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Priority-based reserved spectrum allocation by multi-agent through reinforcement learning in cognitive radio network

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ABSTRACT

Research in cognitive radio networks aims at maximized spectrum utilization by giving access to increased users with the help of dynamic spectrum allocation policy. The unknown and rapid dynamic nature of the radio environment makes the decision making and optimized resource allocation to be a challenging one. In order to support dynamic spectrum allocation, intelligence is needed to be incorporated in the cognitive system to study the environment parameters, internal state, and operating behaviour of the radio and based on which decisions need to be made for the allocation of under-utilized spectrum. A novel priority-based reserved allocation method with a multi-agent system is proposed for spectrum allocation. The multi-agent system performs the task of gathering environmental artefacts used for decision making to give the best of effort service in this adaptive communication.

KEYWORDS
Spectrum allocation policy; multi-agent system; machine learning; cognitive radio network; priority-based reservation

1. Introduction

In the emerging communication era, it is very hard to get radio spectrum resources for wireless transmission, which is limited and highly expensive. Resources should not be wasted and they have to be utilized with the maximum of its capacity. Cognitive radio networks (CRNs) [1] termed adaptive wireless radio networks use several technologies like orthogonal frequency-division multiple access (OFDMA), antenna arrays, and so on. CRNs [2] along with software-defined radio (SDR) fine-tune automatically its operation to accomplish the desired goal of resource allocation of licensed primary user's (PU's) unused spectrum to the unlicensed secondary user (SU). SDR [3] is a kind of communication technology in which the systems are very much aware of the dynamic states and environment and will be able to make decisions based on the predefined goals and radio operating environment. Cognition cycle is classified to be operating in different stages of spectrum sensing, spectrum detection, spectrum allocation, and management. The spectrum-sensing phase identifies the unused primary channels by periodically detecting the radio environment applying any spectrum-sensing algorithm [4,5]. Different signal detection techniques include matched filter detection [6], energy detection [7], wavelet detection [8], and cyclostationary detection [9]. Spectrum allocation is not fixed allocation nowadays; the problem with this fixed allocation is that either it is partially utilized or it remains ideal for most of the time. Dynamic spectrum allocation would be a proper solution. Just with the raw information available if the spectrum is allocated dynamically can lead to improper allocation. Therefore, if the system has the capability to make decisions with assisted expert advice, along with raw information, that would yield a good result of maximized spectrum allocation without disturbing the PUs' network access. Thus, the system should be constructed with intelligence using machine learning.

2. Related works

2.1. Artificial intelligence

Artificial intelligence (AI) can be defined as "the art of creating machines which perform functions that require intelligence when performed by people" [10] and "the branch of computer science that is concerned with the automation of intelligent behavior" [11]. AI techniques like fuzzy logic machine learning, neural networks (NNs), etc. are applied in various fields of engineering in developing games and robots [12].

Machine learning can be assimilated in the CRN to develop intelligence and knowledge in a wireless system; challenges, implementation, and applications of AI in CRNs are presented by Abbas et al. [13].

Cognition cycle is a continuous process during which its radio operating parameters can be observed periodically and adjusts system parameters based on the observed results to take right decisions on the right time to ensure optimized resource utilization.

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A learning scheme that predicts the capabilities of radio environment using NNs is designed and evaluated to exploit the radio resources for maximized utilization and the benchmark is set for NN-based learning schemes [14].

Multi-agent systems are defined as the hardware or software unit; solving problems through assisted knowledge is termed to be AI. An agent is considered as a task accomplisher with the definite goal to be achieved, equipped with all necessary skills, resources, and knowledge. To address the complex problem, a multi-agent system is created. Complex problems are divided as subtasks and assigned to different agents; these multi-agents need to collaborate among themselves to accomplish the goal that cannot be achieved with the single agent. Each agent is assigned with an individual goal, roles, responsibility, and resources required.

2.2. Reinforcement learning

Reinforcement learning (RL) is the AI technique that supports the multi-agent system by helping the agent to study the environment and take decision on a trial-and-error basis, to maximize the rewards by minimizing the errors. The RL model is based on certain parameters like environment condition, actions, policies for the transition between states, reward of transition rules, and agent observation policy [15,16].

Yau [16] proposed a static and centralized network that uses RL to configure the complete cognition cycle, based on the PU utilization, QoS levels, and packet error rate; dynamic channel ranking is done with the help of RL at the SU level while reducing delays.

Arunthavanathan et al. [17] uses the RL method to assist in selecting the channel for route finding algorithm of a multi-hop network. The channel selection is based on the agent that has got the highest reward points. The agents acquire rewards based on the decisions through RL.

The author of [18] defines a Markov model with SUs assigned with two priorities of handoff probability and dropping probability which demonstrate the enhanced system performance with the new scheme.

To enhance the CRN quality, the author of [19] uses Modulation techniques to differentiate throughput between the two applications – e-mail and video, modulation techniques such as 64-QAM, 16-QAM and QPSK are compared.

3. Proposed methodology

A novel spectrum allocation algorithm is proposed which fulfils the cognition cycle of spectrum sensing assisted by reinforced learning. Spectrum sharing is done through the multiple agents deployed in every node with the goal of data acquisition about the radio environment and parameter/status collected and stored in the repository. The spectrum allocation is carried out with the new algorithm and policy assisted by the AI incorporated in agents to take proper decisions with respect to resource allocation and spectrum management. The proposed system is constituted by different components at different stages, which includes spectrum sensors, a repository, a decision support system (DSS), a policy reasoner, and an RF module. Figure 1 shows an architecture diagram of the intended system.

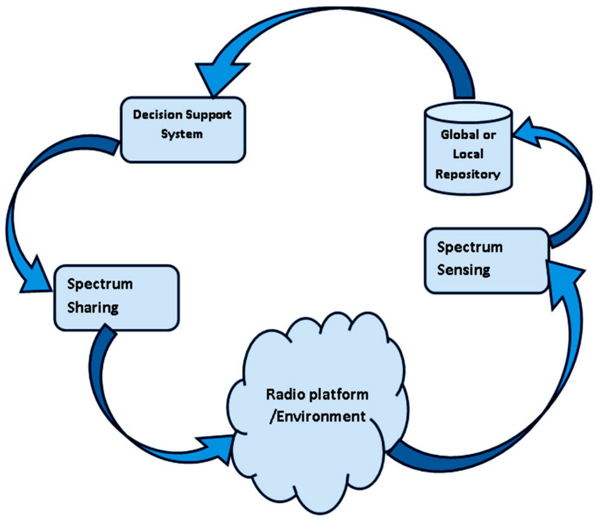

Figure 1. Priority-based reserved allocation system.

The spectrum sensors: The sensor's main task is to scan the radio environment for free available channels that are not used by PUs and also the channels that are sparingly used. This may even use any sensing methods available. It is suggested that any machine learning techniques can also be used.

Radio frequency (RF): The RF module is responsible for signal transmission (sending and receiving) over the channels and includes modulation, coding technique, error handling, and protocol.

Decision support system: In the intended system, SWARM multi-agent system is software deployed into all the user nodes for achieving specific objectives of gathering the required parameters, sending it to the repository, learning the environment, and coordinating with other nodes in deciding on spectrum access. The characteristics of the agent are autonomy, solidarity, expandability, resilience, and awareness. The agents are programmed to be aware of their environment through reinforced learning. They have to be equipped with the intelligence to make decisions of its own, have to be designed to achieve the desired task assigned to it, and have to be programmed to look for a new task on completion of its own task.

In PUs, the main task of a swarm agent is to collect the information like channel occupancy rate, channel utilization, PUs' behaviour that is when the PUs occupy the channel, when they leave the network, frequency of channel access, BER, transmitting power, bandwidth, data rate, etc. It relays the information gathered to the repository. In SUs, the objective of the swarm agent is to accumulate the information such as how much capacity is required for communication, QoS parameters like SNR, and data rates and then send this information to the repository and place a request for channel for transmission. DSS now decides the spectrum allocation based on the policy applied through the policy reasoner and the repository by applying the algorithm and implementing the same through the multi-agents.

Repository module is a data store, where the detailed characteristics of the sensed channel information are stored. The information gathered by the swarm agent across several nodes or channels is stored to support decision-making.

The DSS helps in optimized allocation of the resource by employing the strategy/policy along with the raw data available in the repository through a query-based system. The request from the SUs with the required QoS parameter has to be considered by the DSS. Along with the gathered information, SU's request, and policy reasoned, it will be able to arrive at optimized allocation of resources.

3.1. Decision making

The DSS is implemented with the policy and studies the environment through the multi-agent RL method, and the decision of the spectrum is based on the priority algorithm.

The DSS is implemented with multi-agent RL, and the decision of DSA is based on the policy and priority-based algorithm.

The policy can be expressed as a state, $s \in S\{s_0, s_1, s_2, s_3, \ldots s_n\}$, and an action $a \in A\{a_1, a_2, a_3, \ldots a_n\}$ with permissible policy $\pi: S \to A$.

The policy is a set of rules or parameters based on which the agent will take decision or control the environment. It can be a fixed one and can also be a combination of any of the following parameters. The author of [7] defines the policy to be: (1) Identify the nodes based on the IP address. (2) Transmission is encouraged if the location is 30 miles away from the location coordinates of 39 10′ 30″ N, 75 01′ 42″. (3) Transmission (time) is to be denied during 8.00–10.00 of local time. (4) Frequency band for transmission is restricted to be in the range of 5180–5250 MHz. (5) Allow transmission only if no power sensed on the RF 80 dBm. The main task of the swarm agent is to gather the information and to judge on the proper channel allocated for the SUs requested QoS through the priority-based reserved allocation algorithm.

3.2. Priority-based reserved allocation algorithm

The proposed algorithm aims at transmission of different data types like text, audio, image, and video. The algorithm has the policy of reserving channels based on the priority. The highest priority is given to video data that need the highest channel capacity. Data of higher data rate for highly demanding QoS by the SUs. That means less required SUs are not allocated with high data rate channels. The text data will demand channel of a lower data rate whereas video or image data may consume channel with a higher data rate. Allocating a higher capacity channel for text data type again leads to wastage of resources. By this algorithm, channel with low data rate will always be allocated for SUs that demand less QoS. Having in mind that if a higher capacity channel is used to transmit low demanding text data, again it leads to less channel occupancy ration and under-utilization of the channel. If the basic channel sensing algorithm is used, it checks for the channel occupancy which leads to misinterpretation of channel estimation. With the help of reinforced learning and by applying priority-based reserved allocation algorithm, suitable channels for suited data can be allocated on the right time for proper utilization of resources.

Rp is assumed to be a repository data store, which is defined using an array of structures. Each subscripted variable stores characteristics of PU that are gathered by MAS. PUi–Rp$\{0, 1, 2 \ldots n\}$ n no. of parameters of different data types, in which each defines QoS of Sui–Rs$\{0, 1, 2 \ldots m\}$ m no. of parameters of different data types.

The following are parameters required for the proposed PBRA algorithm for channel allocation.

Parameters of a Secondary User
Rs_1 – IP to identify SU.
Rs_2 – Type of data (e.g. Txt, avi, bmp, jpeg, psd, mp3, mp4, flv, mvi)
Rs_3 – Size if the data need to be transferred

Parameters of a Primary User
Rp_1 – Channel Id
Rp_2 – Capacity
Rp_3 – Time of occupancy of Pus
Rp_4 – Duration for channel free of transmission
Flag
RRi, mediate – Intermediate values for interchanging the values.

The Rp2 – is an array that holds the values of channel capacity of the PU in the network need to be sorted in sorted in ascending order. Based on the capacity of the channel the spectrum can be allocated to SUs. Following is a sample pseudo code for finding the best suited primary channel for SU with QoS requirement.

Scan the database for updated data periodically to find whether the PU resume it channel and to find free available channel. The following is pseudocode for channel allocation of secondary user with the requirement being text data. Similarly, code needs to be included for SUs requirement being Image, Audio, Video, other data with different priority.

```
int fragment[100], Rs3, Rp2,i,j,,lowest = 9999;
int flag [100], mediate, RR[100], Pn,Sm;
// The number of PU channel Pn;
// The number of SU requesting channel for Transmission Sm;
// Rp2 – Capacity;
// Rs3 –Size if the data need to be transferred;
for(i = 1;i < = Sm;i++) {
      for(j = 1;j < = Pn;j++) {
         if( flag[j]! = 1) {
            mediate = Rp2 [j]– Rs3 [i];
            if (mediate > = 0)
               if (lowest > mediate) {
                  RR[i] = j;
                  lowest = mediate;
               }
            }
         }
         excess[i] = lowest;
         flag[RR[i]] = 1;
         lowest = 10,000;
      }
         for(i = 1;i < = Sm && RR[i]! = 0;i++)
         return 0;
}
```

```
for i = 1 to m
      If Rs2 is of txt,
for j = 1 to n //Scan the repository that can accommodate data calculate
   channel
      data size = Rp2(j)/Rp3(j) //(calculation of how much data can be
   transmitted within the available duration)
if channel data size > = Rs3(i)
      allocate Rp1(j) to Rs1(i)
else
and correspondingly check the time of occupancy
calculate the time tx1 that channel is to be occupied for the data size of
   RS3
if Rp3 approximately equal choose Rpj for transmission allocate Rp1j for
   Rs1i else
next j
next i
```

4. Results and discussion

The system is simulated in the testbed of an NS3 simulator by creating the nodes and configuring them to be of PUs and SUs. The simulated system implements the above policy parameters, RL for the agent.

The efficiency of MAS is evaluated empirically using an evolutionary driven method. The simulated system result reveals the efficiency of the proposed system approach and the performance is shown through the graph. Figure 2 shows the graph of points plotted for the simulated values of SU and their corresponding network throughput simulated for both without MAS and with MAS. Through a decision support system, almost all the requesting SUs in the network will be allocated with available PUs channel that satisfies QoS, the throughput will be high.

The simulation shows the outperformance of throughput of the network with MAS over the system without MAS. The second parameter considered for assimilation network performance is access delay which is shown in Figure 3. The access delay is also reduced for the system with RL-assisted sensing rather than the system without RL assistance. Since the MAS allocation is assisted by Machine learning and PBRA algorithm the

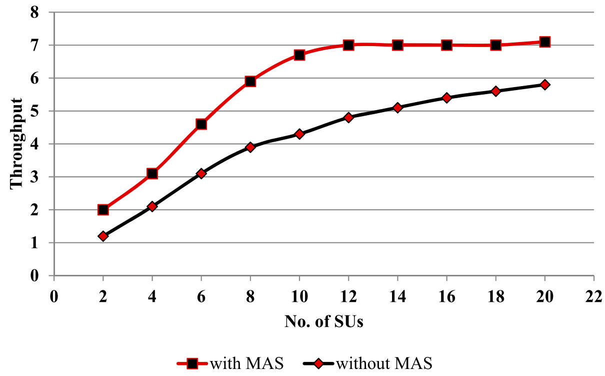

Figure 2. Secondary user vs. network throughput.

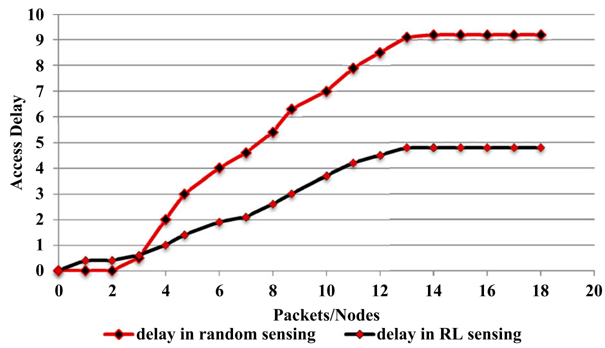

Figure 3. Access delay

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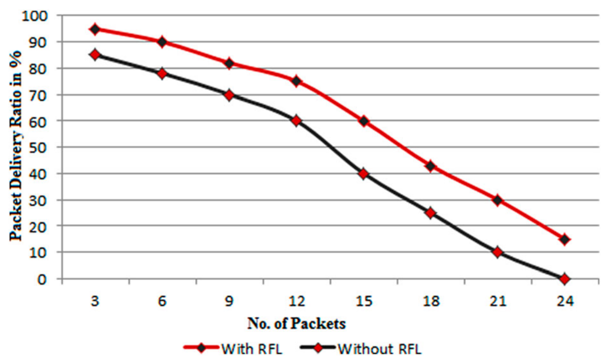

Figure 4. Packet delivery ratio.

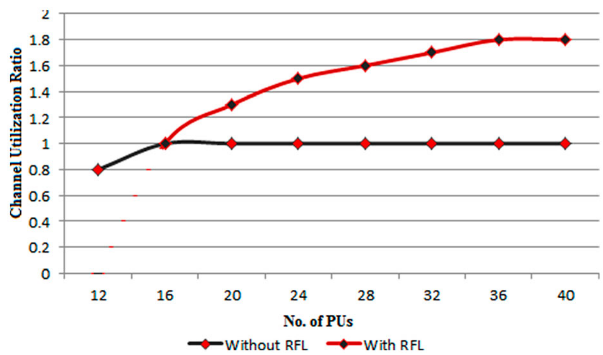

Figure 5. Channel utilization of Pus.

decision will be made faster and allocates the appropriate channel to SUs, the wait time to access the network (access delay) getsreduced.

Table 1. Comparison of Channel allocation techniques in CRN.

Approach	Type	Inference reduction (yes/no)	Routing handled (yes/no)	Multi-channel (yes/no)
Optimal path allocation	Distributed	Yes	Yes	No
Channel allocation algorithm	Distributed	Yes	No	Yes
Coin algorithm	Game Theory	Yes	No	Yes
Cognitive radio-based algorithm	Game Theory	No	No	No
Channel assignment algorithm	Multimedia model	No	No	Yes
Threshold-based algorithm	Multimedia model	No	Yes	Yes
PBRA	Artificial Intelligence	Yes	Yes	Yes

The performance of MAS-assisted CRN implemented with the priority-based reserved allocation algorithm is comparatively improved in packet delivery ratio shown in Figure 4. The throughput and Packet delivery ratio is directly proportional. PDR will also remain high only if the network is not overloaded or has no wireless link-related issues. The channel utilization which is shown in Figure 5 is also utilized to its maximum capacity. The underutilized channel of the PUs are identified through sensing and these channels will be allocated through priority-based reserved allocation algorithm and will be utilized to the maximum of its capacity.

The Niroshini Infantia [20] shows the comparison of several channel allocation algorithm and its performance as in Table 1.

Table 1 presents the comparison of channel allocation techniques in CRN. It analyses each work in terms of interference reduction, route handling and multichannel capability. Comparatively, PBRA is better than the other approaches.

5. Conclusion

To achieve the same objective of maximized spectrum utilization with the expert assistance, a novel approach of multi-agent systems along with RL has been used. Since the system is supported by AI which enables the nodes to make autonomous decision in choosing the proper channel and to switch between different channels, nodes equipped with all required information, stored in repository, are capable of making decisions faster and quicker. The simulation shows better results with maximized spectrum utilization. In future to make a decision faster the database can be implemented with the ontology. To enhance the performance, the ontology tree construction for the knowledge representation can be done as future work.

Disclosure statement

No potential conflict of interest was reported by the authors.

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