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An intelligent channel assignment algorithm for cognitive radio networks using a tree-centric approach in IoT

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ABSTRACT

Cognitive radio network (CRN) is getting growing interest of the researchers due to its wide applicability for spectrum sharing with massive number of active devices in Internet of Things (IoT). In existing schemes, a large part of the spectrum may remain underutilized which was assigned to service providers as primary users (PU). Secondary user (SU) may be the alternative to use the spectrum. The main challenge is that SU keeps on sending the packets in an incremental manner until a free channel is found in real conditions. It results in excessive communication and packet loss. This paper presents an efficient tree-centric approach where a centralized base-station maintains a tree of available channels and intelligently allocate to the SUs as per the real-time availability of channels. It analyzes for the effective usage of these channels by the SUs. It also manages the authenticated SUs to avoid any interference due to the hidden node problem. A number of extensive simulations are performed using network simulator. The existing instantaneous approaches require 10 to 12 attempts to send request for acquiring free channel with an average delay of 315 ms, the Hybrid-P1 and Hybrid-P2 approaches consumed 4 requests each with a delay of 128 ms to 135 ms. Our proposed CDC mechanism achieves a channel access mostly in 1 to 2 requests with an average delay of about 72 ms. Results are extracted from the trace files that prove the dominance of proposed scheme.

1. Introduction

Cognitive radio network (CRN) supports the external users to access the allocated bandwidth in an authenticated manner. The traditional approaches are insufficient for providing extensive number of channels to the upcoming commercial applications. CRN provides an opportunity to intelligently detect and allocate the underutilized band to the secondary users (SU). The channels are regularly utilized by the many commercial applications in mobile telephony, TV channels, weather, healthcare and transportation [1]. CRN can play a vital role to fulfill the demands of the huge number of devices in the Internet of Things (IoT). Cognitive Radio (CR) nodes try to utilize the channels by keeping minimum interference for the licensed users [2]. CRNs provide the support for consuming the unused band by the secondary users. The motivation behind this work is that the spectrum should be effectively utilized by the SUs. It demands the effective channel usage so that the paid bandwidth may not be underutilized. The CRN based spectrum allocation manages to use the free channels. The proposed work will maintain the channel utilization status in a tree centric way to better utilize the bandwidth.

CRN has the capability to learn on the basis of cognitive knowledge and take intelligent decisions for channels management. For the main part of the spectrum assigned to service providers or PUs, it has been seen that the frequency bands or spectrum are not used optimally [3]. It manages the packets with a decision making techniques for improving the quality with cognitive support [4]. CR enhances communication reliability and efficient spectrum utilization [5] for many emerging paradigms for AI based CRN in the IoT scenario [6,7]. CR demands the equipment update in mobile devices and upgradation in existing transmission infrastructure like addition of cognitive base stations (CBS) [8].

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The spectrum sharing model [9] requires the record keeping for the SUs that are actively using the channels. It is beneficial for optimized allocation of channels for SUs [10] where the access method for SUs includes the overlay region. In case of hybrid region, it may access by exploiting the free spectrum.

This paper presents a CBS-based **E**ffective **S**pectrum **A**llocation and **M**anagement (ESAM) which maintains the real-time state of the available channels in a tree-centric way. The scheme manages to effectively allocate channels to the SUs. The main contributions of this work are enumerated as follows;.

1) The literature is explored on the topic of spectrum allocation techniques in CRN to utilize the channels by the SUs.
2) The proposed work presents a tree centric spectrum allocation mechanism where the CBS maintains a tree of available channels and assigns to SUs as per request. It reduces the delay for accessing the channels by the SUs and hence maximizes the throughput.
3) A novel algorithm is presented that enrich the use of CBS to cross check the channel utilization in real-time by maintaining the record.
4) Moreover, a tree of authenticated SUs is maintained at CBS to avoid any interference with the PU caused due to hidden node.

The rest of the paper is structured as follows. Section 2 explores the related work and Section 3 presents system model and problem statement. Section 4 discusses the proposed solution. Section 5 discusses about results and Section 6 concludes our work. Section 7 explores the future work.

2. Related work

This Section explores literature on spectrum sensing and spectrum sharing among the SUs in CRN. The SUs keep on sensing the available slots in an incremental manner which cause delays and packet loss in case where channels are already in use by the PUs [11]. X. Fernando *et al.* presented the spectrum sensing mechanisms that are applicable in cognitive radio based internet of things. It focused on reducing the energy consumption and involving the group based clustering scenarios to improve the connectivity and data sharing [12]. In Ref. [13], the energy-efficient allocation involves the training of data for acquiring a list of reliable channel where the channels on odd and even numbers are allocated to the alternate tasks. In Ref. [14], the mobility factor is also considered that effects the quality of users at the edge of the cell where the signal strength is weak. It is mandatory to manage the opportunities during the mobility scenarios as well.

The idea of improving the transmission in case of multichannel CR is presented in [15] and [16]. In the sensing slot, SU divided sub-channels as per sensing energy and noise. The harvested energy is compensated to achieve the optimized throughput in the transmission slot. Some recent advancement in sensing is considered [17]. Bera Debasish et al. [18] described that system consists of one PU, K secondary users, and one fusion center in one place. All SUs sense the state of a PU by using an energy detection technique. The received signal X(t) is given in Eq. (1) where S(t) is the signal that is being transmitted from the primary transmitter, n(t) is the Additive White Gaussian Noise (AWGN), and A denotes a channel gain. The spectrum sensing is modeled as the binary hypothesis testing problem, H0 represents a PU is idle or not active and H1 represents a PU is busy or active.

$$\mathrm{X(t)} = \left\{ \begin{matrix} n(t) & H0 \\ A.S(t) + n(t) & H1 \end{matrix} \right\} \tag{1}$$

The fading problem is taken into account where SUs can exchange local sensing results with each other and manage a set. A final decision is obtained by combining all local observations and comparing them against a global detection threshold. For decision fusion, the local detection threshold of individual compared with non-cooperative spectrum sensing involving only one detector in Ref. [19]. An adaptive sensing period-based scheme on traffic demand is introduced [20] where some SUs rather than all take part in sensing, in a time-slotted manner. Each SU estimates the False Alarm Probability (Wrong sensing) & Detection Probability (find busy) and the results are combined at the Fusion center and decisions are taken on whether that particular SU can use the channel. These techniques not only provide improved sensing results for decision-making but also minimize security threats to PU transmission by taking into account the credibility (Cr) of each SU involved in the sensing mechanism. In contrast to this, our work manages record for authenticated SU and a list of reliable channels which will enhance the channel utilization. In Ref. [21], a system model is divided into three stages. The first is the learning stage, where the Cr of every SU is evaluated. During this stage, the Access Point (AP) evaluates each SU by comparing the results with neighbors. If the results are found correct, then the credibility is 1 otherwise 0 is assigned to that particular SU. In second stage, each SU sends the result to AP. In the third stage, the AP takes a combined decision which is based on the received local sensing results. Moreover, the AP calculates the result for each SU and then compares the decision with a predefined threshold. In contrast to this, our work manages record at CBS for taking decision about the SUs and the accessibility to channels.

The spectrum allocation schemes for CR networks and multi radio platform effectively utilize the unused channel of licensed PUs [22]. The use of game theory also provides solution as explored in survey for stackleberg game based schemes where the resources are assigned as game players [23]. In some cases, SUs may overtake the privilege of using the free channel by overhearing the private communication of PUs. In [24], dynamic interaction of buyers and sellers of frequency bands manages the interference coordination to improve throughput. The agents interact to reach a point that is beneficial for PU and SU to maximize utilities and optimize the use of free bands. This interaction may require negotiation on buying and selling prices of channels. The approach in Ref. [25] is a reverse or double auction-based scheme in which players look forward to a common point of interest by making counter offers on the price of a channel. To make an appropriate offer Markov process is used for the prediction of the price range.

Cooperative and joint sensing of unexploited channels by PUs is done to save the energy of SUs. In Ref. [26], secondary and cognitive users are implanted to act as relay nodes to eliminate the interference among PUs and CUs. Appropriate engagement of channels is based on proper sensing and allocation which can be ruined by employing the attacks. The approach [27] diminishes the effect of falsification attacks by introducing an effective mechanism. In this situation, the problem is subdivided into the allocation of resources and the number of SU decision problems. In Ref. [28], the scheme predicts the channel utilization by the PU and then allocate the SU accordingly. A Markov based hybrid model is used to maintain a matrix of expected next states for the PU which is named as Hybrid-P1 approach. Moreover, the Hybrid-P2 approach considers the history of both next and previous state of PU to prepare the matrix for channel selection. It is better than the INS approaches. However, the prediction of the next state does not ensure the access to the channels by SU as the PU may have a variety of states. In contrast to this, our scheme considers the actual utilization by PU and maintains a list of available channels at that time.

In Ref. [29], a Markov chain based model reduces the chances of blocking the access to the channel by the SU due to the unavailability of the PU. It uses the two models in a chain to enhance the system for better performance in terms of accuracy. In Ref. [30], the dynamic channel allocation scheme uses the Markov chains to manage flow of channel assignment. It also reduces the chances of blocking. Moreover, the SUs

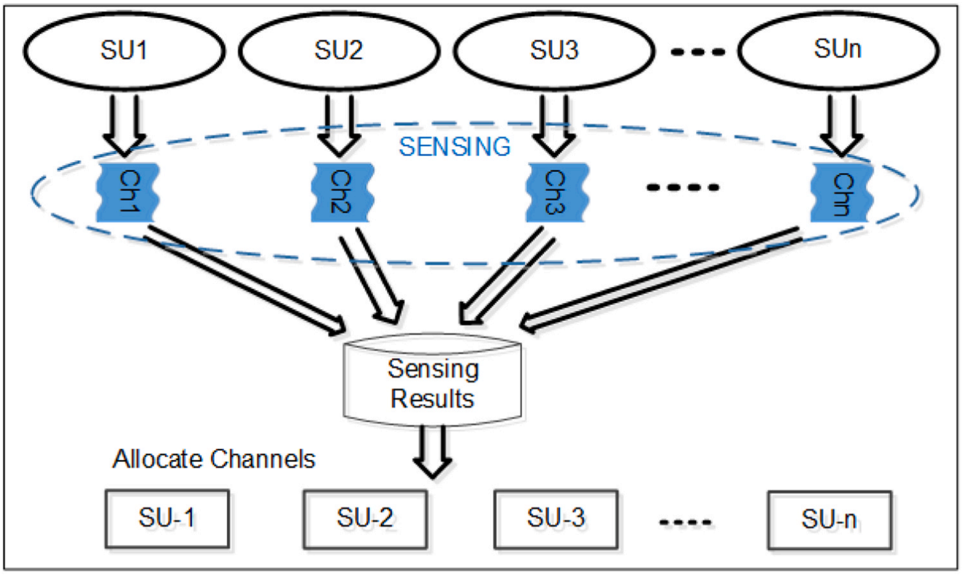


Fig. 1. Cooperating sensing and channel allocation.

are also given the opportunities as per the flow classification. In contrast to the Markov chain based approaches, our scheme maintains a tree of reliable channels at the CBS for better accessibility for SUs. Secondly, a list of authenticated SUs is also maintained. Thirdly, the proposed algorithm monitors the behaviors of SUs as per the requested parameters to block the SU in case of violating committed access. CRN provide support to overcome the limitations of the radio spectrum. Moreover, overlay and underlay are the two basic methods to access the free channels. Moreover, various schemes provide several hybrid methods to improve the radio spectrum. Dhurandher et al. introduce a HUST technique for hybrid spectrum utilization that enhances the PU detection possibility to optimize radio spectrum. The scheme provides efficient performance when compared to overlay and underlay schemes [31].

3. System model and problem statement

CR nodes have the ability for rapid spectrum sensing, coordination, and cooperation using a variety of techniques and methods. CR nodes can recognize free parts of the spectrum. Thus, there should be some mechanisms that efficiently utilize free channels without wasting resources while preserving the minimum level of interference for PUs. Consequently, CR provides a dynamic spectrum for efficient spectrum usage. The CR system always tends to keep on sensing the whole spectrum band resulting in wastage of energy. In this context, the accuracy of these sensing results cannot increase the network throughput. Due to these uncertain sensing results and the sudden movement of PU, the SU needs to sense another channel to continue its transmission. This work assumes that each SU can only sense one channel. Moreover, it continues to sense channels for a specific period to collect complete activity information of a PU as shown in Fig. 1.

The main problems during collaborative sensing are;

a) The channel may be occupied by any unknown SU_1 to SU_n leaving the whole network under selfish attack mode as there is no information of currently working SU. There is no option for maintaining any tree of reliable channels available in real-time conditions in INS, Hybrid-P1 and Hybrid-P2 [28]. It becomes more challenging for collaborative sensing where many SUs work together to avail a large number of channels.

b) The databases maintain the licensed allocation of certain spectrum but it lacks in maintaining the real-time use of the channels which may cause spectrum holes at run-time.

Table 1
Notations for ESAM.

Notation	Description
γ	Total Channel Reliability
σ	total channel utilization
$t_{1\ldots n}$	Time Intervals to access channel by PU
T_{free}	Free time of a channel
U_{ch}	Usage of a channel
A_{count}	Number of arrivalss
PU	Primary User
SU	Secondary User
CBS	Cognitive Base Station

c) The large number of SUs try to search for free channels in instantaneous (INS) approaches which access the channels by sending requests again and again to check free channel. For finding the spectrum holes in an incremental manner, it results in losing energy and causing delay through retransmission.

4. Effective Spectrum Allocation and Management (ESAM) scheme

Spectrum can be managed efficiently by allocating the channels to secondary and PUs without collisions. In Centralized Distribution Centre (CDC) based proposed approach, the CBS creates a tree of available free spectrum holes by sensing the whole bandwidth using the sensing techniques and applying reliability/susceptibility constraints. The tree is organized according to the reliability of channels for better transmission. It can assign the most reliable channels to SUs for providing minimum channel sensing time as compared to previous approaches. A brief description of the notations is listed in Table 1. The system manages the utilization of the channel by the Pus so that the availability for the SUs can be identified in the current scenario. The total Channel Utilization(σ) is given in Eq. (2). However, it overviews PU activities in a straightforward manner but it does not help to figure out the channel reliability. Time slots are represented by t_1, t_2, …, t_n for showing the arrival time of PU on the channel.

$$\sigma = \frac{(t_1 + t_2 + \ldots + t_n)}{Total \quad time \quad of \quad all \quad channels} \times 100 \tag{2}$$

The rate of change of channel is directly proportional to interference. The transmission is carried on if it is below the threshold value to avoid interference with the PU. As the interference crosses the threshold it switches to another channel. It should be ensured that the switched channel has that capacity for successful transmission to occur. Channel Reliability(γ) is calculated using Eq. (3) where T_{free} is free time of a channel, $U_{ch}$is usage of a channel, A_{count} is number of arrivals.

$$\gamma = \frac{T_{free} \times 100}{(U_{ch} \times A_{count}) + T_{free}} \tag{3}$$

A set of sample values based on observed communication are chosen for the description. A pool of all channels is calculated where the highest reliable channel is placed on top. It is used to assign channels to SU on-demand. At each interval, SU keeps updating the CBS about the activities of a particular PU. CBS applies reliability constraints on the received information and creates a pool of free channels accordingly. Server changes in the movement pattern of PU may degrade the channel reliability even if it uses the channel for a short amount of time in each interval. In this regard, two calculations are shown here emphasizing the variation in reliability based on the number of PU arrivals. The calculations show that free space does not affect the throughput compared to the number of PU arrivals. For example, in Channel 1 with 10 Arrivals $= \frac{75*100}{25*10+75} = 23.07$ where free space is 75 % and Channel 1 with 20 arrivals$= \frac{75*100}{25*20+75} = 13.04$ having 75 % free space.

The activities by PU are periodic where the PU uses the channel at some specific time. Hence, the channel is found to be free at different specific intervals. Keeping this point in mind, CRN with N secondary users SUs and M PUs have been considered in this research work. Each SU corresponds to a transmitter-receiver pair and each PU transmits data via a licensed channel. There are M licensed channels where {1, 2. M} denotes the set of PUs. Assume that CRNs work in a time-slotted manner and the slot duration is T. Since cooperative sensing has been used in each section there is a fusion center that collects sensing results from SUs and makes a decision on the channel availability. At the beginning of each slot, SUs perform sensing. Each SU selectively joins in cooperative sensing based on the knowledge of the traffic demand and channel capacity.

4.1. Reliable channel allocation scheme

This Section explores the proposed scenario where SU initiates the request for acquiring a free channel that may be reliable for successful packet transmission. It also handles the best utilization of the spectrum band by switching PU and SUs for channel access. The SU requests the CBS to get a free channel by sending a Channel Acquire packet which contains MAC, geographical location, usage time, and bandwidth required. Channel Offer packet is sent from a CBS to an asking SU. The packet contains the CBS ranked assignment for the SU. The Channel Request packet consists of the assignment parameters and SU uses it to either acknowledge the CBS Channel Offer packet or renegotiate the currently assigned channel or ask another channel assignment as the PU came back.

Channel ACK is sent by the CBS in response to Channel Request. This packet accepts or declines the SU request. If a request is accepted, then the SU is added to the tree of working SUs and a single channel or set of channels is assigned to SU in case the available channels are more than the requested channels. CBS has the authority to forcefully reassign or terminate a SU's assignment by sending a Channel Reclaim packet. CBS analyses the requirements of a SU and assigns a channel accordingly. Besides this, CBS has a valid tree of all SUs working in a current spectrum bandwidth and maintains the regular status. It minimizes the spectrum management threats and security issues. The list of authentic SUs is maintained at CBS to protect against unauthorized access to the network. CBS also ensures that no SU occupies the channel more than its required time. It makes the freely available channel list alive so that other SUs can use these available channels. In cases where PU returns back, there will be no interference to PU. The CBS not only validates the current running SUs from the tree but also find the users in the tree which were using the channels against the asking parameter. CBS forcefully terminates the SU allotment after verification. The architecture of the procedure is shown in Fig. 2.

The CBS uses Algorithm 1 to perform channel allocation and reliability management. Initially, the two trees are initialized that will store the channels according to their reliabilities and the other tree to store the working SU information. Both trees are managed at the CBS in a dynamic way. In steps 3 to 12, the CBS iterates for each SU and cross check whether the threshold time is crossed. It starts scanning channels on by one for a certain period through energy detection technique. The information is sent to the CBS after a specific time interval. Next, CBS collects the information from all the SUs and applies the reliability formula on each channel, and then stores it in the Channel_Reliability_List with the highest reliability on top. Next, the *AnalyzeUsage* function is called to evaluate the utilization by that SU which is passed as input argument to this function.

The steps 13 to 25 illustrate the function for analyzing the channel usage. Finally, For Loop is applied for the SU in the Working_SU_List. It checks whether each SU is working according to the requested parameters or not. Moreover, in step 16 it checks about the status of the channel allocated to a certain SU and its level of utilization as well. In proposed solution, the algorithm entirely depends on the currently working SU list/tree which resolves the issue of dependency on neighbors in existing schemes. Therefore, after every threshold time the algorithm iterates, it checks in tree of currently working SUs in real time. If the channel is working accordingly, then the user is valid otherwise declared as a selfish user. This channel will be deleted from the working SU list and sending the Channel Reclaim packet to take back the channel allotted to selfish user and channel status is reset.

In the receive function in steps 26 to 45, it receives the request packet with various fields. It checks the packet type as *Channel_Request_packet* and then check the size of the demanded channels by the SU. It compares with the channels available in the reliable channels list. It iterates the steps for the demanded count of channels to assigns channels from the top of the list as per the reliability. The CBS selects the channels at real time and informs SU via *Channel_Ack* packet. In other scenario when the Ack is received back at CBS, then it puts the channel into the working user list [] and removes it from the channels list. It keeps the channel to observe its utilization. In case of the *Channel_Status* packet sent by the users, the CBS maintains the status for each channel in the *Working_SU_List []*. In case of any unknown packet type, it is discarded. The algorithm is scalable and can be applied to different types of cognitive radio networks and IoT devices. It uses the tree based approach to handle the available channels which can be searched in a proven efficient time. In the iterations from steps 4 to 10, N number of users are processed. In case of iterations in steps 14 to 24, the M number of SUs are processed. The steps 29 to 32 explore the iterations in a Log N times. The overall running time can be shown as O(M+N) by considering the higher costs. The algorithm works in real-time with varying conditions. It can handle the variety of SUs in varying environment even when the utilization of PU and SU is dynamically changing in busy or free hours. The algorithm dynamically manages for request types in the receive function and can effectively analyze the usage of the channels.

Algorithm 1. Channel allocation and reliability management at CBS.

```
Initialize the Channel_Reliabit lity_List []
Initialize the Working_SU_List []
For SU i=1 to N do
  If Working_SU_List [i] →Time-elapsed > threshold_time then
    Sense each channel using the Energy detection technique.
    Each SU sends sensed result to CBS
    Combine the sensing results with calculated reliability for each channel
    Add the channels to Channel_Reliability_List [] with highest reliable on top.
    Call Function AnalyzeUsage(Working_SU_List [i])
  End If
  Increment i by 1
End For
Function AnalyzeUsage (Sender as Input)
  For each user in Working_SU_List [] do
    If Compare (Working_SU_List [“Request→Sender”] →parameters with allocatedParamas) then
      If Check (Working_SU_List [“Request→Sender”] →Channels →status)
        . Channel is valid, if free then release it for accessibility by other PU or SU
      Else
        Remove from Working_SU_List [“Request→Sender”].
        Send Channel_Reclaim_Packet to SU
        Reset Working_SU_List [“Request→Sender”] →Channels →status
      End If
    End If
End For
End Function Analyze
Function Receive (Request as Input)
If Request→Type is Channel_Request_packet then
  If Request→ChannelsDemanded < Sizeof (Channel_Reliability_List [])
    While allocatedCount is not equal to Request→ChannelsDemanded do
      Request→Sender→Channels [allocatedCount] = AssignChannel (Channel_Reliability_List [])
      Increment allocatedCount by 1
  End while
  send Channel_Ack packet to asking SU at Request→Sender
End If
Else If Request→Type is Ack then
  If ACK is ok/assign, then
    Move Channel from Channel_Reliability_List[]
    Add to Working_SU_List [“Request→Sender”] →Channels
  End If
Else If Request→Type is Channel_Status then
    Set Working_SU_List [“Request→Sender”] →Channels →status = Request→Sender→Channels →status
Else
    Discard the Unknown Request
End If
End Function Receive.
```

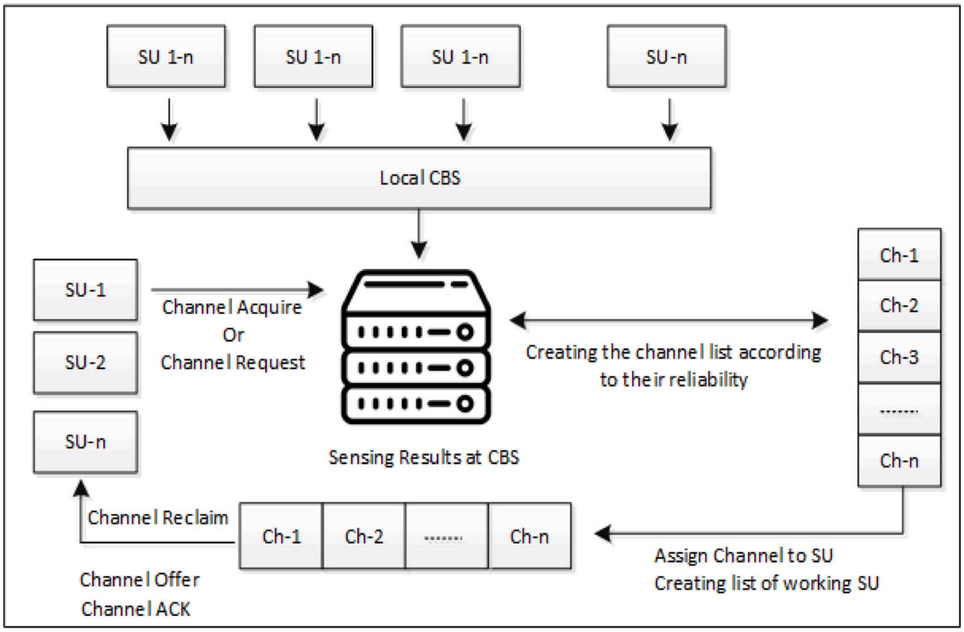


Fig. 2. Proposed model for CBS based channel allocation.

5. Results and discussion

The efficiency of the proposed scheme over the traditional approaches has been evaluated through network simulator NS-2.35 on Fedora. The nodes are deployed as per the system models by using the Tool Command languages (TCL). The TCL is also used to initiate messages by the SUs as per the real-time traffic to access the channels. The actual functionality of packet creation, send and receive is implemented using back-end logic in C language. A set of separate classes are created to manage the hierarchy of the devices like SUs, Pus and CBS and the respective back-end flow for send and receive functions. To extract the results from the generated trace file, the AWK scripts are created. The total number of SUs considered in the environment ranges from 2 to 100 for different scenarios. Medium access results are obtained by taking three SUs who try to access the free spectrum on their own. The experiment was performed under various access delays and total packet requests experienced by the SUs and compared with the results of the proposed CDC. The base schemes for comparison are INS, Hybrid-P1 and Hybrid-P2 [28]. A list of simulation parameters is given in Table 2.

5.1. Average delay and the detection rate

Fig. 3(a) elucidates the average delay to access the free channel. In this case the time varies as per the availability of the channel but average time raises as the number of SUs are increasing. Results show that at an instance of time = 10, the INS approach consumes an average of 315 ms due to excessing time to find the free slot whereas the hybrid-P1 and hybrid–P2 consumes less time of 135 ms and 128 ms due to the state management and probability table for predicting the behavior of PU. The hybrid approach maintains a table of probability for PU’s availability. It also checks the expected state in next slot in hybrid–P1 whereas the hybrid-P2 scheme considers both next and previous states of that channel. The proposed CDC approach dominates with average time delay of 72 ms due the tree-centric approach for maintain the list of reliable free slots. It achieves better results in contrast to the probability based hybrid approach due to better reliability on the assigned channel from a central tree. Fig. 3(b) illustrates the detection rate whether all the SUs get the chance to detect and avail the channels with less number of collision with the accessibility of the PU. The existing INS approaches suffer with degradation. In case of 12 SUs, the detection rate is 68 % for INS schemes whereas the Hybrid-P2 achieves 82 % due to prediction for next state based on the history for the previous and present state of PU. The Hybrid-P1 achieves 75 % due to the prediction for next state of the PU. The prediction may not be fully successful every time to avail the exact state of the PU. The CDC approach achieves 91 % due to the central tree of available channels maintained as per the real situation. The detection rate (D_R) is given in Eq. (4) which is based on the utilization by the PU in certain instances. In this context, if the appearance of PU on any particular channel is increased then the chances of collision also increases. The Channel which has a low appearance of PU is ranked at higher level in the tree and vice versa.

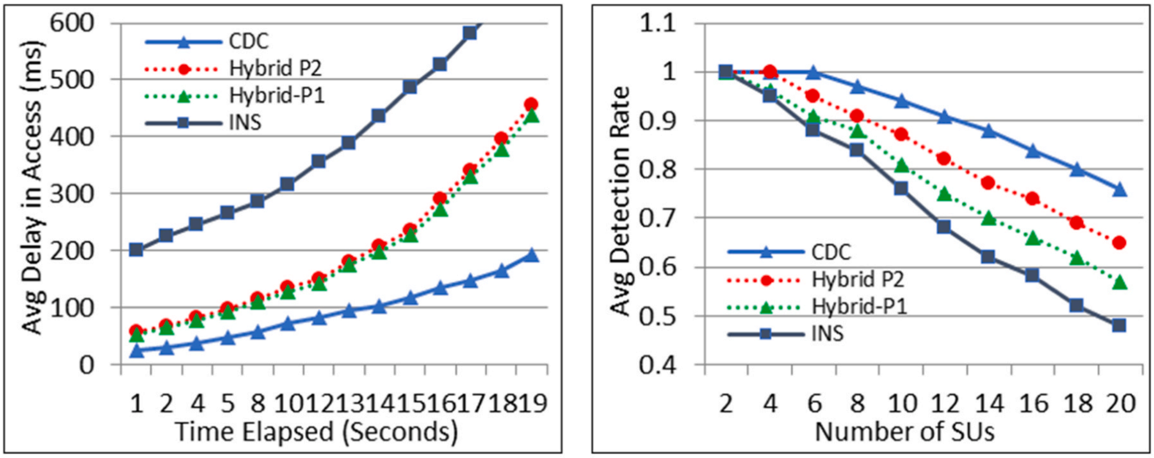
$$D_R = \frac{Number \quad of \quad detected \text{or} Currently \quad working \quad SU}{Actual \quad Number \quad of \quad working \quad SUs} \tag{4}$$

Table 2
Simulation parameters for ESAM.

Parameters	Values
Simulation Time	1000 s
Area Size	400 m x 400 m
Transmission Range	300 m
Antenna Type	Omni Directional
Queue Size	50 m
Data Transmission rate on Channel	2 Mbps
Packet size from SU	100KB
Number of PUs	20 users
Time Consumed	01–19 s
SU Density	02–20 users

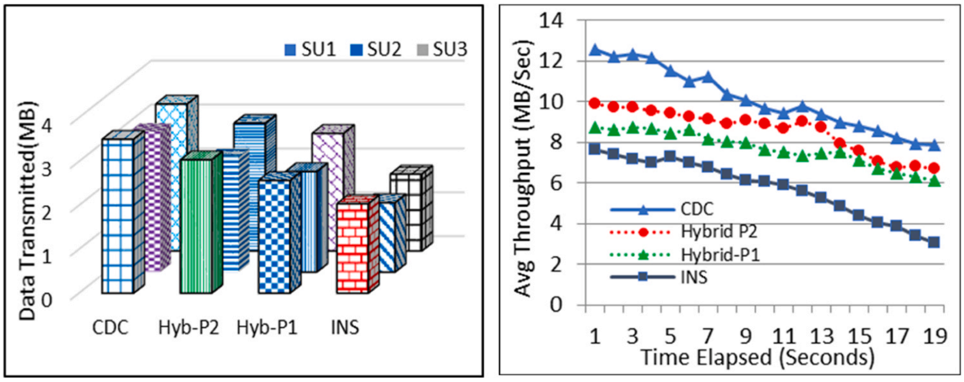
5.2. Data transmission and throughput

Fig. 4(a) elucidates that the overall average data transmitted on a single channel during the timespan for the utilization by the SUs. It is demanding to allocate reliable channels to SUs for better data sharing with wide timespan. Results are shown for selected three SUs attempting to avail the channel in a certain time period to show the overall effect of underlying mechanism to allocate channels. The average amount of data transmitted by SU1 for every 2 s on Channel 1 is 2.04 MB for the INS approaches which is less due to less availability of the reliable channel. On the contrary, the Hybrid-P2 and Hybrid-P1 transmit 3.04 MB and 2.57MB due to the probability factor for predicting about next state of



(a) (b)

Fig. 3. The access delay is shown in (a) and (b) is about detection rate for SU.



(a) (b)

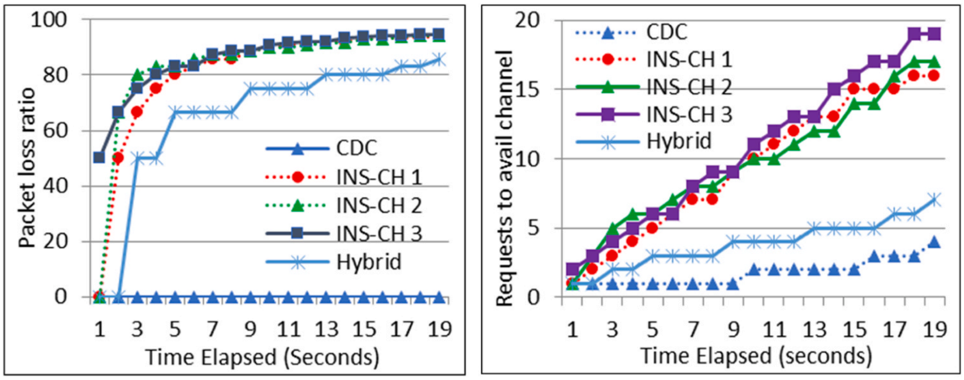
Fig. 4. The data transmitted is shown in (a) and Throughput in (b).

the certain chain through matrix of the Markov Model. The proposed CDC transmits 3.51MB due to the availability of reliable channels from the main tree maintained at the CBS to allocate to the requesting SU.

Fig. 4(b) illustrates average throughput achieved through the utilization of channels by the SUs. It has been observed that initially more channels are available to be used by SUs which results in higher throughput which decreases by the passage of time. Results show that the instantaneous approaches consume an average bandwidth of 5.94 Mbps on all channels which is less due to less chances for the availability of reliable channels. The hybrid approaches consume 7.64 Mbps and 8.67 Mbps bandwidth for P2 and P1 which is better than INS. These approaches predict next or previous state of the channels. The proposed approach achieves average bandwidth of 9.96 Mbps on all the available channels that are more reliable due to maintaining a tree of reliable channels on real time.

5.3. Packet loss ratio and the count of requests

In existing approaches, SU tries to find a spectrum hole and sends packets to any particular channel. In this context, SU keeps on sending the packets until access the free channel. Fig. 5(a) elucidates the packet loss ratio by dividing the packets successfully received and the total packets sent. At instance of time = 11 s, the packet loss ratio is 90.9 %, 90 % and 91.6 % for any 03 channels like INS-CH 1, 2 and 3, respectively. In this case, the SUs access the channels by sending multiple requests instantaneously where most of the packets are dropped unless the channel is available to transmit the packets sent by SUs. In case of hybrid schemes, the loss ratio is 75 % at the same time interval. It raises due to the fact that the expected available channel is selected on the basis of the probability to send the requests. In most of the cases, free channel cannot be ensured on the basis of the expected probability which was calculated based on the history of utilizing a certain channel by the PU which may differ in actual. In the proposed approach, when SU acquires any channel, it sends a single Channel Acquire packet to CBS, and CBS in response sends back the Channel ACK or Channel Offer packet with a zero percent loss rate. Each packet will be responded by the CBS to either assign the channel or send a reply when the channel any of the channel is available as per the state of that channel maintained in the central tree. The Fig. 5(b) elucidates the number of requests sent to avail a certain channel by the SU. The comparative analysis is shown for the channel accessibility as per the requested parameters. The SUs attempted to access these channel on their own in several requests to sense the availability of channels. Results show the varying behavior as per the availability of the channel from the PU. In cases where the time elapsed is 11 s, the number of requests attempted are 11, 10, and 12 requests in an instantaneous approach for any 03 channels like 1, 2, and 3, respectively. It consumes more requests to sense the availability of the channel time to time. On average, the total number of requests during the 19 s were 9.473, 9.789 and 10.736 for accessing these selected channels 1, 2 and 3. In most of the cases, the channel 3 is mostly availed later in contrast to other channels. The hybrid P1 and P2 approaches consumes 4 requests at an instance of time = 11 whereas the proposed CDC dominates by taking only two requests received at CBS to avail the channels by these users with an average access rate of 3.842 and 1.789,



(a) (b)

Fig. 5. The packet loss ratio is shown in (a) and total requests to avail a channel in (b).

respectively. The hybrid approach maintains a table of probability for PU's availability and the expected state.

6. Conclusion

In this work, the CBS based approach is used to centrally handle the tasks and manage the operations. In this work, the CBS maintains a tree for the available channels to allocate to SUs as per the authenticated users list. This work enhances the role of CBS to cross check the utilization of the assigned channels as per the requested parameters and save the details for analysis as given in proposed algorithm. To validate the tree of currently working SUs, this work enables the CBS to monitor the authentic users and identifies their usage of channel against the asking parameter. The CBS can block the access of these channels by the SUs. In our approach, there is no need to sense the channel repeatedly by the SUs. This work is validated through extensive simulations in network simulator where TCL is used for node deployment and message initiation. For message sending pattern and tree-base functionality, C language is used. The results are extracted from the trace files by using the AWK scripts. Results show that the average throughput is 5.94, 7.64, 8.67 and 9.96 Mbps in case of INS, Hybrid-P1, Hybrid-P2 and the proposed CDC. The INS approach suffers with degradation as the detection rate is 68 % in case of 12 SUs whereas the Hybrid-P1 and Hybrid-P2 and CDC achieve 75 %, 82 % and 91 %, respectively.

Challenges and future prospective

The main challenge of this work is that the throughput may be effected due to channel switching where the SU doesn't stop transmission due to the sudden movement of PU. In future, this work will be extended to analyze more sensing techniques to create tree of channels with movement information of PU and finding the exact periods of PU arrival and departure on a particular channel.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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