SPECTRUM SELECTION TECHNIQUE TO REDUCE THE NUMBER OF CHANNEL SWITCHING FOR DYNAMIC SPECTRUM ACCESS IN COGNITIVE RADIO NETWORKS
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ABSTRACT
The awareness of Cognitive Radio (CR) was introduced to increase the effectiveness and efficiency of spectrum consumption. In a Cognitive Radio Network (CRN), each secondary user (SU) is expected to select the best radio frequency (RF) spectrum band for opportunistic use when the primary users (PUs) have temporarily vacated the spectrum allocated to them. Many spectrum selection techniques have been proposed in the literature to select vacant spectra in CRNs. However, most of these methods do not adequately consider the effect that frequent channel-switching might have on the quality of service (QoS) requirements of the SUs. In addition, the channel usage arrangement over time by PUs is not considered. In this paper, we propose a heuristic-based spectrum selection technique (HBSST) with the aim of selecting the best available channel for use by SU without causing harmful interference to the PU in a cognitive radio network (CRN) with minimum number of channel switchings. We used a smart learning mechanism to obtain the spectral opportunities in the primary network since the channel usage by PUs follow a deterministic time arrangement. Results shows that HBSST out performs the Random spectrum selection scheme in terms of channel switching.

KEY WORDS
Cognitive Radio, Radio Frequency, Channel Switching, Smart Learning Mechanism.

1. Introduction
With the rapid growth in wireless communication services, wireless communications as a whole has become the effective standard for our growing and diverse demands. Numerous wireless technologies utilize radio frequency (RF) spectrum for communication purposes. Therefore, RF spectrum is considered as the most expensive resource which needs to be controlled wisely in order to give room for future transformations. The RF spectrum consists of frequencies from the range of 3 KHz – 300GHz. Based on the experiments carried out by Federal Communication Commission (FCC), it was shown that spectrum utilization, on a pool of licensed RF band, still varies from 15% to 85% with respect to frequency, time and geographical location [1] –[3] as shown in Figure 1 below.

It is believed that more ultra-high frequency (UHF) spectrum will be made available once the television digital switch over (DSO) is completed in Africa. Studies have shown that the spectrum assigned to the PUs is under-utilized in some geographical locations [4], [5]. Therefore, a new communication paradigm to exploit the existing wireless spectrum opportunistically is considered necessary by many countries in order to overcome the limited available spectrum and inefficiency in spectrum utilization [6].

To enable opportunistic access to the radio frequency (RF) spectrum and the efficient sharing of allocated bands, more flexible spectrum management techniques are required, such as opportunistic spectrum sharing, where SUs are allowed to operate on frequency bands without the permission of PUs provided that they do not introduce harmful interference with PUs. For this reason, cognitive radio (CR) is being intensively investigated by the research community, major industry communication regulators and standardization bodies as a key enabling technology [7].

Cognitive Radio (CR) [8] is defined by the Federal Communication Commission (FCC) as "an intelligent wireless communication system capable of changing its transceiver parameters based on interaction with the environment in which it operates". A cognitive radio network imposes distinctive challenges owing to the fact that there is high fluctuation in the available spectrum over...
time. Thus, the various CR nodes offer different available channels at different times. As a result, some challenges are introduced, such as: (1) spectrum sensing, which needs to be done correctly and frequently; (2) the availability of routes between nodes that recognize different channels and multi-hop routing; (3) spectrum decision and sharing in a distributed setting without a central coordinator; and (4) coordination among the nodes with or without the availability of a common control channel.

Most countries have regulatory agencies that regulate the radio spectrum by means of renewable licenses. Consequently, in order to allow the radio frequency (RF) spectrum to be accessed opportunistically by SUs, there is a need to develop an opportunistic spectrum selection technique for opportunistic spectrum selection. In this paper, we propose a HBSST for spectrum selection in CRNs with minimal number of channel switching.

The rest of the paper is organized as follows: Section 2 discusses the related work on spectrum selection techniques. Section 3 discusses our system model and its principle of operation. Section 4 discusses the obtained results. Section 5 concludes the paper.

2. Related Work

In order to satisfy the quality of service (QoS) requirements of SUs, SU or cognitive radio (CR) user has to be able to select the best available spectrum band, a process known as spectrum selection. In [9], the authors proposed an automata learning based channel selection algorithm which optimally selects a channel by maximizing the probability of completed transmissions and also minimizes the number of costly switching. [10], propose an automatic channel selection algorithm which co-exists with Wi-Fi network. Their algorithm selects a channel on predetermined values on the industrial, scientific and medical (ISM) band with the aim of meeting the QoS requirements of the CR users. In [11], a game theoretic based spectrum selection scheme is proposed. In this scheme, the CR nodes are considered as players whilst the objective of the game is to satisfy the given criteria for the winning game. In [12], the authors proposed a QoS based framework which aims at selecting the best available channel by utilizing the bandwidth delay product in order to meet the QoS requirements of the CR users. In [13]-[15], the authors investigated the optimal number of candidate channels to maximize the spectrum accessibility and the procedures to determine the set of candidate channels. According to studies, the usage of spectrum follows a deterministic time arrangement over geographical locations [3]. In [16]-[17] spectrum occupancy measurements are done in two UHF RF spectrum bands: 450 MHz – 470MHz and 790 -862 MHz in major South African cities. The results from these measurements clearly show that RF spectrum in these two sub-bands have been under-utilized more than 80% by the PUs. It can be seen that spectrum utilization by PUs follows a deterministic time arrangement over location.

Table 1 below shows some of the channel idle arrangement over time in South Africa.

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Channel No.</th>
<th>Available Time (Hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>470 – 478</td>
<td>CH 21</td>
<td>00:00 - 07:00</td>
</tr>
<tr>
<td>502 – 510</td>
<td>CH 25</td>
<td>08:00 - 16:00</td>
</tr>
<tr>
<td>542 – 550</td>
<td>CH 30</td>
<td>19:00 - 07:00</td>
</tr>
<tr>
<td>566 – 574</td>
<td>CH 32</td>
<td>17:00 -07:00</td>
</tr>
</tbody>
</table>

It can be seen from Table 1 above that the channels like (CH 21), (CH 25) are free from 12am - 7am, 8am – 4pm respectively. Hence, these free channels are suitable for cognitive radio tasks. We used a linked list as a smart learning mechanism to obtain the spectral opportunity for use by SUs in the primary network since the spectral opportunities rapidly vary with location.

3. System Model and Concepts

We consider a centralized cognitive radio network (C-CRN) topology. This C-CRN comprises of M PUs and N SUs. The paired SUs co-exist under the coverage area of a primary network. This primary network consists of one television (TV) broadcasting transmitter (of high power) and several PU devices as shown in Figure 2 below.

The RF spectrum consists of X non-overlapping channels with their identities ranging from 1 to X and each with bandwidth, \(BW_x\) where \(x \in X'\) and \(X' = \{1...X\}\).

These X channels are modelled as ON- OFF source which takes the value ON if there is a PU present on the channel and takes the value OFF if there is a PU absent on the channel. More so, these X channels are selected based on their deterministic time arrangement. A dedicated common control channel is utilized for swapping information between the CR users. The term CR users and SUs are used interchangeably. In this system model, all CR users can either perform transmission or sensing but not instantaneously. Each CR user keeps track of the list of available channels using the smart learning mechanism in the primary network. This information is passed to the dedicated common control channel. In order to achieve this,
The linked list is used as a database to capture spectral opportunities. The nodes of each linked list comprises of the information on the available spectra represented by the start time \((S_t)\) and finish time \((F_t)\) (in time unit) during which the channel is free. One time unit is equal to the sampling interval of the channel. The start time \((S_t)\) is mentioned as the time from which the channel seems to be unoccupied by the PU whilst the finish time \((F_t)\) is mentioned to the time at which the channel ceases to be unoccupied by the PU. The subscript \(t\) symbolizes the node identity (ID) given by \(t \in T\), where \(T = \{1, ..., T\}\) and \(T\) symbolizes the last node ID in the linked list. The value of \(T\) may be at variance for each linked list.

3.1 Smart Learning Mechanism

The CR system attempts to learn the deterministic time arrangement of the PU traffic within 24 hours during the learning phase using the smart learning mechanism. Based on the spectral occupancy obtained within 24 hours, the CR system can select the appropriate channel as required by CR users. These requirements could be minimal channel switching or maximal throughput. The CR system samples all the \(X\) channels for 24 hours with sampling interval of \(g\) minute and a sampling time of \(w\) seconds (where \(w \ll g \times 60\)), this literally means that the spectrum is sensed every \(g\) minute for \(w\) seconds. Thus, the total time required for sampling \(X\) channel is \(w \times \frac{X}{60}\) minute (where \(w \times X/60 < g\)). The value of \(w\) is chosen such that the CR system would not sample channels too often nor omit the transitions on the channels. The values of \(S_t\) and \(F_t\) as shown in Figure 3 above symbolizes the time units planned to the real-world time with \((S_t, F_t) \in \{0, ..., 1439 ((24 hours \times 60 mins) - 1)\}/sampling interval\), whereas one time-unit duration is equal to one sampling interval (\(g\) minute). If \(g\) is small, then the number of nodes in the linked list may increase. In the worst-case scenario, the maximum number of nodes in the linked list equals \(((24 \times 60)/g)/2\) when the channel alternates between being free and being occupied in consecutive samplings. \(\Phi\) is used as a parameter to short the length of the linked list. If the length of the spectral opportunity is greater than \(\Phi\), then this spectral opportunity is inserted in the linked list, that is, \(\forall t \{E_t - F_t \geq \Phi\}\).

At the beginning, all the linked lists are considered empty and points to address NULL. The CR nodes are updated or inserted in the linked list when the sampling interval is utilized and satisfies the threshold parameters. The time unit starts from 0(00:00 hours) and increases by 1 with each sampling interval or every \(g\) minute. An example of the linked list of channel 27 (CH 27) after a period of 15 hours using \(g = 10\) minutes is shown in Figure 4 below.

As seen in figure 4 above, the first node represents that channel 27 is unoccupied from 0 to 17 time units (00:00 - 03:00 hours), is occupied by the PU from 18 to 59 time units (03:00 -10.00 hours), and is the unoccupied from 60 to 88 time units (10:00-14:50 hours). The sampling continues for 24 hours, at the end of which the CR system would have obtained spectral opportunities for all the channels. This information is passed to the dedicated common control channel, which combines the information received from all the nodes to obtain the comprehensive system spectral opportunity. This combination is required so that every node in the CR system agrees on the spectrum availability. A simple method to obtain a comprehensive spectrum opportunity is to convert all the linked lists into matrices and to compute the intersection on them. The conversion of linked lists to matrices was done using MATLAB. MATLAB is based on dealing with matrices/vectors and arithmetic; it offers matrix based computation that allows users to perform numerical computation more easily. The linked lists received by the dedicated common control channel from each node are described as \(R_{d,e}\) where \(d \in X\), \(e \in N\), and \(N = \{1, ..., N\}\). Let \(\alpha = \left(24 \times \frac{60}{g}\right) - 1\) and \(\alpha' = [0, ..., \alpha]\). We let the matrix for the linked list received from node \(e\) to be \(MATX(e)\), where \(e \in N\). The row and column of the matrix represent channels and time units, respectively. The conversion from the linked lists to this matrix can be done as follows. In the following conversion, we drop index \(e\):

\[
MATX_{d,f} = \begin{cases} 
1, & \exists t \{f \in [S_t, ..., F_t]\} \\
0, & \text{otherwise}
\end{cases} \quad \forall d \in X' \quad \forall f \in \alpha' \quad \forall t \in T'.
\]

(1)

The predicate logic \(\exists t \{f \in [S_t, ..., F_t]\}\) or \(\exists t \{S_t \leq f \leq F_t\}\) evaluates to true whenever the time-unit value falls within \(S_t\) and \(F_t\) values. Therefore, the elements of the matrix are either 0 or 1, representing of a PU is present or not, respectively on a channel to the given time unit for node \(e\). Overall, \(N\) such matrices are obtained. To consolidate all the global information, the dedicated common control channel with CR access point performs AND operation on all the corresponding location of the matrices to obtain a channel availability matrix satisfying the channel availability of all the nodes in the CR system.

This is expressed mathematically as:

\[
A_{d,f} = \bigcup_{e=1}^{e=N} MATX_{d,f(e)} \quad \forall d \in X'; \forall f \in \alpha'.
\]

(2)

As shown in Figure 4 below, the first node represents that channel 27 is unoccupied from 0 to 17 time units (00:00 - 03:00 hours), is occupied by the PU from 18 to 59 time units (03:00 -10.00 hours), and is the unoccupied from 60 to 88 time units (10:00-14:50 hours). The sampling continues for 24 hours, at the end of which the CR system would have obtained spectral opportunities for all the channels. This information is passed to the dedicated common control channel, which combines the information received from all the nodes to obtain the comprehensive system spectral opportunity. This combination is required so that every node in the CR system agrees on the spectrum availability. A simple method to obtain a comprehensive spectrum opportunity is to convert all the linked lists into matrices and to compute the intersection on them. The conversion of linked lists to matrices was done using MATLAB. MATLAB is based on dealing with matrices/vectors and arithmetic; it offers matrix based computation that allows users to perform numerical computation more easily. The linked lists received by the dedicated common control channel from each node are described as \(R_{d,e}\) where \(d \in X\), \(e \in N\), and \(N = \{1, ..., N\}\). Let \(\alpha = \left(24 \times \frac{60}{g}\right) - 1\) and \(\alpha' = [0, ..., \alpha]\). We let the matrix for the linked list received from node \(e\) to be \(MATX(e)\), where \(e \in N\). The row and column of the matrix represent channels and time units, respectively. The conversion from the linked lists to this matrix can be done as follows. In the following conversion, we drop index \(e\):

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\]

(2)
The channel availability matrix agrees with the CR nodes present in the system with respect to the availability of the channel. An example matrix is shown in figure 5 below.

Figure 5: Example of a channel availability matrix

We assume that, any given time slot (time unit), at least one channel is available for communication. Hence,

\[ \forall f \exists d [A_{d,f} = 1], \text{ where } f \in \alpha', d \in X'. \]  

(3)

Different SUs have different requirements for the channel selection. The matrix \( A \) can be processed to obtain the desired channel or set of available channels satisfying the users’ constraints. If a single available channel is required at a given time-slot, then we can represent the solution with a vector. The vector index is represented by the time slot, whereas its content represents the channel ID. Therefore, this vector guides the CR system to choose a given channel at a time slot. A typical vector is initialized as:

\[ P_f = \{d: \forall f \exists d [A_{d,f} = 1]\}, \text{ where } \forall d \in X'; \forall f \in \alpha'. \]  

(4)

Multiple vectors may satisfy this equation hence, multiple solutions may exist if no constraints are applied. The given vector simply chooses a channel that is available during a time slot. Therefore, this represents the solution space of all the possible vectors.

3.2 Algorithm for HBSST

Minimal channel switching in terms of channel selection means that the number of channel switching events expected for effective communication during overall period is minimized [18]. In cognitive radio network (CRN), channel switching may be triggered by the detection of PUs on the operating channel, which causes performance degradation due to interference, or traffic load in the current channel [19]. HBSSS-MCS algorithm is proposed to select the available channels such that the SU would stay on that channel for a longer period of time without switching to another channel. We formulated the problem as to obtain the \( \text{P}_{\text{MIN}} \) consisting of channel ID corresponding to time units in the CR system such that the number of switching between the channels in the vector is minimal.

In other words, the problem is to find a vector \( \text{P}_{\text{MIN}} \) which has the minimum total number of channel switching. This is expressed mathematically as:

\[ \sum_{f=0}^{\alpha-1} \text{Channel Switching}(\text{P}_{\text{MIN}}_f) \leq \sum_{f=0}^{\alpha-1} \text{Channel Switching}(P_f) \]

(5)

where \( \forall P \in \{\text{set of vectors } P \text{ obtained from equation (4)}\} \)

Channel Switching\( (\cdot) \) is a binary function defined as:

\[ \text{Channel Switching}(Q_d) = \begin{cases} 1, & \text{if } Q_d \neq Q_{d+1} \\ 0, & \text{otherwise} \end{cases} \]  

(6)

The algorithm for HBSSS-MCS which was adopted from [20] seeks for the channel which has the maximum uninterrupted vacancy available.

4 Results and Discussions

It is expected that each SU to vacate the channel once the presence of the PU has been detected. While switching channels, some of the information being conveyed is being lost which leads to quality of service (QoS) degradation. In order to avoid the QoS degradation of cognitive radio (CR) users or SUs, channel switching has to be minimized. To evaluate the performance of our scheme, we model the availability of channels as a two state Markov chain. The ON state represents that there is a PU present on the channel and therefore cannot be used by the SUs. In this system model, we are interested in knowing which channel is suitable for use by SUs (i.e. channel with longer idle time) amongst pools of available primary channels at a particular period of time over location, hence minimising channel switching. Let \( \eta \) and \( \theta \) be the parameters of the channel availability model signifying the possibility of changeover from ON and OFF and OFF and ON state correspondingly. Since we are concerned about channels whose availability does not change suddenly, we assign \( \eta = \theta = 1 \). A low value of \( \eta \) and \( \theta \) implies that the system is expected to stay either in ON state or OFF state most of the time without state transition.

We compared our proposed scheme against random spectrum selection scheme [10]. Random spectrum selection scheme aims at reducing the number of channel switching by randomly selecting a channel which maximizes the probability of successful transmission and also provides a throughput to the system with the help of PU activity. Figure 6 below shows the Number of channel switching against the sampling interval for overall duration of 24 hours with maximum number of samples =10. It can be seen from the graph that the number of channel switching for HBSST decreases with increasing number of sampling...
interval as compared to Random Spectrum Selection Scheme. This is attributed to the fact that HBSST is able to get the overall picture of many more channels in the system simply due to its information of spectral opportunities ahead of time and hence it is able to select a channel where the SU will camp for longer thus minimizing the number of channel switchings. Meanwhile, Random Spectrum Selection Scheme does not get sufficient time to study all the available channels together with their characteristics in the database, thus the SU switches more frequently between the few channels that are observed and thus suffers performance loss.

Figure 6: Number of channel switchings vs Sampling Interval

Figure 7 below shows the Number of channel switching versus Number of channels in the CR system. It can be seen that the number of channel switchings required in Random spectrum selection scheme is unresponsive to the number of channels used in the CR system except for HBSST. This is attributed to the fact Random Spectrum Selection Scheme lacks the information of spectral opportunities ahead of time and thus suffers from performance loss. Meanwhile, for HBSST, the number of channel switchings decreases with an increase in the number of channels. This is attributed to the fact that HBSST has information of spectrum opportunities ahead of time. Hence, HBSST performs better.

Figure 8 below shows the channel switching rate by SUs against different number of channels. It can be from the graph that the channel switching rate (channels/hour) for HBSST decreases lesser compared to the Random Spectrum Selection Scheme with the increasing number of channels. This is attributed to the fact that HBSST is able to get the overall picture of many more channels in the CR system ahead of time. Random Spectrum Selection Scheme on the other hand lacks the information of spectrum opportunities ahead of time; hence it causes the system to suffer performance loss.

It can also be seen from the graph below that with 5 channels, HBSST and Random Spectrum Selection Scheme are almost equally poor since there are not many channels to choose from. When the number of primary channels is increased, HBSST performs better because there is less switching. For example, with 30 channels, it could be seen that Random spectrum selection scheme switches at 0.6 channels/hour while HBSST switches at 0.3 channels/hour. Hence, HBSST performs better.

Figure 7: Number of channel switchings vs. Number of channels

Figure 8: Channel switching rate versus Number of Channels.

5 Conclusion

In this paper, the system model and principle of operation of our proposed scheme is described. We also show the TV broadcasting band in South Africa based on their deterministic time arrangement. Since the spectral opportunity is known ahead of time, better spectrum decisions can be made. We proposed a smart learning mechanism to learn and capture the spectral opportunity of the TV band which follows a deterministic time arrangement. Simulation results show that HBSST outperforms the Random selection scheme in terms of minimizing the number of channel switchings in the CR system. In future, we are planning to develop a similar model which will be compared with other spectrum selection schemes considering the following: switching delay, end-to-end delay, overall transmission time and power consumption of the SUs evaluated based on the overall transmission time of the SUs in the CR system.
References


