minimum          | - Increased waiting Time - Bandwidth underutilization |
|                  | FAHP [52]        | Full backup     | Minimum              | Minimum          | - Bandwidth underutilization - No on-going sensing mechanism |
| Reactive Handoff Schemes | DFHC [18]        | No Backup       | Maximum              | Maximum          | - Improved waiting time - Improved handoff delay   |
|                  | M/G/1 Queuing Based [50] | No Backup | Maximum              | Maximum          | - Handoff processing time is not considered - Improved handoff delay |
|                  | Zigbee Scheme [52] | No Backup       | Maximum              | Maximum          | - False alarm probability - Cannot work Under multi-path fading or shadowing conditions |
| Hybrid Handoff Schemes | Hybrid Scheme [53] | No Backup       | Average              | Can be maximum   | - Improved waiting time - Improved handoff delay   |

3. PUTPOSH Model

3.1. Overview of the Model

The PUTPOSH approach contains the dual handoff modules i.e., proactive and reactive. The PUTPOSH scheme permits CRU to detect patterns of PU’s traffic and select a reactive or proactive scheme accordingly. On the arrival of PU, CRU may intelligently decide whether to do handoff or wait for an ongoing channel by considering the overall service time into account.

The PUTPOSH approach has the following properties:

1. The cognitive radio networks (CRNs) is assumed to be a time divided system and every CRU performs spectrum sensing in the first half of every time slot. The actual transmission of the CRU is performed in the second part of the time slot where the target channel is sensed as idle.
2. When the target channel is consumed by a PU, the CRU will perform the actual mobility management function by considering the waiting on an up-to-date channel or shifting its communication to the new channel.
3. CRNs comprise of autonomous channels, where every channel has high and low precedence queues. Every high priority queue has served one PU while the lowest precedence queue served several SUs on the first-come-first-serve (FCFS) basis.
4. A handoff decision protocol is divided into the transmission and sensing time slots. The interarrival of PU is noticed by the cognitive radio user (CRU) in its current channel. It ought to spend the initial part of every timeslot in monitoring the free channels while the communication is completed in the second part of the time slot.
5. When the multiple unused channels are assessed, the CRUs will choose any vacant channel for its next transmission and this random decision is according to the uniform distribution. Furthermore,
if no other channel is found to be free, the CRU will wait and stay on its current channel until the free channel is available.

3.2. Framework

Figure 1 shows the proposed primary user traffic pattern based opportunistic spectrum handoff framework. The proposed design contains three different parts; (i) spectrum sensing, (ii) spectrum mobility management, and (iii) spectrum handoff decision. These are connected in Figure 1 and also described in the following subsections respectively.

3.2.1. Spectrum Sensing

In the spectrum sensing module (Figure 1), the PU movement is continually observed by the CRU during transmission on the currently occupied channel. The spectrum sensing part can be achieved by integrating one of the existing sensing methods, i.e., matched filter (MF) [15], cooperative sensing (CS) [16,42] or energy detection (ED) [17,43,44]. In the presented PUTPOSH model, the energy detection technique is used in the spectrum sensing part for the reason of its working difficulty and for the low computational features [45,46,52]. It is considered as a generalized approach when it is compared with the MF and CS. In the ED approach, the recipients do not need any information on the PU’s signal [18,53] and the signal is observed by comparing the given threshold value with the energy detector’s output. The threshold value is fixed but depends on the earlier arrival of the PU. The apparent energy stage is increased when PU arrives on its licensed band. When an energy level’s threshold is specified, the apparent energy stage is tested multiple times either in the presence and in the absence of the PU. As the power of the arriving signal increases than the given threshold, the handoff process is initiated to execute handoff actions.
3.2.2. Spectrum Mobility Management

The spectrum mobility management obtains the interarrival information of the PU by spectrum sensing. The dwelling period of a PU is forecasted at the assigned channel with respect to the previous waiting behavior. The stopover stay of the PU at the assigned channel depends upon its communication requirements and can be of any time period. Therefore the dwelling period is assumed and based upon the random distribution method [18,21]. The decision of either to wait and stay at the ongoing path or to execute the handoff event is based on the current result. On the one hand, the CRU does not make the handoff decision when the PU continued communication for shorter intervals of time. The CRU may carry its communication and can wait for the ongoing spectrum band. On the other hand, the CRU chooses to make a handoff decision when the PU continued for a longer period at the previous licensed band (see Spectrum mobility management module in Figure 1). To allocate vacant channels, the waiting time is considered as the overall time of a CRU for a longer period at the previous licensed band (see Spectrum mobility management module in Figure 1). To allocate vacant channels, the waiting time is considered as the overall time of a CRU for a longer period at the previous licensed band (see Spectrum mobility management module in Figure 1).

3.2.3. Spectrum Handoff Decision

The spectrum handoff decision chooses on a suitable handoff class between reactive and proactive w.r.t. the lowest overall service time of the CRU. The overall service time of the CRU is based on the following times: sensing time, processing time, waiting time and transmission time. According to Figure 1 (in the spectrum handoff module), ReA time and PrA time represent the overall service time of the reactive and proactive handoff judgments respectively. In this paper, the ReA and PrA time values are assumed to find the threshold and also to compare different approaches. The overall minimal service time is implemented for the spectrum handoff decision. Subsequently, the CRU can maintain its transmission on the recently selected channel.

The Spectrum handoff module in Figure 1 shows that the proposed PUTPOSH strategy begins with the recognition of the PU interarrival by spectrum sensing and forecasts PU dwell period in the assigned channel. Hence in this step, the CRU either dwells on the recent channel or moves into the SH decision stage.

3.3. The Queuing Model

A preemptive resume priority (PRP) M/M/1 queuing model is used to differentiate the usage of the spectrum behavior of PUs and SU (see Figure 2).

![Figure 2. Cognitive radio user behavior on the arrival of primary user (PU).](image-url)
The characteristics of the proposed queuing model are as follows:

1. Two kinds of users can be served by each channel, i.e., high priority PUs and low priority CRUs.
2. The PUs have preemptive priority to interrupt the communication of CRUs. Once the CRU is interrupted, it leaves the existing channel and starts sensing further available channels to continue its transmission.
3. A CRU may experience several interruptions during its transmission.
4. In the case of multiple users with similar priority; access to the requested channel is served on the basis of first come first serve.

In Figure 3, the presented PUTPOSH approach contains two channels and two queues for PUs and CRUs. The PU reserved its position in a high priority queue while the CRU is located in a lower priority queue. When the transmission is interrupted by PU, the CRU may wait and stay with the ongoing operations stage or may transfer its communication to one of the new channels. The outstanding transmission of the CRU is placed at the head of the lower priority queue. The remaining transmission of CRU is positioned at the tail of the lower precedence queue [10–12]. In any case, the channel is available for transmission and CRU will continue its communication.

3.4. Timing Diagram of the CRU Transmission in the Handoff Scheme

Figure 4 delineates the timing diagram of a CRU transmission in the presented adaptive hybrid handoff scheme. CRU starts its transmission on channel 1 and after some intervals of time, the CRU proactively senses the arrival of the PU. The CRU compares the predicted PU waiting time and also the handoff delay on the same channel. Based on the comparison decision, the CRU reacts to perform a handoff on channel 2. During transmission on channel 2, the CRU senses the PU arrival and again makes the similarities of the overall service time (in case of stay and wait on the recent channel and performing the handoff).

Moreover, CRU predicts the stopover of PU for a short duration and may wait and stay until PU completes its data transmission. As soon as PU resumes the channel, the CRU restarts its transmission on channel 2. After some time intervals, CRU again detects the PU arrival for a longer duration at channel 2 and performs the handoff at channel 1, another free channel. In the last part, the CRU performs a handoff to channel 3 to complete its transmission and may resumes the channel again.
outstanding transmission of the CRU is placed at the head of the lower priority queue. The remaining transmission of CRU is positioned at the tail of the lower precedence queue [10–12]. In any case, the channel is available for transmission and CRU will continue its communication.

Figure 3. Queuing behavior of cognitive radio user (CRUs) and PUs (two channels and two queues).

3.4. Timing Diagram of the CRU Transmission in the Handoff Scheme

Figure 4 delineates the timing diagram of a CRU transmission in the presented adaptive hybrid handoff scheme. CRU starts its transmission on channel 1 and after some intervals of time, the CRU proactively senses the arrival of the PU. The CRU compares the predicted PU waiting time and also the handoff delay on the same channel. Based on the comparison decision, the CRU reacts to perform a handoff on channel 2. During transmission on channel 2, the CRU senses the PU arrival and again makes the similarities of the overall service time (in case of stay and wait on the recent channel and performing the handoff).

Figure 4. Time stream of the CRU transmission in the handoff scheme.

4. Simulation Setup and Performance Evaluation

4.1. Simulation Setup

The proposed PUTPOSH and some of the existing related approaches were implemented and simulated using Matlab. The existing approaches: (1) reactive handoff—DFHC [18]—(2) proactive handoff—fuzzy logic-based spectrum handoff (FLSH) [47]—and (3) hybrid handoff—DSA [53]—are selected to simulate with PUTPOSH. Two diverse Poisson procedures are used to produce PUs and SUs [20] in the CRN at constant time. The overall service time and the inter-arrival time are measured as non-integer instances of users. The data transfer of the low priority CRUs can be interrupted by the high priority PUs. To avoid the collision of the same priority CRUs during the channel access, the first come first serve scheduling strategy is used.

The parameters utilized to achieve simulation outcomes are listed in Table 2. The simulation was executed multiple times (generally about 1000 times) and the frequent values are taken to plot different graphs. We presume the packet length of SUs and PUs was 10 bytes for conducting the experiments. The overall service time of CRU included the waiting time, the processing time of the channel, the data transmission time and the sensing time respectively. The dealing out time of the channel is supposed to be 0.05 msec [10,12]. The arrival rates of PU and CRUs were followed by the Poisson processes. For simplicity, the arrival rate value of CRU was fixed to 0.1 and compared with the parameters at dissimilar values i.e., 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, and 0.08 of PU interarrival rates. This disparity aspect helped us understand the behavior of a CRU in the proposed PUTPOSH scheme with various interarrival rates of the PU. Moreover, the overall service time of CRU and PU was taken as 0.5 and 0.4, respectively, and the order of the PU was considered a superior precedence than SU. Therefore, the overall service time of CRUs depends on the arrival rate of the PU and different arrival rates of PUs may effect the overall service time.

The simulation starts with the recognition of a PU by a CRU at a momentarily engaged licensed band. The CRU may make a decision to ensure a handoff to the next available channel or to stay and wait at the ongoing channel. The decision of transferring communication to a new vacant channel or may waiting in an ongoing channel depends firmly on the service time. When handoff was achieved, the overall service time for reactive and proactive decision was considered. With the overall least service point, CRU makes the decision to execute reactive or proactive handoff.
Table 2. Experimental settings: parameters with their values and units.

| Parameters     | Of                          | Values          | Units          |
|----------------|-----------------------------|-----------------|----------------|
| Packet Length  | Primary User                | 10              | Bytes          |
| Packet Length  | Cognitive Radio User        | 10              | Bytes          |
| Processing Time| Channel                     | 0.5             | MSec           |
| Arrival Rate   | Primary User                | 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08 | Arrival per slot |
| Arrival Rate   | Cognitive Radio User        | 0.01            | Arrival per slot |
| Service Rate   | Primary User                | 0.5             | Slots per arrival |
| Service Rate   | Cognitive Radio User        | 0.4             | Slots per arrival |

4.2. Performance Evaluation

The efficiency of the PUTPOSH approach is observed by considering the following attributes: overall service time, throughput, number of handoffs and channel utilization. To achieve comparison results, the proposed handoff technique is compared with the DFHC (reactive handoff), FLSH (proactive handoff), and DSA (hybrid handoff) approaches.

4.2.1. PU Detection through Sensing Module

The probability distribution of PU detection through the sensing module of PUTPOSH is shown in Figure 5. The energy recognition method is used to sense the PU arrival. The detection prospect depends on the signal-to-noise ratio (SNR). To measure the efficiency of any strategy, the detection probability is considered an important factor. However, the existing techniques in CR did not deliberate the detection probability. In this experiment, the detection probability is calculated to make sure that PUTPOSH works well with the changes in SNR. According to Figure 5, the PU recognition probability remains lofty with the higher values of the SNR (i.e., values larger than 0.8). This is due to the fact that energy recognition works proficiently well with the superior standards of SNR [37,53]. CRU acquires the link to deliver data for a particular communication is recognized as the overall time. The best state for CRU is to attain the minimum time for data delivery with minimum delay. PUTPOSH intelligently switches between reactive and proactive handoff decision in order to reduce the delivery time of data and consequently the threshold value of PU interarrival is extracted. With the lower value of SNR, the energy detector is unable to distinguish between PU signal and the noise. The solution to this problem is the use of sensing techniques that are based on eigenvalue centered methods. Eigenvalue-centered methods are simple and based on the low-complexity spectrum methods that are capable to distinguish between PU signal and the noise with lower SNR. The eigenvalue centered energy detection scheme performs in a decent way alongside the low-frequency selective channels and with the noise uncertainty. With the incorporation of the eigenvalue-based method, the performance of PUTPOSH is well-organized and efficient.

4.2.2. Discovering Threshold Value

The overall service time is basically the total time required by CRU to transmit the entire data at the destination. The perfect situation for CRU to broadcast information with a smaller amount of holdup to attain the least amount of overall service time. In order to reduce rapidly the overall service time, the presented system logically switches between reactive and proactive handoff judgments. In this way, the threshold value is discovered for the interarrival of the PU. The overall service time of the reactive and proactive decisions w.r.t. the handoff is illustrated in Figure 6. The total service time of a proactive handoff is lower than the reactive handoff up to 0.05 and the comparison is performed on the basis of PU interarrival rate. In the proactive method, the handoff process is performed prior to trigger the handoff event. Over the lower PU arrival rate, the proactive handoff shows better performance than the counterpart. When the speed of PU flows over 0.05, the reactive handoff method shows better results because the handoff process is completed after the handoff event. Therefore, threshold value 0.05 is extracted by PUTPOSH when it switches between proactive or reactive handoff.
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Figure 5. Distribution probability of PU detection over the signal to noise ratio.

4.2.3. Comparison between PUTPOSH and Existing Handoff Schemes

Overall Service Time

When the arrival rate of PU fits up to the threshold value, the PUTPOSH strategy switches to the reactive handoff and allows a superior rate to the proactive handoff. Similarly, when the threshold value remains or becomes higher than the arrival rate of PU, the PUTPOSH strategy allows CRU to move to the proactive handoff. In this case, PUTPOSH produces 12.80% better results than the reactive handoff (shown in Figure 7). Hence PUTPOSH, as a hybrid approach, uses the advantages of both the proactive and the reactive strategies whenever required.
to trigger the handoff event. Over the lower PU arrival rate, the proactive handoff shows better performance than the counterpart. When the speed of PU flows over 0.05, the reactive handoff method shows better results because the handoff process is completed after the handoff event. Therefore, threshold value 0.05 is extracted by PUTPOSH when it switches between proactive or reactive handoff.

Figure 6. Threshold value detection to toggle among reactive and proactive handoff decisions.

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Figure 7. Comparison of primary user traffic pattern-based opportunistic spectrum handoff (PUTPOSH) with reactive and proactive handoffs w.r.t. the overall service time.

Number of Handoffs

Figure 8 represents the number of handoffs executed by the CRU. The existing handoff strategies, as compared to PUTPOSH, executed an additional quantity of handoffs; during each phase, the PU is detected and the handoff is executed by proactive and reactive approaches. On the interarrival of PU, the existing approaches worked by frequently changing between channels and had no mechanism of stay and wait to execute the transmission. The PUTPOSH scheme perceptively chooses whether to execute the handoff or not, conditional to the prediction of the overall service time. The intelligent decision to handle handoff operation helps PUTPOSH to achieve 14.28% better results than the existing DFHC (reactive handoff), FLSH (proactive handoff), and DSA (hybrid handoff) approaches. However, with the help of this way, the infertile handoffs actions are evaded.

Figure 8. Comparison of PUTPOSH with the existing handoff schemes w.r.t. the number of handoffs.

4.2.4. Comparison of PUTPOSH with Stationary Spectrum Access and Hybrid Approaches

Channel Utilization

The PUTPOSH scheme is compared with the stationary spectrum access method in terms of channel consumption (see Figure 9). A fixed spectrum access approach is categorized by the spectrum access method where only licensed operators are permitted to exploit the channel. CRU cannot utilize the spectrum resourcefully, even when PU is lacking. The PUTPOSH scheme, being a lively spectrum access pattern, depicts extraordinary results in terms of channel consumption because it permits CRU to exploit the vacant spectrum in the absence of PU [2,18]. The solitary PU is permitted to exploit the band in the static spectrum access, and is effected by the underutilization of the channel. The comparison (in Figure 9) reveals that the PUTPOSH scheme produces 20% better results than the static spectrum access (for both reactive and proactive) approaches.

Figure 9. Comparison of PUTPOSH with stationary spectrum access and hybrid approaches w.r.t. channel utilization.
4.2.4. Comparison of PUTPOSH with Stationary Spectrum Access and Hybrid Approaches

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![Figure 9. Comparison of PUTPOSH with stationary (reactive and proactive) spectrum access, and hybrid schemes w.r.t. the channel utilization.](image)

4.2.5. Throughput Analysis of PUTPOSH as a Function of Primary User Arrivals

Figure 10 shows the throughput analysis of the PUTPOSH strategy. The throughput of primary, secondary and overall system is calculated in terms of the arrival rate of PU. The CRU has limited or opportunistic access to the channels and the lowest throughput is achieved against every PU arrival. At the channel, PU has priority access and yields greater throughput. The overall system throughput represents the combined throughput of a CRN system that can be achieved through PUTPOSH. With the PUTPOSH approach, the growing number of PU interarrivals due to the condensed total service period and the effective channel exploitation.

Table 3 summarizes the quantitative analysis of the existing and PUTPOSH schemes in a comparative manner. The comparison is based on the overall service time, the number of handoffs and the channel utilization, which are already discussed in the above subsections.
Table 3. Comparison of PUTPOSH and existing schemes based on overall service time, number of handoffs and channel utilization.

| Comparison Parameters | PU Arrival Rate (Per Slot) | Reactive Handoff | Proactive Handoff | Hybrid Handoff | Proposed (Handoff) | Results (%) (Proposed is Better) |
|-----------------------|-----------------------------|------------------|-------------------|----------------|-------------------|----------------------------------|
| Overall Service Time  | 0.03                        | 9.9              | 10.4              | 9.9            | 9.9               | Has 12.6% superior rate than reactive, 28.57% than proactive and reactive and 14.28% than hybrid schemes. |
| Number of Handoffs    | 4                           | 45               | 45                | 40             | 35                | 20% than existing. |
| Channel Utilization   | 4                           | 0.4 (static)     | 0.5 (Proposed—dynamic) |                |                   |                                  |

Figure 10. Throughput analysis of the PUTPOSH approach w.r.t. the function of PU arrivals.

4.2.6. Handoff Delay of PUTPOSH and Hybrid (DSA) Schemes

A DSA scheme applies proactive spectrum sensing and reactive handoff action jointly; firstly, the target channel selection is prepared beforehand or during CRU data transmission and secondly, the spectrum handoff is performed after the handoff triggering event. In PUTPOSH, a hybrid solution is referred to as “adaptive”, if the decisions of channel selection and handoff are made by continuously monitoring the arrival and departure patterns of the PU. When PU moves quite regularly, a CRU may adapt to a reactive handoff strategy. While in the case of rare PU movements, a proactive handoff solution is preferred by the corresponding CRU. Figure 11 shows the comparison of the PUTPOSH scheme with a hybrid approach (DSA) in terms of handoff delay. The graph in Figure 11 shows that the DSA has more handoff delay than the PUTPOSH scheme because sensing is achieved prior to the arrival of the PU whereas the handoff action is performed after the PU’s arrival. Therefore the cumulative handoff delay of the DSA remains high as compared to PUTPOSH. The queuing procedure in PUTPOSH adequately reduces the handoff delay because of its adoptive environment, and thus the cumulative delay becomes lower than the DSA.
5. Conclusions

Spectrum Handoff is a vital part of the spectrum management process in CRNs. It is the method of moving the ongoing communication of a CRU to a vacant channel at the arrival of PU without a glitch. In this research, a new handoff (PUTPOSH) approach has presented—on the one hand, it maximizes the channel utilization and the throughput while on the other hand, it minimizes the overall service time and the number of handoffs in CRNs. In PUTPOSH, firstly, an energy detection sensing scheme was employed for the announcement of a PU in its licensed spectrum band. Secondly, a PUTPOSH pattern was projected, where a CRU intelligently switched between reactive and proactive handoffs depending upon the overall service time. Hence the presented approach has achieved the aids of both proactive and reactive schemes. The comparison of the PUTPOSH with the existing proactive, reactive and hybrid handoff strategies has also conducted. The results show that the PUTPOSH approach gets good performance in terms of overall service time—having a superior rate than the proactive and 12.8% robust than the reactive handoff. In terms of the number of handoffs, the PUTPOSH gives 14.28% better results than proactive (FLSH), reactive (DFHC) and hybrid (DSA) approaches. The PUTPOSH scheme produces 20% better results than the static spectrum access and throughput in CRNs. PUTPOSH can professionally reduce the overall service time and the number of fruitless handoffs of a CRU while keeping the channel busy and the system throughput at the highest level.

This work can be extended in a number of means; (1) a situation can be considered where a CRU can transfer its respective data on numerous accessible primary channels concurrently, (2) a management tool amongst the CRUs retrieving the primary spectrum holes can be developed, (3) CRU can interconnect to exchange the information regarding the movement of the PU and their stopover as well on a conforming channel to make the communication more reliable, and (4) spectrum handoff requires frequent spectrum sensing and channel information that takes a significant amount of power. Hence the energy-efficient spectrum sensing and mobility are still open challenges in CRNs.

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