



Artificial Intelligence-Based Spectrum Allocation Strategies for Dynamic Spectrum Access in 5G and IMS Networks

¹Adebayo, I. Aderonmu, ²Olanrewaju Oluwaseun Ajayi

¹Department of Electrical Engineering,
Tshwane University of Technology,
Pretoria, South Africa,

²Department of Electrical Engineering,
University of the Cumberland, USA

ABSTRACT

The advent of Cognitive Radio (CR) technology has significantly enhanced the efficiency and effectiveness of spectrum utilization. In Cognitive Radio Networks (CRNs), secondary users (SUs) dynamically select available radio frequency (RF) spectrum bands for opportunistic use when primary users (PUs) temporarily vacate their allocated spectrum. Despite numerous proposed spectrum selection methods, many fail to adequately address the impact of frequent channel switching on the Quality of Service (QoS) for SUs and the overall throughput of the CR system. Moreover, these methods often overlook the temporal patterns of channel usage by PUs. This paper presents an Artificial Intelligence-Based Spectrum Allocation Strategy designed for dynamic spectrum access in 5G and IP Multimedia Subsystem (IMS) networks. Our approach introduces two heuristic-based algorithms: the AI-driven Spectrum Selection for Minimal Channel Switching (AI-SS-MCS), which identifies the optimal channel for SUs to minimize switching frequency, and the AI-driven Spectrum Selection for Maximum Throughput (AI-SS-MT), which maximizes the CR system's overall throughput. The "optimal" channel is defined as one that allows SUs to remain connected for extended periods with minimal interruptions and offers the highest throughput. Additionally, the study propose an intelligent learning mechanism to identify and exploit spectral opportunities. Our results demonstrate that AI-SS-MCS and AI-SS-MT outperform traditional Random Spectrum Selection Schemes, significantly reducing channel switching and enhancing throughput, thereby proving their efficacy for advanced 5G and IMS network applications.

ARTICLE INFO

Article History

Received: September, 2023
Received in revised form: November, 2023
Accepted: January, 2024
Published online: June, 2024

KEYWORDS

Cognitive Radio, Radio Frequency, IMS,
5G, Channel Switching, AI Learning
Mechanism

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 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.

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajayi@aol.com

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

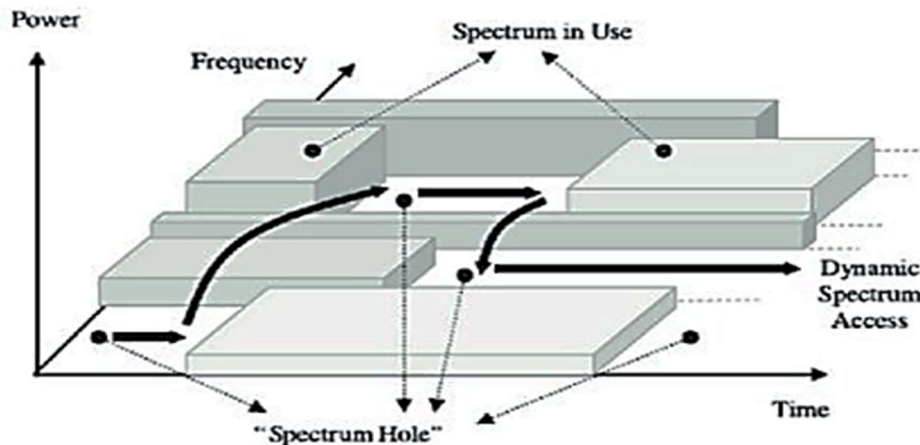


Figure1: RF spectrum is wasted [1] – [3]

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 AI-SS-MCS and AI-SS-MT for spectrum selection by SUs with minimal number of channel switching and maximum throughput. The rest of the paper is organized as follows: Section 2 discusses the related work on spectrum selection methods. Section 3 discusses our system model and its principle of operation. Section 4 discusses the obtained results. Section 5 concludes the paper.

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajayi@aol.com

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

LITERATURE REVIEW

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. According to studies, the usage of spectrum follows a deterministic time arrangement over geographical locations [3]. In [11]-[12] 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.

Table1: Channel Idle Pattern over Time in South Africa

Frequency (MHz)	Channel No.	Available Time (Hours)
470 – 478	CH 21	00:00 - 07:00
502 – 510	CH 25	08:00 - 16:00
542 – 550	CH 30	19:00 - 07:00
566 – 574	CH 32	17:00 -07:00

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.

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:

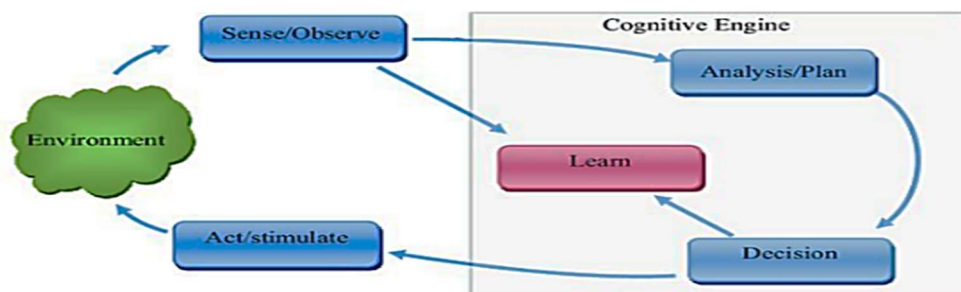


Figure 2: System Model

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajayi@aol.com

Department. of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

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 $X' = \{1 \dots X\}$.

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, each CR user maintains a linked list for each channel in X as shown in Figure 3 below.

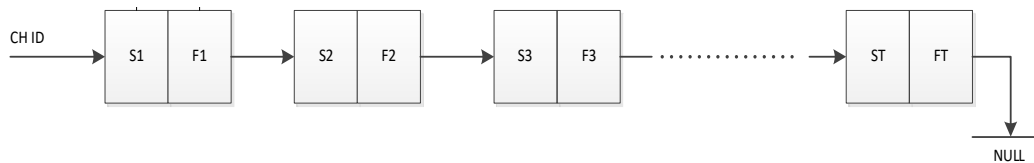


Figure 3: Linked list depiction for unoccupied period of time.

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 $T' = \{1 \dots T\}$ and T symbolizes the last node ID in the linked list. The value of T may be at variance for each linked list.

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

$w \ll g * 60$), this literally means that the spectrum is sensed every g minute for w seconds. Thus, the total time required for sampling X channel is $w * \frac{X}{60}$ minute (where $w * X/60 < g$). 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 $(S_t, F_t) \in \{0, \dots, 1439 ((24 \text{ hours} * 60 \text{ mins}) - 1) / \text{sampling interval}\}$, 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 $((24 * 60) / g) / 2$ when the channel alternates between being free and being occupied in consecutive samplings. Φ is used as a parameter to short the length of the linked list. If the length of the spectral opportunity is greater than Φ , then this spectral opportunity is inserted in the linked list, that is, $\forall t \{F_t - S_t \geq \Phi\}$.

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

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajavi@aol.com

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

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.



Figure 4: Channel usage arrangement of CH 27 for 15hours

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

we drop index e :

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

The predicate logic $\exists t[f \in \{S_t, \dots, F_t\}]$ 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:

$$A_{d,f} = \bigcup_{e=1}^{e=N} MATX_{d,f(e)} \quad \forall d \in X'; \forall f \in \alpha'. \quad (2)$$

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.

$R_{d,e}$ where $d \in X'$, $e \in N'$, and $N' = \{1, \dots, N\}$. Let $\alpha = (24 * \frac{60}{g}) - 1$ and $\alpha' = [0, \dots, \alpha]$.

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,

Corresponding author: Adebayo, I. Aderonmu
 bayoo4real2000@yahoo.com, contactajayi@aol.com
 Department. of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.
 © 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Time Units (f)		0	1	2	3	4	...	α	
Channel ID (d)	3		1	1	1	1	0	...	1
	4		1	1	0	0	0		0
	5		0	0	0	0	0		1
	...		1	1	1	0	0		1
	1		0	1	1	0	1		0
	2		:	:	:	:	:		:
		0	1	1	1	1		1	

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,

$$\forall f \exists d \{A_{d,f} = 1\}, \text{ where } f \in \alpha', d \in X \quad (3)$$

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:

$$P_f = \{d: \forall f \exists d [A_{d,f} = 1]\}, \text{ where } \forall d \in X'; \forall f \in \alpha' \quad (4)$$

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.

Algorithm for AI-SS-MCS

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 [13]. 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 [14]. AI-SS-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 **PMIN** 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 **PMIN** which has the minimum total number of channel switching. This is expressed mathematically as:

$$\sum_{f=0}^{\alpha-1} \text{Channel Switching } (PMIN_f) \leq \sum_{f=0}^{\alpha-1} \text{Channel Switching } (P_f) \quad (5)$$

Where

$$\forall P \in \left\{ \begin{array}{l} \text{set of vectors } P \text{ obtained from equation} \\ \end{array} \right\} \quad (4)$$

$\text{Channel Switching}()$ is a binary function defined as:

$$\text{Channel Switching } (Q_d) = \begin{cases} 1, & \text{if } Q_d \neq Q_{d+1} \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

where Q is a vector and d is its index.

The algorithm for AI-SS-MCS which was adopted from [15] seeks for the channel which has the maximum uninterrupted vacancy available.

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajavi@aol.com

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Algorithm for AI-SS-MT

AI-SS-MT provides a channel selection scheme in such a way that SU would select those channels that provide the highest throughput (bandwidth). The maximum throughput vector (**PTH**) can be calculated as:

$$BW(d) > BW(d + 1), \forall d \in X' \quad (7)$$

The algorithm first sorts the channels in the decreasing order of bandwidth. Then at each time-slot (time unit), AI-SS-MT selects the channel having highest bandwidth. If a channel is not available, it selects the next higher bandwidth channel. The final vector **PTH** provides the maximum throughput to the SU. Since the throughput of channel may vary with time, the algorithm for AI-SS-MT is repeated after a certain interval with updated bandwidth of each channel.

RESULTS AND DISCUSSION

To evaluate the performance of our HBSS-MCS and AI-SS-MT, 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 and has maximum throughput) amongst pools of available primary channels. We compared our

proposed scheme (AI-SS-MCS and AI-SS-MT) 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. We chose to compare our scheme with random spectrum selection scheme because of its popularity.

Figure 6 below shows the Number of channel switchings 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 switchings for AI-SS-MCS decreases with increasing number of sampling interval as compared to Random Spectrum Selection Scheme. This is attributed to the fact that AI-SS-MCS 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.

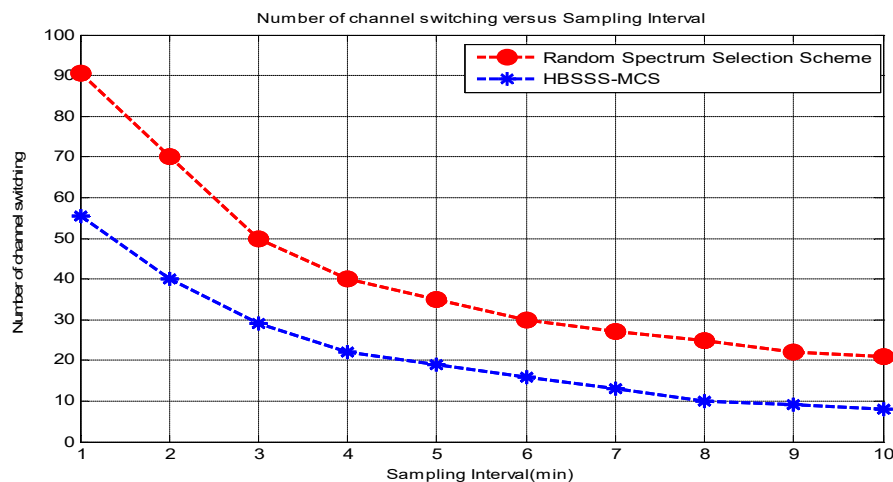


Figure 6: Number of channel switching vs Sampling Interval

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajayi@aol.com

Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved

Figure 7 below shows the Number of channel switchings 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 AI-SS-MCS. 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 AI-SS-MCS, the number of channel switchings decreases with an increase in the number of channels. This is attributed to the fact that AI-SS-MCS has an information of spectrum opportunities ahead of time. Hence, AI-SS-MCS performs better.

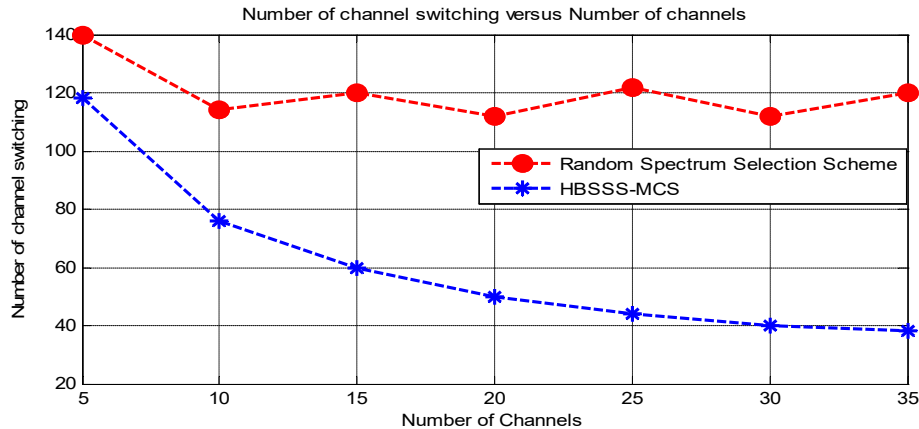


Figure 7: Number of channel switchings vs. Number of channels

Figure 8 below shows the channel switching rate by SUs against different number of channels. It can be seen from the graph that the channel switching rate (channels/hour) for AI-SS-MCS decreases lesser compared to the Random Spectrum Selection Scheme with the increasing number of channels. This is attributed to the fact that AI-SS-MCS 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, the schemes are almost equally poor since there are not many channels to choose from. When the number of primary channels is increased, AI-SS-MCS performs better because there is less switching. For example, with 30 channels, it could be seen that Random spectrum selection scheme switches at 0.6channels/hour while AI-SS-MCS switches at 0.3 channels/hour. Hence, HBSST performs better.

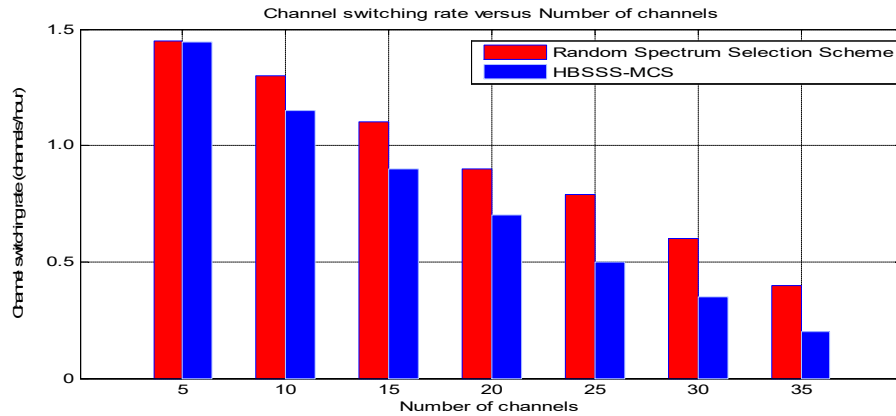


Figure 8: Channel switching rate versus Number of Channels.

Figure 9 shows the throughput obtained versus the sampling interval against the sampling interval with maximum number of samples = 10. These results obtained in Figure 9 show that the throughput of the system is independent of the sampling interval used. It can also be seen that AI-SS-MT provides the highest throughput compared to random spectrum selection scheme. This is attributed to the fact that HBSS-MT is able to get the overall picture of many more channels in the system simply due to its knowledge of spectral opportunities ahead of time and hence it is able to select a channel where the SU will camp for longer thus maximising the throughput of the CR system.

Meanwhile, random spectrum selection scheme does not get sufficient time to study all the available spectrum together with their characteristics in the database due to the random access to the available spectrum, hence, the SU switches more frequently between the few channels that are observed, thus minimising the throughput of the CR system. Our simulation result also shows that with AI-SS-MT, the throughput of the CR system is improved by 50% compared to the random spectrum selection scheme. Obviously, AI-SS-MT improves the quality of communication.

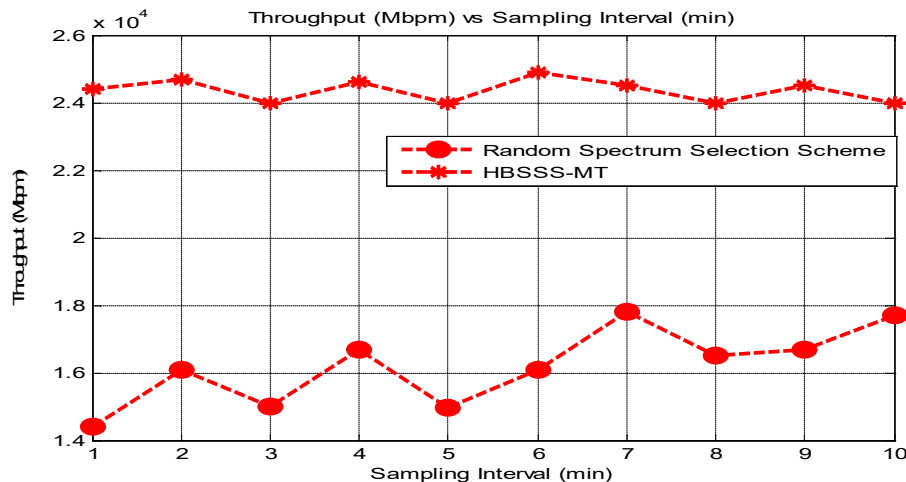


Figure 9: Throughput versus Sampling Interval

Figure 10 below shows the graph of End-to-End Delay versus Number of Channels. End-to-end delay is the time taken for a data packet to be transmitted across a network from source to destination. It can be seen that the random spectrum selection scheme suffers a higher end-to-end delay because it requires a higher end-to-end delay because it requires a greater number channel switchings. In other words, when the time taken to transmit data across a network from source to destination is longer, it therefore means that the SUs will have

more time on the available channel; hence, it reduces the number of channel switching across the network by SU which leads to degradation of quality of service. With AI-SS-MCS, the end-to-end delay is minimised since it's requires less number of channel switching compared to Random spectrum selection scheme. AI-SS-MCS improves the end-to-end delay of the CR system by 6% compared to the random spectrum selection

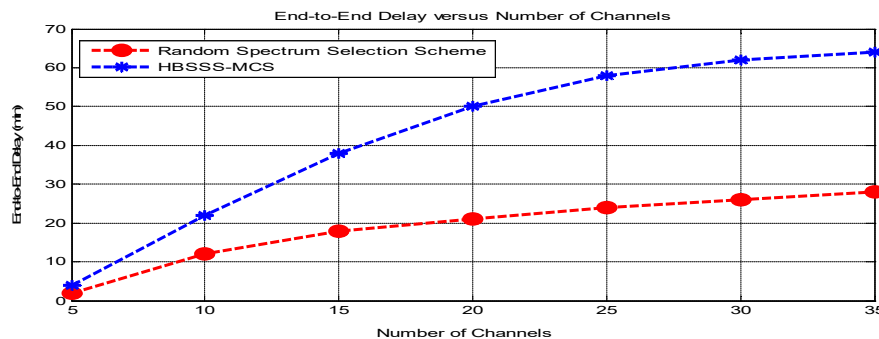


Figure 10: End-to-End Delay versus Number of Channels

Figure 11 below shows the Average data throughput against Number of channels. It can be seen from the plots that when there is an increase in the number of available channels, HBSS-MT stands better chance to select the best channel for use by SUs in terms of throughput compared to random spectrum selection scheme.

The data throughput of each scheme is increasing linearly because the throughputs of each channel are also increasing linearly with the number of channels in the system. The average throughput of AI-SS-MT is improved by 21% compared to random spectrum selection scheme.

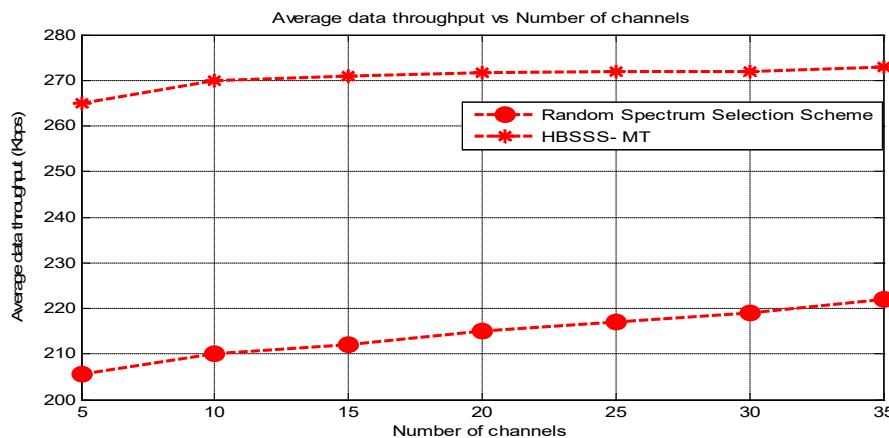
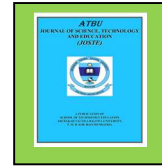


Figure 11: Average data throughput versus different Number of channels.



CONCLUSION

In this paper, we detail the system model and operational principles of our proposed AI-based spectrum selection scheme, which leverages deterministic time arrangements of the TV broadcasting band in South Africa. By knowing the spectral opportunities ahead of time, our scheme enables more informed spectrum decisions. Our simulation results clearly demonstrate that our proposed schemes, AI-SS-MCS and AI-SS-MT, significantly outperform the Random selection method in minimizing channel switchings and maximizing throughput. Utilizing a linked list as a smart learning mechanism, we accurately predict spectral opportunities based on deterministic time usage patterns. This foresight allows for superior spectrum decisions and enhances overall system performance.

Comparative performance analysis with the Random spectrum selection scheme confirms that AI-SS-MCS and AI-SS-MT deliver enhanced system efficiency and reliability. Looking ahead, we plan to develop and compare our model with other spectrum selection schemes, taking into account critical factors such as switching delay, end-to-end delay, overall transmission time, and power consumption of secondary users (SUs). This future work will further validate our approach by evaluating these parameters within the context of the CR system's overall transmission time.

REFERENCES

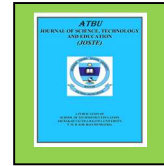
- Federal Communications Commission, *Notice of proposal rulemaking and order*, ET Docket No. 03-322, USA, Nov. 2003
- I. F. Akyildiz, W.-Y. Lee, M. C. Vuran, and S. Mohanty, "NeXt generation/dynamic spectrum access/cognitive radio wireless networks: a survey," *Elsevier Computer Networks*, vol. 50, no. 13, pp. 2127–2159, 2006.
- M. A. McHency, P. A. Tenhula, D. McCloskey, D. A. Reberon, and C. S. Hood, "Chicago spectrum occupancy measurements and analysis and a long-term studies proposal protocol," in *Proc. 1st Int. Workshop on Technology and Policy for Accessing Spectrum*, Boston, MA, USA, Aug. 5 2006.
- Maziar Nekovee, a Survey of Cognitive Radio Access to TV Whitespaces, *International Journal of Digital Multimedia Broadcasting* Volume 2010. http://www.queensu.ca/iasarspectrum.eu/images/stories/Documents/publications/Nekovee_journal2010.pdf.
- CEPT Report 24, Technical considerations regarding harmonization options for the Digital Dividend: A preliminary assessment of the feasibility of fitting new/future applications/services into non-harmonized spectrum of the digital dividend (namely the so-called "white spaces" between allotments) <http://www.erodocdb.dk/docs/doc98/official/pdf/CEPTRep024.pdf>.
- R. A. Rashid, M. A. Sarijari, N. Fisal, S. Yusuf and N. H. Mahalin "Spectrum Sensing Measurement using GNU Radio and USRP Software Radio Platform" In *Proc. of The Seventh International Conference on Wireless and Mobile Communications 2011*. pp 237-242 .
- J. Mitola III, Maguire, and G. Q. Maguire, Jr., "Cognitive radio: making software radios more personal" *IEEE Personal Communications*, vol. 6, no. 4, (1999).
- Federal Communications Commission (FCC): Facilitating opportunities for flexible, efficient and reliable spectrum use employing cognitive radio technologies: Notice of proposed rulemaking and order. ET Docket 03–108 & 03-322, (2003)
- Yang Song; Yuguang Fan; Yanchao Zhang, "Stochastic Channel Selection in Cognitive Radio Networks," *Global Telecommunications Conference, 2007 Washington DC (GLOBECOM '07)*, Nov 2007, pp.4878-4882.
- Bennai, M.; Sydor, J.; Rahman, M., "Automatic channel selection for cognitive radio systems," *IEEE 21st International Symposium on Personal Indoor and*

Corresponding author: Adebayo, I. Aderonmu

✉ bayoo4real2000@yahoo.com, contactajavi@aol.com

Department. of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa.

© 2024. Faculty of Technology Education. ATBU Bauchi. All rights reserved



- Mobile Radio Communications (PIMRC)*, pp. 1831-1835, Sept. 2010
- ICASA, "450 MHz - 470 MHz: Consolidated Audit Report," May 2010; <https://www.icasa.org.za/Portals/0/Regulations/Spectrum%20Usage%20and%20Spare%20Frequencies/Consolidated%20Spectrum%20Audit%20450MHz-470MHz%20final%20100510.pdf>.
- ICASA, "790 MHz - 862 MHz: Consolidated Audit Report," May 2009; <https://www.icasa.org.za/Portals/0/Regulations/Spectrum%20Usage%20and%20Spare%20Frequencies/790MHz-862MHz%20Consolidated%20Spectrum%20Audit%20Report.pdf>
- Adebayo I. Aderonmu, Linoh A. Magagula, Karim Djouani (2014), "*spectrum selection technique to reduce the number of channel switching for dynamic spectrum access in cognitive radio networks*" Proceedings of the IASTED International Conference modelling and Simulation (Africa MS 2014), September 1 - 3, 2014 Gaborone, Botswana
- H N Nie, C Comaniciu, Adaptive channel allocation spectrum etiquette for cognitive radio networks in IEEE DySPAN, 269–278 (2005)
- H Zheng, L Cao, Device-centric spectrum management. in IEEE DySPAN, 56–65 (2005)
- Aderonmu, A.I., Adegandjou, R.H., Masonta, M.T., Mzyece, M. (2013). VHF Spectrum Monitoring Using Meraka Cognitive Radio Platform. In: Jonas, K., Rai, I.A., Tchunte, M. (eds) e-Infrastructure and e-Services for Developing Countries. AFRICOMM 2012. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 119. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-41178-6_6
- A Saleem, L Kyung-Geun, Fair, efficient and power optimized spectrum sharing scheme for cognitive radio network. EURASIP J. Wirel. Commun. Netw (2011). Doi:10.1186/1687-1499-2011-201