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Research paper

Reduction in Path Failures by Adopting Multi-Channel Multi -Path in Routing For Dynamic Activity of Primary Users

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Abstract

The Cognitive radio (CR) expertise has been recently proposed to deal with the spectrum shortage problem resulted by inappropriate spectrum supervision policies by enabling unauthorized users to use the authorized spectrum band in opportunistic and non-intrusive vigilant approach. In CRAHNs, the data routing is one of the main challenge as the channel accessibility and the activity of primary users are unpredictable. In this article, a new algorithm is proposed which counteracts the problem of path failure by adopting multi-channel multi-path reverse route for RREP packets. The protocol utilizes the hybrid of path and spectrum diversity techniques in routing. The performance assessment is conducted through simulation using the NS-2 simulator. The performance of the proposed protocol is compared with CAODV and D2CARP protocols in terms of packet delivery ratio, average energy, end-to-end delay, throughput, overhead and hop-count. The simulation consequences prove that the proposed protocol do better than CAODV and D2CARP in terms of the above mentioned performance metrics.

Keywords: *CR, CAODV, D2CARP, PU, SU, CU.*

1. Introduction

The Cognitive Radio (CR) has been identified as the enabling technology of the Dynamic Spectrum Access (DSA) paradigm due to its inherent capabilities of sensing the surrounding radio environment. This imposes the development of Cognitive Radio Networks (CRNs) to improve spectrum efficiency. Joseph Mitola first proposed the concept of cognitive radio which can enhance the personal wireless service by a Radio Knowledge Representation Language (RKRL).

The Federal Communications Commission (FCC) has defined cognitive radio as: "A cognitive radio is a radio that can change its transmitter parameters based on interaction with the environment in which it operates."

Another definition of cognitive radio is given by S. Haykin in his paper [1]: "Cognitive radio is an intelligent wireless communication system that is aware of its surrounding environment (i.e. outside world), and uses the methodology of understanding-by-building to learn from the environment and adapt its internal states to statistical variations in the incoming radio frequency stimuli by making corresponding changes in certain operating parameters (e.g., transmit power; carrier frequency, and modulation strategy) in real-time, with two primary objectives in mind: (i) highly reliable communication whenever and wherever needed and (ii) efficient utilization of the radio spectrum."

The CRAHN is composed of wireless nodes communicating in a peer to peer fashion without infrastructure support and is characterized by self-configuring architecture. In CRAHN, the cognitive radio technology enables the network to utilize the spectrum band in an opportunistic fashion without interfering to primary users. The available spectrum bands are distributed over the complete frequency range that varies in space and time. Therefore, every user shows diverse spectrum availability according to the activities of PU. The PU transmission is protected from the SUs, so that the licensed user communication is not affected by the presence of SUs. In CRAHN, the topology information is incomplete which results in the increased collision between CUs and interfere the PUs communication too. It does not uses a fixed end-to-end routes due to the uncertain nature of PU activity. The end-to-end QoS requirements depend on the PU activity statistics and number of spectrum bands.

Cognitive Radio is considered as the enabling technology of the Dynamic Spectrum Access (DSA) paradigm which is envisaged to solve the spectrum scarcity problem, thus facilitating the accommodation of new wireless services as well as providing an effective solution to the ever increasing user demand. To realize ubiquitous spectrum-aware communication, the CR devices need to incorporate the functionalities of spectrum sensing, spectrum decision, spectrum sharing and spectrum mobility. The CRAHNs suffer various routing issues due to mobility of nodes, energy restraint, dynamic spectrum availability and absence of any centralized infrastructure support.

The article strongly advocates the hybrid approach scheme that can counteract the performance degradation experienced by CUs due to the activity of frequency and space varying PUs. The proposed protocol uses the concept of multi-channel multi-path reverse routes for the RREP packets which results in lesser number of packet drops during mobility of the nodes and presence of PU activity.

In this article, a new concept of multi-path multi-channel reverse route is introduced that exploits the path and spectrum diversity simultaneously that offers efficient route recovery process when a link failure occurs in the network. The main aim of this protocol is to reduce the path failures due to PU activity and achieves better result in terms of packet delivery ratio, average throughput,

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end-to-end delay, average hop-counts, overhead and average energy.

2. Motivation

The goal of this section is described in two folds:

- To present the impact of PU activity on routing when it varies in space and frequency domain.
- To present the benefits of multi-channel multi-path for reverse routes in CRAHNs.

Most of the recently proposed routing protocols for CRAHNs do not utilize diversity technique, while only some proposals have resorted to spectrum or path diversity techniques. Thus, there is a need to develop an efficient routing algorithm that can take into account the path and spectrum diversity techniques and improves the reliability of transmission by reducing the link failures and increases the packet delivery ratio. The different types of diversity techniques are explained below:

- Path Diversity Technique: If the activity of PU varies in space then the CUs switch dynamically over different paths that allows CUs to use the available paths for communication purposes. The path diversity cannot hold good when the activity of PU varies in frequency domain.
- Spectrum Diversity Technique: If the activity of PU varies in frequency domain then the CUs switch dynamically over different channel that allows CUs to use the available channels for communication purposes. The spectrum diversity cannot hold good when the activity of PU varies in space domain.
- Dual Diversity Technique: The path cannot counteract the activity of PU when it changes in frequency domain, while the spectrum diversity cannot counter the activity of PU when it changes in space domain. Hence, the above mentioned problem can be solved by utilizing both the diversity techniques together.

3. Related Work

Zhu et al. [2] presented Spectrum-Tree based On-Demand Routing Orotocol (STOD-RP) which builds a spectrum-tree in every spectrum band and solves the problem of collaboration between spectrum decision and route selection. Each spectrum tree chooses single one origin node that stores information to all supplementary nodes.

Chowdhury and Felice [3] proposed the SpEctrum Aware Routing protocol for CRAHNs (SEARCH) which jointly performed path and channel selection during path establishment. The SEARCH is based on geographic routing.

Bowen Li et al. [4] proposed the Ant-based Spectrum Aware Routing (ASAR) protocol which applies the ant colony algorithm for providing the features of self-learning and adaptation to solve the problem of dynamic spectrum availability in CRAHNs in distributed manner. The ASAR protocol utilizes the reinforcement learning function for the better path.

Han and Huang [5] presented the Reliable Link Routing (RLR) protocol which combines reactive and proactive routing approach and takes into account the spectrum mobility. The RLR protocol decreases the routing overhead and improves the link consistency in multi hop CRNs. The protocol applies the proactive routing method when the target is within two hop range, while it works as a reactive routing method when the target is beyond two hop range.

Cacciapuoti et al. [6] proposed the Cognitive Ad-hoc On-demand Distance Vector (CAODV) protocol which is an expansion of the AODV routing protocol. The CAODV protocol was designed to avoid regions of PUs mobility for the duration of route establishment and packet detection, applying collective path and channel assortment to curtail route cost and provides the multi channel communication to get better overall performance. The CAODV protocol supports a dynamic CRN in which SUs are mobile while PUs are stationary.

In [7], Beltagy et al. proposed Non-Close Multipath (NCM) routing protocol which addresses the problem of multipath routing in CRNs caused by PUs mobility. The NCM protocol best suits the multi-hop CRNs with stationary SUs and mobile PUs.

Badoi et al. [8] proposed IP Spectrum Aware Geographic based Routing Protocol (IPSAG) for CRNs, which is based on the idea of the IP hop-by-hop, spectrum awareness and geographic dependent routing algorithm.

Talay and Altilar [9] proposed the UNITED node (UNITED) routing protocol to raise the data throughput and minimize the latency. The UNITED protocol is a cluster-based routing protocol.

In [10], Kamruzzaman et al. proposed the Spectrum and Energy aware Routing (SER) protocol which supports the energy-restraint multi-hop CRAHNs. The SER protocol increases the throughput, improves the network lifetime and provides robust routing.

Zheng et al. [11] presented Multi-Objective Reinforcement Learning (MORL) based routing protocol for CRNs, which addresses the problem of uncertainty on spectrum availability in dynamic CRNs. The MORL utilizes the principle of multi objective learning to deal with the issue of various performance metrics. The MORL minimizes the transmission interruption under preferred restraint of packet loss.

4. Problem Identification

In the presence of PU mobility, the routing problem becomes the most challenging issue in CRAHNs. The path- diversity routing protocol allows SUs to exchange with dynamism between various paths for communicating with one other in space domain dependent PU mobility by exploiting path diversity. The different SUs cannot communicate with each other when PU mobility changes in frequency domain. The spectrum diversity technique is used to allow SUs to change with dynamism between various channels in frequency-domain-dependent PU activity. The main problem in CAODV protocol is that the path and spectrum diversity are exploited individually due to which performance of the network degrades. The performance degradation cannot be counteracted by only exploiting the path or spectrum diversity. In addition to the above mentioned problem, the problem of link failure with the increase in mobility of nodes is also a major problem in CRAHNs.

5. Proposed Methodology

To improve the performance deprivation caused by PU mobility, a new routing protocol is introduced which utilizes the path and spectrum diversity practices jointly. During data transmission process, the source node immediately switches amongst various paths and various channels, when path breakdown occurs. Therefore, the performance degradation due to PU mobility can be mitigated.

To apply the spectrum diversity in route discovery procedure, a source node broadcast RREQ packet to all of its neighboring nodes through all the available channels. When an intermediate node or the target obtains the RREQ packet, a RREP packet is created and broadcasted reverse to the origin node through all the accessible channels which are not influenced by PU mobility. In order to exploit path diversity, the origin and destination node will not disregard extra RREQ packets obtained from various First Hop Node (FHN) and Next Hop Node (NHN). The multi-path multi-channel routes are provided at the end of the path discovery mechanism. To select an optimal transmission path, least hop-count is considered as a routing metric. The multi-path multi-channel provides a solution of the problem of packet drop due to link failures.

5.1 Integration of D2CARP in NS-2

The D2CARP protocol for multichannel is an extension of the existing AODV protocol with few modifications. The protocol can be added in the NS-2 library by changing some of the files of AODV protocol. The modifications are required in the following files:

Common/mobilenode.cc
Common/mobilenode.h
Indep-utils/propagation/threshold.cc
Mac/channel.cc
Mac/mac_802_11.cc
Tcl/lib/ns-lib.tcl
Tcl/lib/ns-mobile
Tmix/tmix-delaybox.cc
Trace/cmu-trace.cc
Wpan/p802_15_4 mac.cc

After modifying the above files, open a new terminal and run the command "./configure." When the configuration is completed, run the command "make clean" in the terminal and finally run the command make. The D2CARP protocol for multichannel for AODV protocol is now added to the library and it can be called from the library when required.

6. Performance Evaluation

There are 12 SUs and 4 PUs over a simulation area of 1000m x 1000m terrain. The PU activity is checked by ON/OFF model with the PU activity parameter of 75. The ON state shows that the channel is occupied by PU activity while the OFF state shows that the channel is idle or free from PU activity. The transmission range of the users are set to 250 m with the CBR traffic load having size 512 bytes and packet interval of 5 seconds. The simulation time is set to 1020 seconds. The radio propagation model used is two-ray ground reflection model. The MAC layer uses IEEE 802.11.

Fig. 1: Simulation Scenario

Table 1: Simulation Parameters

Parameter Name	Value
Simulation Area	1000m × 1000 m
Simulation time	1020 seconds
No. of SU	12
No. of PU	4
PU activity parameter	75
No. of channels	10
Traffic Type	CBR
MAC layer	IEEE 802.11
Packet size	512 bytes
Transport layer	UDP
PU transmission range	250 m
SU transmission range	250 m
Radio propagation	Two ray Ground-Reflection
PU check	Every 5 seconds

In this section, the recital assessment of the proposed protocol with CAODV and D2CARP protocol is carried out by using NS-2 simulator. The simulation result of packet delivery ratio, throughput, hop-count, average energy, overhead and delay are shown the following figures. In this comparison, we evaluate the impact of increasing the nodes mobility rate and the number of PUs.

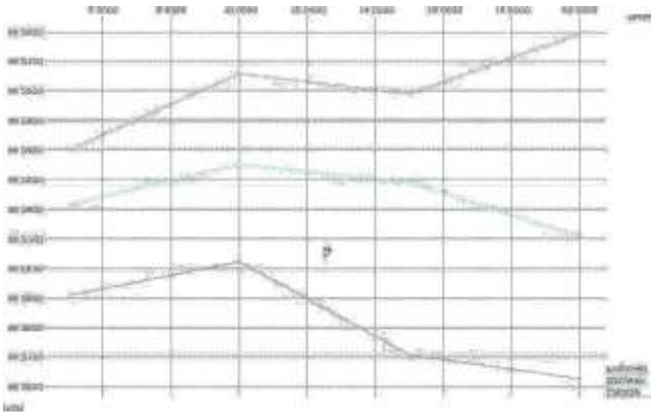

Fig. 2: Packet delivery ratio versus number of nodes

Fig. 2 shows the results of packet delivery ratio versus number of nodes for the proposed protocol, CAODV and D2CARP protocols. The performance of all the three protocols are evaluated by using NS-2 simulator and the result shows that the proposed protocol outperforms the CAODV and D2CARP in terms of packet delivery ratio with the increase in number of nodes.

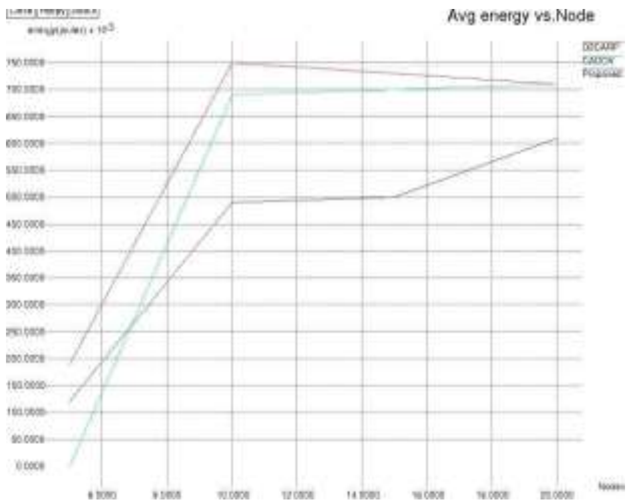

Fig. 3: Average energy versus number of nodes

In fig. 3, the performance of the proposed protocol, CAODV and D2CARP is evaluated in terms of average energy versus number of nodes. The result shows that the proposed protocol outperforms the other two protocols in terms of the average delay with the increase in the number of nodes.

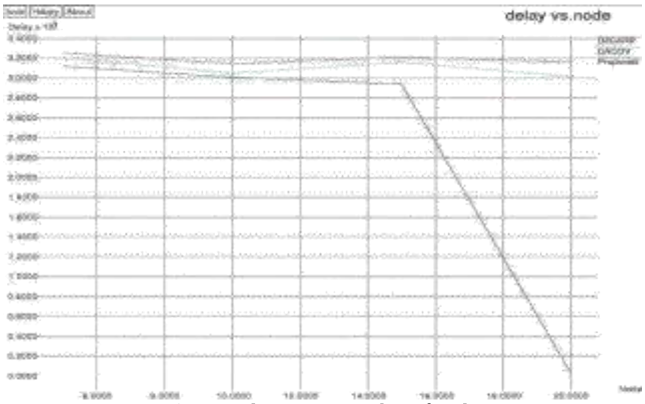

Fig. 4: Delay versus number of nodes

Fig. 4 shows the results of delay versus number of nodes for the proposed protocol, CAODV and D2CARP protocols. From the simulation results, it is clear that the proposed protocol outperforms the CAODV and D2CARP protocols in terms of delay for large number of nodes.

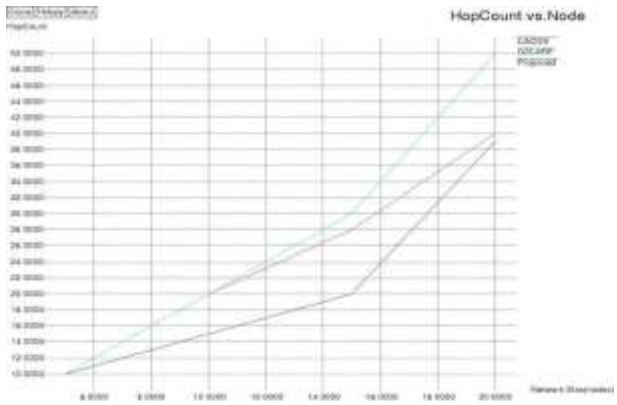

Fig. 5: Hop-count versus number of nodes

In fig. 5, the hop-count of the proposed protocol is compared with that of the CAODV and D2CARP protocol with the increase in number of nodes. The performance of the protocol is evaluated against the number of nodes. With the increase in the number of nodes, the hop-count increases in case of CAODV and D2CARP protocol. On the other hand, the value of hop-count decreases for the proposed protocol. Thus, the proposed protocol outperforms the CAODV and D2CARP in terms of hop-count.

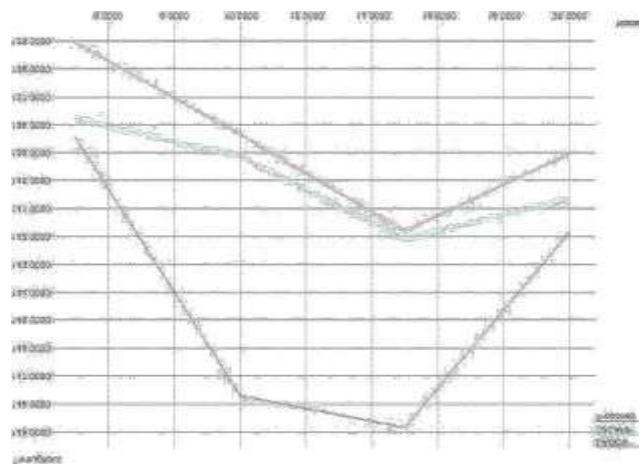

Fig. 6: Average throughput

In fig. 6, the average throughput of the proposed protocol is compared with that of the CAODV and D2CARP protocol. The performance of the protocol is evaluated by using NS-2 simulator for different number of nodes. The performance of the CAODV and D2CARP is degraded with the increase in number of nodes. On the other hand, the performance of the proposed protocol achieves higher throughput as compared to the CAODV and D2CARP protocol.

7. Conclusion and Future Directions

In this article, a new concept of multi-path multi-channel reverse route is introduced that exploits the path and spectrum diversity simultaneously which offers efficient route recovery process when a link failure occurs in the network. The main aim of the proposed protocol is to reduce the path failure due to PU activity and achieve better results in terms of packet delivery ratio, throughput, end-to-end delay, overhead, average energy and hop-count. The performance evaluation of the proposed protocol is investigated by using NS-2 simulator under identical conditions and it has been found that the proposed protocol outperforms the CAODV and D2CARP protocol.

There are still many open issues in CRAHNs which are not yet taken into account. Some of the open issues or future research for routing protocols in CRAHNs are described as follows:

- The malicious attacker may attack on the available spectrum channel either by jamming or by overusing the channel. Thus, network security is an open issue for routing protocols in CRAHNs.
- The cross-layer routing design is one of the most interesting future research work for routing protocols in CRAHNs as it uses the relationship between routing and spectrum management to adapt the changes in node density, network topography, link quality and radio interface.
- In the future work, the integration of the robustness aware routing protocol with cognitive radio devices will be carried out to reduce the link failure during node mobility and effective route maintenance algorithm.
- In case of path breakages, the route recovery algorithm is not taken into account in this article, so in future work, the efficient route recovery algorithm is also considered for reliable communication in the CRAHNs.

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