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A Review of Cognitive Radio using Mobile Ad-hoc Network Protocols: Approaches and Challenges

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Abstract: ***With increasing interest in using cognitive radio (CR) technology in wireless communication systems for MANET, it is envisioned that future devices will be CR-enabled. This paper discusses CR technologies using different routing protocols for mobile networks aimed at improving spectrum efficiency. CR for mobile networks has the potential of becoming a killer CR application in the future due to a huge consumer market for mobile communications. This paper surveys novel approaches and discusses research challenges related to the use of cognitive radio technology in mobile ad hoc networks. The review explains how CR technologies such as dynamic spectrum access, adaptive software-defined radios and cooperative sensing will enhance mobile communications using applicable routing protocols such as AODV, DSDV and DSR. After observing their basic principles, their performance and characteristics are evaluated. In addition, several challenges an,d requirements have been identified.***

Keywords: Mobile Ad hoc Network (MANET), Ad hoc on demand distance vector (AODV) Cognitive Radio Ad-Hoc Network (CRAHNs), Primary users (PU's)

1. Introduction

The electromagnetic radio spectrum is a natural resource, the use of which by transmitters and receivers (transceivers) is licensed by government agencies. However, this resource is presently underutilized. In particular, if we were to scan the radio spectrum, including the revenue-rich urban areas, we would find that some frequency bands are largely unoccupied most of the time, some other frequency bands are only partially occupied, and the remaining frequency bands are heavily used. [1]

A spectrum hole is a band of frequencies assigned to a primary user, but at a particular time and specific geographic Location, the band is not being utilized by that user. Cognitive radio (CR) is a new paradigm that enables nodes to exploit unoccupied frequency spectrum for communications. Cognitive radio based wireless mesh networks (CRNs) have been proposed to enable wireless mesh networks to communicate via dynamic channels. We consider a scenario in which mobile cognitive users (CUs) exploit multi-hop communications and primary user (PU) activity is dynamic, i.e. the primary spectrum band, once available, remains usable for a limited duration (in the order of minutes). In this scenario, the first priority is to build stable paths and moreover, the path discovery process must be quick and resilient against PU activity changes. Many existing literature consider routing in static CRNs with relatively stable communication channel where the duration of the availability of the communication channel is much longer than the communication time. However, there is very limited work looking into routing related issues in dynamic CRNs where the average available duration of the communication channel can be much shorter than the communication time. In recent years, there are many research efforts on a wide variety of techniques to mitigate the impact of interference and to improve network capacity such as directional antennas, multiple-input-multiple-output (MIMO) etc. Increasingly, designs utilizing Multiple channels/ interfaces have gained popularity for improving the capacity of wireless mesh networks.

Advantages of Cognitive Radio

The main purpose of using a cognitive radio over a primitive radio is because of the following advantages;
1) Senses the radio frequency environment for the presence of white spaces.
2) Manages the unused spectrum.
3) Increases the efficiency of the spectrum utilization significantly.
4) Improves the spectrum utilization by neglecting the over occupied spectrum channels and filling the unused spectrum channels [2].
5) Improves the performance of the overall spectrum by increasing the data rate on good channels and moving away from the bad channels [3].

2. Problem Domain

One of the most important problems in routing in multi-hop CRN is the intermittent connection. Unpredicted operation of primary users (PU) prevents secondary users (SU) from having a stable usage of the licensed spectrum. The intermittent connection will lead to frequent route corruptions whose consequence is that the re-routing process must be called several times, increasing transmission delay and packet loss. More specifically, the task of finding and selecting the appropriate path from a source to a destination node in an environment that evolves dynamically can be a highly challenging problem. There can be following conditions possible-

Static: The Primary users are rarely active and hence the system doesn't differ from other wireless systems. In this case, it can be assumed that once a SU finds an available band, it can exploit that band for an unlimited period of time.

Dynamic: The Primary Users have dynamic activities; i.e., they come and go more frequently which cause an intermittent availability of frequency bands for the secondary users.

Opportunistic: The primary users are highly active which makes it rare for a SU to have a whole uninterrupted end-to-end transmission.

3. Solution Domain

The proposed routing technique is based on a modification of the widely adopted On-demand routing protocols as AODV, DSR and proactive routing protocol i.e. DSDV. Unlike most of the previous works, our proposal avoids regions of PU activity during both route formation and packet discovery without requiring any dedicated control channel. Moreover, it assesses the qualities of any available channel, minimizing the route cost by performing a joint path and channel selection at each forwarder. Finally, it exploits the presence of multiple available channels to improve the overall performances. To perform different tasks i.e. when any node has data and it wants to send the data to the destination node. These tasks are route discovery, route maintenance and other management tasks. A multi-metric route selection and combined opportunistic routing algorithms can be used to evaluate the performance of above protocols.

4. Spectrum Sensing Methods For Cognitive Radio

Some of the most common spectrum sensing techniques in the cognitive radio are:

1) **Energy Detector Based Sensing**:
Energy detector based approach is the most common way of spectrum sensing because of its low computational and implementation complexities. In this, receivers do not need any knowledge on the primary users' signal. The signal is detected by comparing the output of the energy detector with a threshold which depends on the noise floor. [4]

2) **Waveform-Based Sensing**:
Patterns known are usually utilized in wireless systems to assist synchronization or for other purposes. Such patterns include preambles, midamles, regularly transmitted pilot patterns, spreading sequences, etc. In the presence of a known pattern, sensing can be performed by correlating the received signal with a known copy of itself. [5]

3) **Cyclostationarity-Based Sensing:**
Cyclostationarity feature detection is a method for detecting primary user transmissions by exploiting the cyclostationarity features of the received signals. Cyclostationary features are caused by the periodicity in the signal or in its statistics like mean and autocorrelation or they can be intentionally induced to assist spectrum sensing. [4]

4) **Matched-Filtering Technique**:
Matched-filtering is known as the optimum method for detection of primary users when the transmitted signal is known.[7] The main advantage of matched filtering is the short time to achieve a certain probability of false alarm or probability of misdetection as compared to other methods. It requires cognitive radio to demodulate received signals. Hence, it requires perfect knowledge of the primary users signaling features such as bandwidth, operating frequency, modulation type and order, pulse shaping, and frame format. [6]

5. Comparison of Various Sensing Methods

A basic comparison of the sensing methods given in this section is presented in Fig. 1. Waveform-based sensing is more robust than energy detector and cyclostationarity based methods because of the coherent processing that comes from using deterministic signal component. However, there should be a priori information about the primary user's characteristics and primary users should transmit known patterns or pilots.

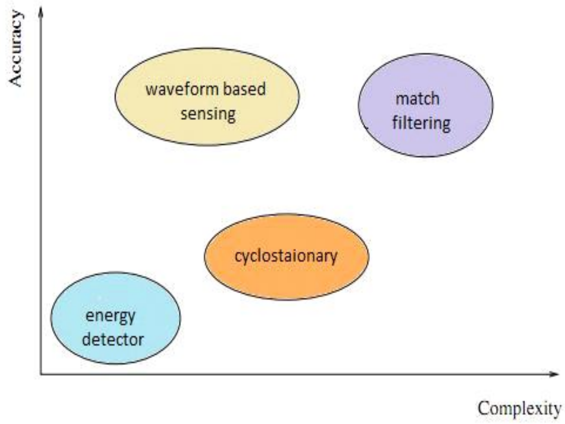

Figure 1: Main sensing methods in terms of their sensing accuracies and complexities

The performance of energy detector based sensing is limited when two common assumptions do not hold. The noise may not be stationary and its variance may not be known. Other problems with the energy detector include baseband filter effects and spurious tones. It is stated in literature that cyclostationary-based methods perform worse than energy detector based sensing methods when the noise is stationary .However, in the presence of co-channel or adjacent channel interferers, noise becomes non-stationary. Hence, energy detector based schemes fail while cyclostationarity-based algorithms are not affected. On the other hand, cyclostationary features may be completely lost due to channel fading. It is shown in that model uncertainties cause an SNR wall for cyclostationary based feature detectors similar to energy detectors. Furthermore, cyclostationarity based sensing is known to be vulnerable to sampling clock offsets. [8]

6. CRP Routing Protocol Overview

The route-setup in the Cognitive radio routing protocol for ad hoc network (CRP) is composed of two stages - (i) the spectrum selection stage, and the (ii) next hop selection stage. The source node broadcasts the RREQ over the control channel, and this packet is propagated to the destination. Each intermediate forwarder identifies the best possible spectrum band and the preferred channels within that band during spectrum selection. The spectrum selection is based on the connectivity edges between the two nodes. Here, the spectrum chosen by a given candidate forwarding node must (i) support the highest propagation distance, with the (ii) longest allowed duration for transmission given the sensing schedules of the neighboring nodes. The next stage is the next hop selection stage, where the candidate CR users rank themselves depending on the choice of the spectrum and the local network and physical environmental conditions. These ranks determine which CR users take the initiative in the subsequent route formation. [9]

7. Cognitive Radio Mobile Ad Hoc Networks

In a CR-MANET, each CU is equipped with one or more pre-defined radios (or transceivers) that can be tuned to a radio frequency band (or a channel) among a range of the spectrum. In addition, a CU has the functionality of scanning available channels at the present moment to avoid inference with the activity of a PU. Through the periodic exchange of beacon information, a CU discovers its neigh-boring CUs, each of which connects to the CU via one or more scanned channels. A scanned channel is assumed to be symmetric. Moreover, the maximum number of channels that can be sensed by a CU is limited. The CR-MANET is heterogenous i.e., the set of available channels and the number of tunable transceivers may vary from one node to another. In general, the number of pre-defined transceiver is smaller than the maximum number of channels that a node can sense. Links in the CR-MANET may change over time. That is, as the network evolves over time, a new channel may become available to connect a pair of CUs, while an existing channel may disappear in the network, e.g., due to node mobility or start of occupancy of PUs. Based on the network settings, a variety of routing schemes based on whether a scheme considers support for single or joint functionality among spectrum decision, PU awareness and re-configurability have been proposed. Some are discussed below:

a) Ad hoc On-demand Distance Vector

AODV-based routing and spectrum assignment protocol with local coordination of traffic flows. The protocol operates on a common control channel shared by all CUs. When an end-to-end path between a source-destination pair needs to be established, the source node broadcasts RREQ, which contains the information about its current available cognitive channels, over the common control channel. The forwarding rule for RREQ is discussed as follows. Assume that CU A broadcasts RREQ after updating the channel information in RREQ with the set of available cognitive channels in A and CU B is a neighbor of A. After receiving RREQ, B determines the routing path and sends RREP to the source if B is the destination. If not, B broadcasts RREQ after updating its channel information with the set of available cognitive channels in B. [10]

b) Destination Sequence Distance Vector

DSDV is a table-driven routing protocol based on the Bellman-Ford algorithm. The main contribution of the algorithm is to prevent the routing loop problem. Every node maintains a routing table in which all-possible destinations within the network and the numbers of hops to each destination are also recorded. Each entry is marked with a sequence number assigned by the destination node. Sequence numbers are used to distinguish stale routes from fresh ones and to avoid the formation of route loops. Routing tables are constructed.

c) Dynamic Source Routing

DSR is one of the pioneering routing solutions for Ad-hoc network, based on reactive paradigm that utilizes a source routing algorithm. DSR consists of two major phases: route maintenance and route discovery. When a source node wants to send a packet, it consults its routing cache. If the required route is available, the node inserts it into the header of the packet. Else, it broadcasts the route discovery packet. Receiving that packet, a node checks its route cache. If the node does not have routing information for the requested destination, it forwards the packet with its own address appended to the route record field of the header. When the request reaches the destination or an intermediate node has routing information to the destination, a route reply packet is sent. It comprises addresses of nodes that have been traversed by the request packet eventually concatenated with the route from the intermediate node's cache. A route error packet is send when a node discovers link failure. Then all the nodes remove from the cache all routes containing the broken link. It eliminates the overhead due to the periodical flooding of the network with route updates. This approach however increases the connection setup delay and its performance degrades rapidly in a mobile environment. Also DSR requires considerable routing overhead because every data packet contains complete routing information.

8. Simulation Steps

The following is the steps for testing the simulation based on routing protocol using NS2. The following is the procedure which is considered during initial implementation:

1) Initialization of channel selection by doing sensing of licensed spectrum using one of above defined sensing method.
2) Creation of Cognitive radio nodes in wireless scenario for the next hop selection stage with route maintenance.
3) Test the data rate transmission of a number of packets in the wireless cognitive network.
4) Using routing protocol for the cognitive radio network data will start to transmit..

9. Conclusion

This paper has surveyed novel approaches and discussed research challenges related to the use of cognitive radio technology for ad-hoc networks. However, the research solutions proposed for general-purpose CR networks cannot be directly applied to CR-MANETs due to their unique features that need to be considered while designing the spectrum management functions for CR-MANETs. In this context, several challenges and requirements for CR-

MANETs have been identified. It provides recent advances and open research directions on applying cognitive radio for mobile networks focusing on architecture, machine learning, cooperation and spectrum management.. A future work will presents extensive simulation analysis for DSDV and AODV routing protocols under various traffic scenarios for CRN. Routing protocols will be evaluated for different scenarios could be inspected while introducing randomness to the packet size and rate.

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