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Increasing the Trust Factor in Cognitive Radio Networks Driven by Software Defined Radio

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Abstract: ***A current network research trend in is the employment of high algorithmic ML tools such as Reinforcement Learning (RL) for analysis and adaptation to various network situations. The selection of a suitable radio channel in a Cognitive Radio wireless multi-channel spectrum, example 802.11 networks, with outside interference is one such situation. The objective of the agent learning the environment, or the pattern is to accurately predict an interference-free channel for the next slot i.e., the channel should not be scheduled for transmission by a primary user. For the scope of this paper, a case of external interference following and predicting a periodic pattern is considered for simulation. NS3 is the simulation platform on which the channel spectrum pattern is created. OpenAI Gym is an Artificial Intelligence toolkit for Reinforcement Learning (RL) research that enables agent-like simulation on NS3 modules. TensorFlow is used to provide libraries for the RL optimizer algorithm employed for emulating random RL input characteristics during channel selection per iteration. A basic reward arrangement (+1 for a correct prediction, -1 for interference) allows for the RL algorithm to learn from mistakes and improve the iteration performance. The results showcase the prediction success rate of the RL algorithm for predicting a free slot, as well as open new windows to RL analysis for network situations.***

Keywords: Reinforcement Learning, NS3, Open AI Gym, TensorFlow

1. Introduction

"Spectrum is the lifeblood of RF communication systems." [1] Radio communication without a usable spectrum is unimaginable. The value of the spectrum has been addressed in many significant papers. Each country also has a well-defined mechanism for assessment and management of spectrum, production of radio, and spectrum usage, along with the associated incomes. Some countries have also identified spectrum frequencies as publicly owned, treating it as a common resource to be shared by all. With a regulatory environment as regulated by the country, the spectrum must be used for the service that provides for the greatest public utility. As such the primary issue is to prioritize current utility needs and grant access to spectrum suitably matched to the most critical public needs (high value frequencies to short-medium range applications etc.) [2]

Cognitive radio is normally associated with enabling resourceful usage of spectrum frequencies. At the end node, cognitive features are realized in the form of awareness, learning, and frequency hopping abilities which are essential to identify and take advantage of opportunities of the spectrum. The spectrum frequency channel can be enabled with the ability to become free when the information transmission is ended, or when a higher priority primary user appears in the same spectrum frequency segment. Higher spectrum efficiency also indicates the users being able to have capacity for increased number of wireless users or devices operating within the same spectrum frequency segments without interfering with each other's communication. This coexistence ability which is interference-free can hence increase the potential number of nodes/subscribers in a CRN.[2]

Limited spectrum utilization is an ability, as is termed required, to facilitate the needed data exchange, or finding out a frequency of the spectrum which has a lower cost of usage. This ability may result in better added value to the spectrum user in the form of reduced costs in a pay-per-use spectrum market environment. [1] Availing of unlicensed spectrum frequencies for short-range, lower priority communication services can be planned properly. If the users are also interference-tolerant, it helps to reduce the demand for licensed spectrum frequency segments. This forms the crux of the problem addressed in this project.

Of late, there have been numerous attempts to develop the networking protocol operations using machine learning (ML) techniques including the above problem of spectrum sensing. Of these techniques, reinforcement learning (RL) based control solutions [3] are preferred because they offer higher performance and better efficiency vis-a-vis traditionally designed algorithms. To become skilled at the best policies, the RL control agent however requires a large interaction sampling with any simulated environment.

1.1 Cognitive Radio Spectrum Sensing

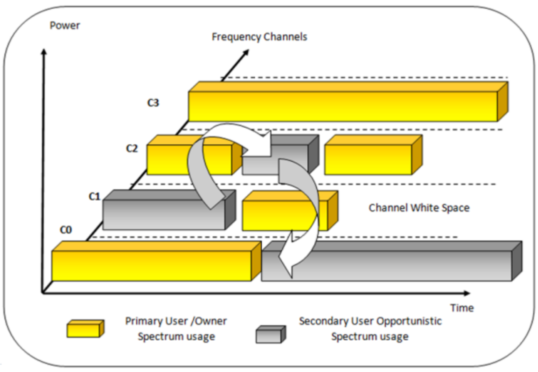

Figure 1: CR Spectrum Sensing

- Spectrum scarcity is one of the primary problems addressed by Cognitive Radio (CR) technology. [2] With rapid developments in wireless technologies and networks, there is a dire need of judicious usage of free spectrum. Apart from the licensed (primary) users, with this methodology, even unlicensed (secondary) users can utilize the spectrum.
- To increase spectrum utilization, allocation of spectrum frequencies is done dynamically in CRNs.
- The main functions of CR are sensing and sharing of the spectrum, decision on spectrum frequencies, and dynamic changes in spectrum frequencies
- Secondary users can conduct transmission in the unutilized spectrum (already assigned to primary users) by ensuring a lowered level of interference. They survey the spectrum frequency channels to find a free channel-slot and select the optimum path which meets the required Quality of Service (QoS) of the application. [2]
- The main function of sensing the spectrum is selection of the channel and detection of spectrum-hole.
- Higher the sensing time, the gathered data will be more accurate. But it is a trade-off with reduction in the time needed for transmission.
- In a co-operative sensing CRN, there is high understanding between the secondary users. This also helps in the decreasing the sensing time [4]

2. Existing System

Cognitive Radio Networks have been explored by many researchers, with the typical employment of ML and other mechanisms to detect white space in the spectrum. In typical simulation setups, complicated pattern matching systems are employed since they are easy to set up and require basic frequency detections to get measurements.[4][2] However, the key issue has always been improving the accuracy of these white space predictions in real-world scenarios, where the spectrum usage does not follow a specific pattern. With an increase in mobile devices, efficient spectrum usage becomes more important to accommodate interference-free communication amongst the devices [2]

2.1 Problem Statement

- Spectrum Hole sensing/prediction is of paramount importance to Secondary Users in a CR environment.
- The problem of radio channel selection in a wireless multi-channel environment, such as 802.11 networks, having an external interference in additional to channel blocks.
- RL optimization algorithms can help predict the occurrences of Spectrum White Space so that Channel can be effectively utilized.
- The objective of the agent is to select for the next time slot a channel free of interference considering a basic example where the external interference follows a periodic pattern, i.e., time-slice sweeping over all available channels.

2.2 Proposed System

The purpose of this research is to improve the accuracy of the spectrum white space selection employing RL algorithms. While using the RL algorithm, test it with a known pattern of spectrum usage, and observe the cumulative rewards gained by the algorithm to determine the learning curve.

2.3 System Architecture

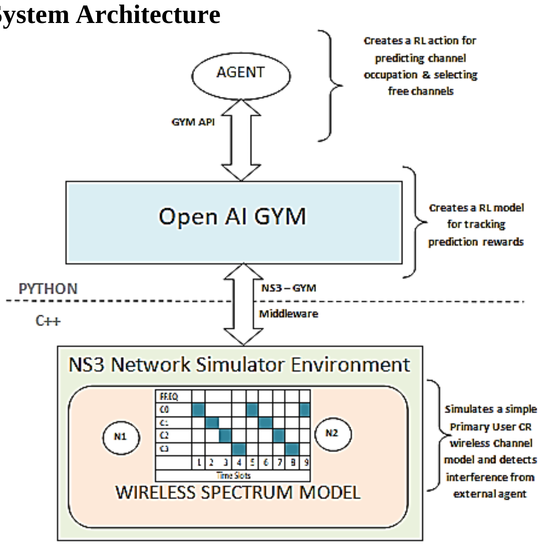

Figure 2: Project System Architecture

The system architecture of the work, as portrayed in Fig. 2, consists of two major components, namely: Open AI NS3-Gym framework and NS3 network simulator. The former is used to create required environment service, while the latter amalgamates their common interface [4].

Algorithm for agent:
1) Input: parameters of the policy
2) for (iterations)... action
3) for (actors)...action
4) Runwaveformgenerator for N steps
5) Compute improvements using fixed pattern
6) Optimize learning ability for maximum returns
7) end for

3. Implementation

3.1 Event mapping for RL algorithms

Mapping of RL events are as below:
- observation – activity on each frequency channel in the present time slot, i.e., band-sensing,
- actions — set the upcoming time niche to be employed for the channel,
- reward — In case of no interference with the primary user it is + 1; otherwise, -1,
- game over / done — if more than 3 interferences have occurred during the previous 10 timeslots.

Implementation of the work is involved of four stages as depicted in table 3. The first step was to import necessary libraries relevant onto the target machine. The second step was the creation of simulation in NS3 using the waveformGeneratorHelper [5] class provided with the C++

libraries. A spectrum set is thus created which adheres to a pattern within the 4 channels – C0, C1, C2, and C3. The third stage involves the development of the interference Agent in Python with both Actor-Critic and PPO RL algorithms to randomly initiate interference in the given pattern. The last stage involves the creation of reporting on the RL event statistics, again based on Python, and executing the algorithm for a run of 200 episodes.

Table 3: Implementation Workflow

Import NS3-GYM with NS3 base TensorFlow2 with Python3
Simulator WaveformGeneratorHelper built-in class to generate waveforms for a fixed pattern {0,1,2,3} Create 100 timeslots to predict channel availability for all slots
Interference Agent Python3 code cognitive agent (novel) RL Adaptive Moment Estimation

A typical episodic execution pattern is shown below in Fig 3

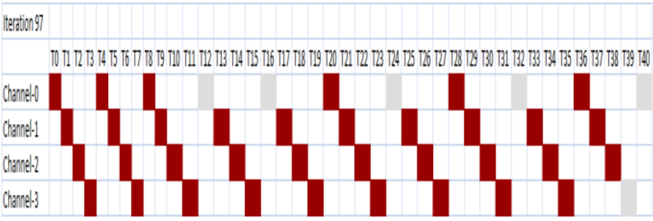

Figure 3: Episodic Execution Pattern

White spaces indicate free slot, while the dark spaces indicate occupied slots. The grey slots are the ones indicating the interferences.

4. Results

The output from each episode of the 200-episode run from both the algorithmic implementations is tracked and fed into excel reports based on Openpyxl [5] Python libraries.

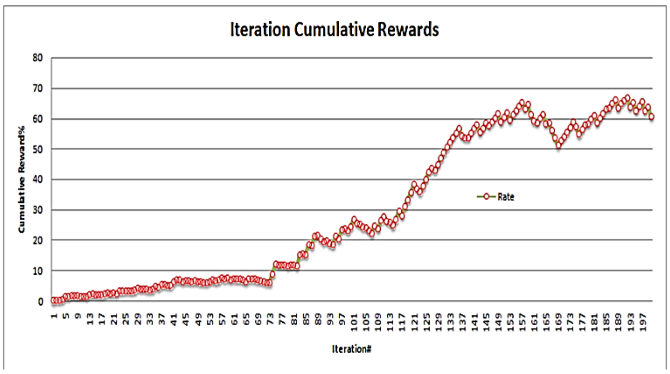

Chart 1: Cumulative Method

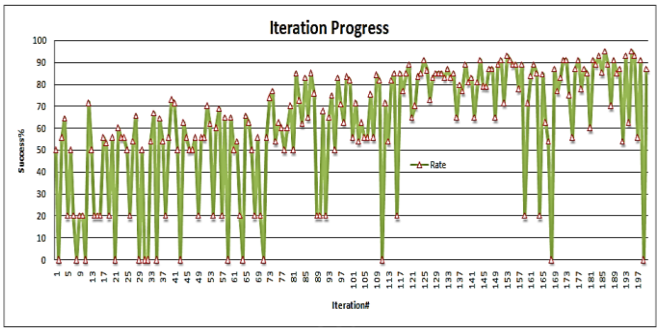

Figure 4: Episode success progress

Fig. 4 shows the learning performance of the algorithm employing the cumulative method. It is seen that after around 70 episodes, employing only its confined state results, the agent has ably trained to expect the conduct of the cyclic interferer and was able to appropriately choose the slot for the next time slot avoiding any interference. In Fig. 9 the episodic success percentage for all iterations is seen. The success rate has jumped from 30% to 80% over the 200 iterations.

After changing the learning parameters and optimizing the waveform generator:

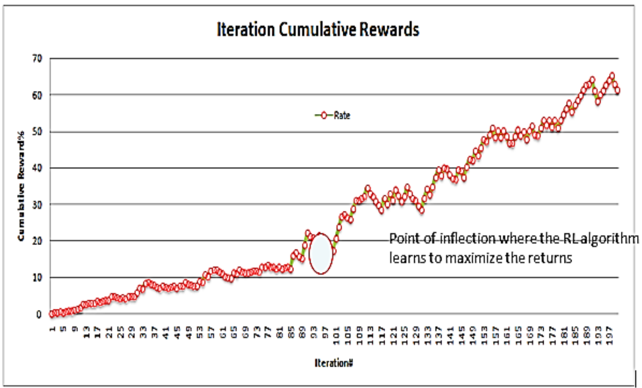

Chart 2: Cumulative Method after improving learning parameters of the agent.

Further the success of the optimization also improves each episodic event.

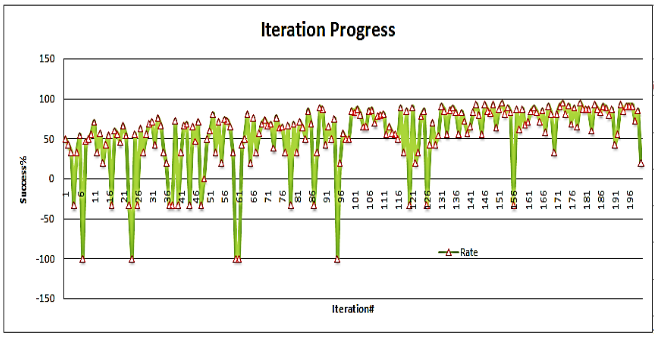

Figure 5: Episodic success percentage after optimization.

In contrast with the first method, with the optimized agent converges around 85-90 episodes. In Fig. 5 the episodic success% for all iterations has jumped from 40% to 90% over the 200 iterations; however, due to the random nature of the input, we also see negative success rates even after the 150-episode mark.

5. Conclusions

The employment of RL methodologies for approaching problems in the networking area is applied for the problem of Cognitive Radio Wideband Spectrum Selection and improves the trust factor between the participating nodes of any cognitive radio networks. This improvement is possible because of the software-controlled functionalities which can be implemented in any wireless communicating devices driven by SDR. This is achieved by connecting the Open AI Gym with the NS3 simulator [8]. As the framework is non-specific and the NS3 simulator can be upgraded, the toolkit can be used in a multitude of networking problems. It is observed that unification of state data of the previous K time-steps before conveying them to the agent can help reduce the agent's learning curve, i.e., with longer scrutiny, the agent can handle more dependencies in a single iteration.

As an extension, the CR transmitter can improve its learning methodologies to adapt to the interferer by conducting narrowband sensing [8]. Here, at any given instant, the agent can observe only the state conditions of the channel it is operating on. Thus, RL algorithms can be employed to learn the behavior of how the spectrum channels are being used by primary users and help train the secondary users to opt a collision-free channel for effective communication. For the future, the set of available environments in the NS3-Gym toolkit can be extended, which can be employed as a point of reference to different RL techniques.

References

[1] Dong, Qi, et al. "A Survey on Simulation Tools and Testbeds for Cognitive Radio Networks Study." arXiv preprint arXiv:1808.09858 (2018).
[2] Li, Yang, et al. "Spectrum usage prediction based on high-order markov model for cognitive radio networks." 2010 10th IEEE International Conference on Computer and Information Technology. IEEE, 2010.
[3] Gawłowicz, Piotr, and AnatolijZubow. "NS3 meets OpenAI gym: The playground for machine learning in networking research." Proceedings of the 22nd International ACM Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems. 2019.
[4] Stooke, Adam, and Pieter Abbeel. "Accelerated methods for deep reinforcement learning." arXiv preprint arXiv:1803.02811 (2018).
[5] Diederik P. Kingma and Jimmy Lei Ba "ADAM: A METHOD FOR STOCHASTIC OPTIMIZATION" (2015)
[6] Shalabh Bhatnagar, Richard Sutton, Mohammad Ghavamzadeh, Mark Lee. Natural Actor-Critic Algorithms. Automatica, Elsevier, 2009, 45 (11), ff10.1016/j.automatica.2009.07.008ff. ffhal-00840470
[7] "Cognitive Radio, Software Defined Radio, and Adaptive Wireless Systems", Springer Science and Business Media LLC, 2007

Author Profile

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