Article 5

Performance Evaluation of Dual Diversity Cognitive Ad-hoc Routing Protocol (D_2CARP) on Primary User (PU) Activation Time: A Simulation Approach

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Abstract
Cognitive Radio (CR) is known to solve spectrum scarcity that intent to improve spectrum utilization. In CR, secondary user (SU); also known as cognitive user need to ensure its transmission will not interfere primary user (PU) link. Link breakages among secondary users are due to PU activity that causing the degradation of network performance. Over the past decades, many routing protocol were developed for CR network. This paper focusses only on Dual Diversity Cognitive Ad-hoc Routing Protocol (D_2CARP) that jointly exploits path and spectrum diversity to provide multi-path and multi-channel solutions to SU. SU can switch to another channel or path if the current path breaks or the channel becomes unavailable. This project aims to provide a comparison network performance in different distributions running under the same routing protocol. The objectives of this project are to imitate a cognitive radio ad-hoc network using Network Simulator 2 (NS-2) and to create two scenarios in Exponential and Uniform distributions. The performance was analysed based on the percentage of packet drop, average packet delay and throughput. The results in both distributions show a slight difference. From the research, it can be concluded that D_2CARP is able to work well under random PU activation time as long as the SU number does not exceed the network capacity.

Keywords: *Cognitive radio ad-hoc network, routing protocol, primary user activation time.*

Introduction

Wireless technology requires electromagnetic spectrum to serve as their communication medium. Past studies by the Federal Communications Commission (FCC) stated spectrum bands allocated through fixed assignment policies are used only in bounded geographical areas or over limited periods of time which only results in between 15% and 85% spectrum utilization(Akyildiz, Lee, Vuran, & Mohanty, 2006). Another experiment by FCC also reveals that the spectrum usage is concentrated only on certain portions of the spectrum while a significant amount of the spectrum remains unutilized (Che-Aron, Abdalla, Abdullah, Hassan, & Rahman, 2015). Dynamic use of the spectrum bands in Cognitive Radio Ad-Hoc Networks (CRAHNs) create adverse effects on network performance if the same communication protocols which consider fixed frequency band are applied (Salim & Moh, 2013). In CRN, common scenarios that distinguish two types of users sharing the same portion of spectrum but implementing two different rules. Primary User is the licensed user that uses traditional wireless communication system. Whereas, the Cognitive User (CU) that equipped with CRs and exploits the Spectrum Opportunities (SOPs) to sustain their communication activities without interfering PUs (Cesana, Cuomo, & Ekici, 2010; Sengupta & Subbalakshmi, 2013).

Due to the decentralized infrastructure in CRAHNs, data routing encounters various challenges such as frequent topology changes, heterogeneous spectrum availability and intermittent connectivity caused by PUs activity. Most routing protocol did not jointly exploit the path and spectrum diversity. For examples, SEARCH routing protocol(K. R. . Chowdhury & Felice, 2009) is based on geographical forwarding and path and spectrum decision is made sequentially and not together while CRP routing protocol(K. R. Chowdhury & Akyildiz, 2011) selects the routing path in one preferred spectrum band only. A routing protocol should jointly exploit path and spectrum diversity to provide multi-channel and multi-path connection for SUs during the data transmission (Rahman, Caleffi, & Paura, 2012). D_2CARP routing protocol is the first protocol to jointly exploit path and spectrum diversity in 2012 and followed by FTCARP (Che-aron, Abdalla, Abdullah, & Md. Arafatur Rahman, 2014) and RACARP (Che-Aron, Abdalla, Abdullah, Hassan, & Rahman, 2015)routing protocol. Since D_2CARPis a new routing protocol, its performance in various condition such as random PU activation time remains unknown.

This project aims to provide a comparison network performance in two different distributions running under the same routing protocol. Hence, simulation on CRAHNs had been set up in Network Simulator 2 (NS-2) using D_2CARP routing protocol. The rest of the paper is organized as follows. Next section discusses related work. It follows with simulation methodology, experimental evaluation and finally the conclusion.

Related Works

Joseph Mitola(2000)introduced the term Cognitive Radio (CR) with the aim to employ underutilized spectrum in an opportunistic manner (Mansoor, Islam, Zareei, Baharun, & Komaki, 2014). Devices with cognitive capabilities can create CR network (CRN) as they can sense a wide spectrum range, dynamically discover currently unused spectrum blocks for data communication and intelligently access the unoccupied spectrum SOP (Cesana, Cuomo, & Ekici, 2011). They can change their transmitting parameters according to their surroundings. Hence, in the paradigm of CRAHNs, CUs can communicate with each other in an ad hoc manner through both licensed and unlicensed spectrum bands without relying on any pre-existing network infrastructure and in a non-intrusive manner to the licensed users(Che-aron et al., 2014).

There are many performance metrics used to measure network performance such as end-to-end delay, packet loss and throughput. D_2CARP measured packet delivery ratio (PDR), overhead, delay and hop count as the network performance metrics. Backup Channel and Cooperative Channel Switching (BCCCS) use channel interference(Zeeshan, Manzoor, & Qadir, 2010) while Local Rerouting and Channel Recovery (LRCR) also use network throughput as network performance metric (Tseng & Chung, 2013).
Generator and seed are used to create random values in NS-2. If the seed is set to zero, the values generated will be totally random but if the seed is other than zero, the values generated will be based on the seed. Seed is the number vector used to initialize the random number generator. The values are generated based on its distribution type and there are five types of distribution in NS-2. They are Pareto, Constant, Uniform, Exponential and Hyper Exponential (Eitan& Jimenez, 2003). This project focused only two types of distribution Exponential and Uniform distribution to generate random PU activation time. Uniform distribution is defined through the minimum and maximum point configured while Exponential distribution is defined by its average value.

Simulation Methodology

The initial step was installing NS-2.34 on Fedora 20. Then, need to apply the required patches, which are multi-channel and D^2CARP patch in order to implement D_2CARP in NS-2. This project simulate the mentioned routing protocol under a random PU activation time by using Exponential and Uniform distribution to create two conditions; where PU is active at random time and PU is active at all the time during simulation. The network performances metric used in this project are packet delay, packet dropped and throughput. Packet delay is defined as time taken by packets to be delivered across the network from source to destination, while packet dropped means amount of packet dropped or lost between the time link failure occurs to the time a new transmission route exists. The throughput is the ratio of the total amount of packet successfully received by destination before the packet delivery time expires.

Scenarios in this project were adopted from (Md Arafatur Rahman, 2013) and the simulation parameter were summarized in Table 1.

Table 1: Simulation parameter

No.	Parameter Name	Value
1.	Simulation Area	1000m × 1000m
2.	Simulation Time	400 seconds
3.	Number of PUs	10
4.	Number of SUs	50
5.	Number of channel	4
6.	PU transmission range	150m
7.	SU transmission range	150m
8.	Mobility model	Random Way-Point model
9.	Traffic type	CBR
10.	Packet size	512 bytes
11.	Data packet interval	50ms
12.	Transport layer	UDP
13.	Checking interval for channel used by PUs	Every 5 seconds
14.	Data transmitting start time	60 seconds
15.	PU active time	100 seconds

The study was conducted in a simulation area of 1000m × 1000m. The simulation time was set to 400 seconds and channel number was set to 4. The number of PU was 10 while SU number was set to 50. Transmission range of both PUs and SUs was 150m and SU mobility model was set to Random Way-Point model.The traffic load was set as Constant Bit Rate (CBR) with 512 bytes of packet size sent every 50ms over UDP connection. SUs detection for channel used by PU's was set to every 5 seconds. Nodes started sending the packets when 60 seconds elapsed during the simulation.

Experiments setup

This project simulates three experiments with two scenarios in each experiment. Each experiment differs in terms of channel number, PU number and SU number. The first scenario uses the

Exponential distribution while the second scenario use Uniform distribution. The first experiment involved increasing the number of channels available from 2 to 10 while the number of primary and secondary users was fixed to 10 and 50 respectively. The second experiment was created with different number of primary users ranging from 2 to 18 with the number of secondary users and number of channel became a constant variable. In the third experiment, secondary users became the manipulative variable with its number increased from 20 to 100 while primary users' number and number of channels became the fixed variables. With two scenarios in each experiment, the total scenarios for this project are six. Table 2 shows the experiment setup in table form. The scenario that starts with the letter 'E' means the scenario uses Exponential distribution while for the letter 'U'indicates the scenarios are using Uniform distribution. The experiments were repeated for three times and average values were acquired.

Table 2: Experiment Setup

Experiment	**Description**	**Exponential Distribution**	**Uniform Distribution**
1	Increasing number of channels	Scenario E1	Scenario U4
2	Increasing PU numbers	Scenario E2	Scenario U5
3	Increasing SU numbers	Scenario E3	Scenario U6

Results and Analysis

Experiments result is summarized in Table 3 below. Packet drop is the highest during scenario E3 which is 71.71221 % because SU numbers were incremented. During scenario E2, PU activation time is totally random and PU number and channel is set to 10 and 4 respectively. Packet drop was the highest for this scenario because channel available is not enough to support SU data transmission. For scenario U6, which also varies in SU numbers but the PU is constantly active all the time during the simulation; the packet drop is 60%.

Table 3: Experiment results

Scenario	Packet drop (%)	Packet delay (s)	Throughput (Kb/s)
E1	58.23641	1.577101	88.4
E2	63.02444	1.704249	68.33333
E3	71.71221	1.94233	57
U4	43.93694	1.519863	111
U5	50.71405	1.958137	92.55556
U6	60.58961	2.414777	77.4

This indicates extending SU numbers more than the network capacity lead to higher packet drop. The network performance between different PU activation time distribution shows small deviation. D_2CARPis able to work well under random PU activation time because the scenarios show same pattern of network performance regardless of the PU activation time. Figure 1 shows packet drop results across scenario in graphical form.

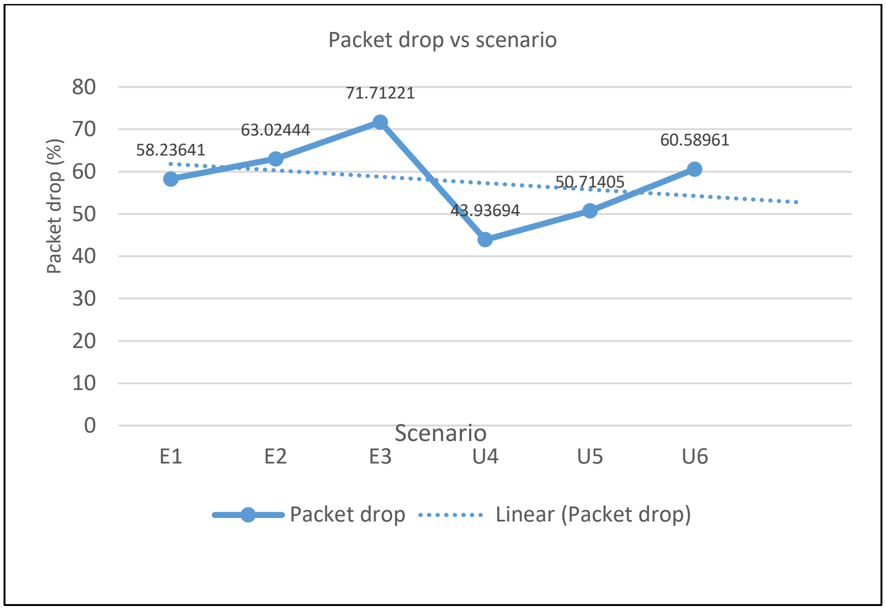

Figure 1: Packet drop vs scenarios

Packet drop for Exponential and Uniform distribution shows same pattern across the scenarios with the highest packet drop achieved was when SU number was increased in scenario E3 and U6. Figure 2 below shows packet delay in all scenarios in graphical representation. Scenario E1 to E3 uses Exponential distribution while scenario U4 to U6 uses Uniform distribution. Although the values are not the same for both distributions, it can be seen that both distribution have the same packet delay pattern across the scenarios.

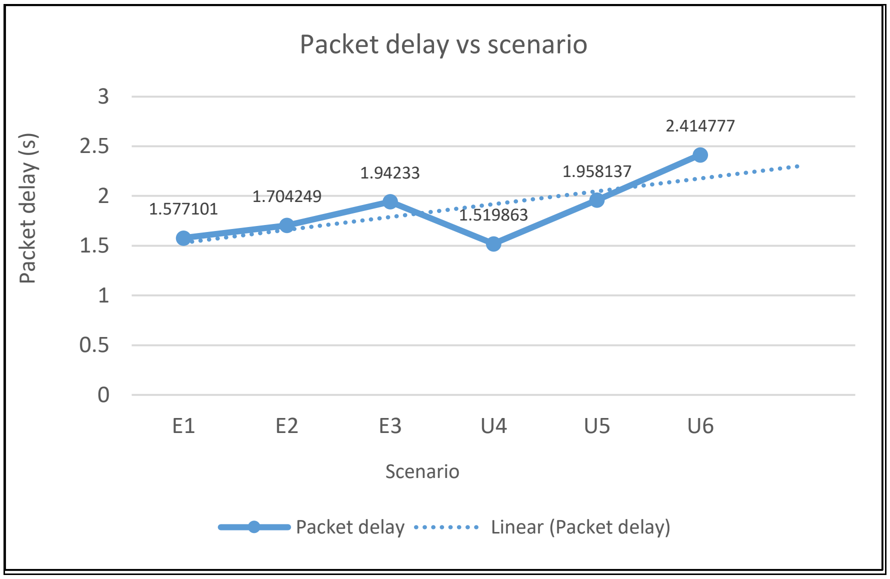

Figure 2: Packet delay vs scenarios

The highest delay achieved is in scenario U6 when SU numbers was increased and the PU is active all the time during the simulation. Scenario E3, which also involves varying SU numbers achieved an average of 1.94233 seconds of packet delay. This is because in scenario U6, the PU is active all the time while for scenario E3, the PU is set to be active at a random time. The smallest average packet delay is identified in scenario U4 and followed by scenario E1, which varies the channel numbers. The difference in average packet delay of scenario E3 and U6 is relatively small. Packet delay results also show the same pattern in both distributions. Figure 3 shows the network throughput across all scenarios in graphical form.

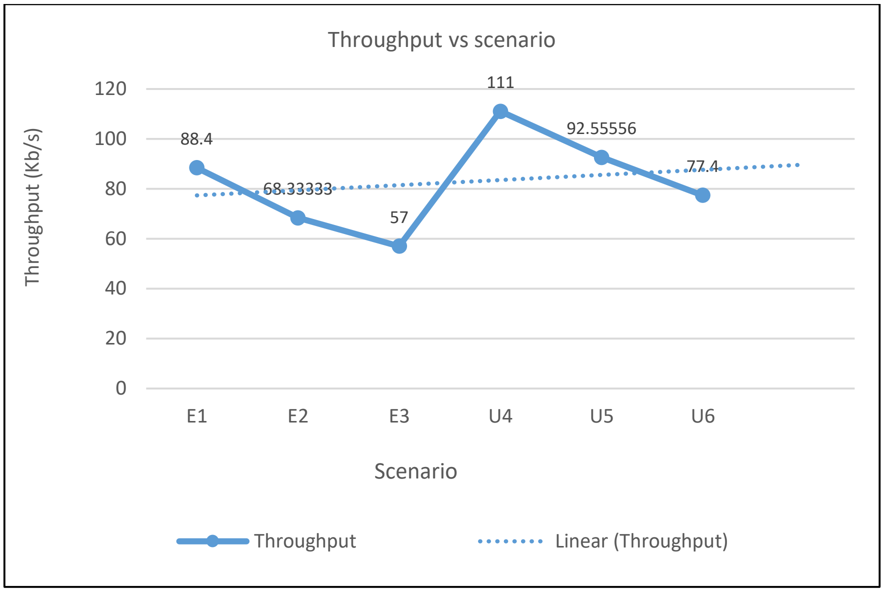

Figure 3: Throughput vs scenarios

Network throughput is the highest in scenario U4 because the scenario involves increasing the number of channels. Scenario E1 shows the second highest throughput because it also involves increasing channel number. The difference between scenario E1 and U4 is their PU activation time.

Discussion

Based on network throughput, D_2CARP has the capabilities to serve SU data transmission regardless of the PU activation time. Network throughput shows lower values when SU numbers was increased. Scenario U6 has the lower network throughput because SU has to compete with each other for idle channels and the PU is active all the time during the simulation. Packet drop is high when SU number exceeds the network capacity which is in scenario E3 and U6. Network throughput increase when the number of channel increased in scenario E1 and U4. The lowest percentage difference of packet drop achieved was 11.71 % in Experiment 3 and the shortest delay difference in both distributions was achieved in Experiment 1 which is 0.05 seconds. Highest throughput was achieved in Experiment 1 which was 111 Kb/s.

Conclusion

This paper has simulated two different distributions under random PU activity in D_2CARP routing protocol. The simulation from the two distributions: Uniform and Exponential are simulated against six scenarios based on packet drop, packet delay and throughput. As discussed in the earlier section, the network performance difference in both distributions shows small values and they also show similar network performance pattern across the simulation scenarios. It can be assumed that PU activation time has little effect to the network performance. In conclusion, D_2CARP is affirmed to work well under random PU activation time regardless of the scenario and condition created.

Acknowledgements
We would like to thank Assoc. Prof. Dr. Arafatur Rahman for assistance with the simulation methodology and helpful suggestions.

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