A Survey on Routing in Cognitive Radio Network

Sudhir Kumar¹, Manisha² and Parvinder Bangar³

¹M.tech Scholar, CBS group of Institutions, Jhajjar
sudhirkumar1061@gmail.com

²Assistant Professor, MRIEM, Rohtak
manishabangar@gmail.com

³Assistant Professor, CBS group of Institutions, Jhajjar
parvinder.bangar@gmail.com

Abstract

Cognitive Radio (CR) can be used as a solution to current unbalanced spectrum utilization. The cognitive ad hoc network can take advantage of dynamic spectrum access and spectrum diversity over wide spectrum. It could achieve higher network capacity compared to traditional ad hoc networks, thus supporting bandwidth-demanding applications. Mobile Ad-Hoc networking has gained an important part of the interest of researchers and become very popular these past few years, due to its potential and possibilities. These protocols determine how messages can be forwarded, from a source node to a destination node which is out of the range of the former, using other mobile nodes of the network. Routing, which includes for example maintenance and discovery of routes, is one of the very challenging areas in communication. Simulators though cannot take into account of all the factors that can come up in real life and performance and connectivity of mobile Ad-Hoc network depend and are limited also by such factors. Here we focused on the potential routing approaches that can be employed in adaptive wireless networks.

Keywords: Cognitive Radio, MANET, Routing Protocol.

1. Introduction

COGNITIVE RADIO (CR) [1, 2] is an enabling technology that allows cognitive users (CUs, i.e., unlicensed users or secondary users) to operate on the vacant parts of the spectrum allocated to primary users (PUs, i.e., licensed users). CR is widely considered as a promising technology that deals with the spectrum shortage problem caused by the current inflexible spectrum-allocation policy. It is capable of sensing its radio environment and adaptively choosing transmission parameters according to sensing outcomes, which improves CR system performance and avoids interfering with PUs [3].

In CRN most research is done on MAC layer issues such as opportunistic spectrum access and spectrum utilization. Whereas CR technology has more impact on upper layer performance issues in wireless network, specifically in Mobile Ad-Hoc Networks (MANETs). In routing issue, data should be routed via stable and reliable path to avoid rerouting and thus congestion in network. This degrades the performance of network such as throughput and delay. As compared to classical routing, routing in CRN is more unstable as it is affected by not only mobility of Cognitive User’s (CU) but also by Primary User (PU) activities. Thus routing in CR-MANETs should have the following characteristics to ensure stable and reliable paths [4].

- PU activity awareness: In CRN path selection should be in such a way that it should not interfere to PU activity i.e. PU interference should be below the required threshold.
- Link-availability: To avoid PU interference, cognitive routing should also be reactive. It should be aware of link-available periods.
- Adaptive behavior: Cognitive routing should be adaptive to selected path based on some prediction to avoid rerouting frequency and to increase end-to-end throughput and to decrease end-to-end delay.

There exists large no. of routing protocols for MANETs but because of distinct characteristics of CR-MANETs, that protocols cannot be apply directly to CR-MANETs [4].
A “Cognitive Radio” is a radio that can change its transmitter parameters based on interaction with the environment in which it operates. Cognitive radio networks provide high bandwidth to mobile users through heterogeneous wireless architectures and dynamic spectrum access techniques. Thus DSA enables cognitive users to use existing spectrum efficiently without disturbing primary user activities. Cognitive radio techniques allows to use or share spectrum opportunistically. Cognitive Radio technology allows users to detect available portion of spectrum as well as primary user’s presence, to select best channel, to share the channel with other users and to free the channel whenever primary user is detected. Cognitive radio has 2 main characteristics.

a. **Cognitive Capability:** It is ability of radio technology to sense the radio environment. It captures the temporal and spatial variations in radio environment and avoids interference to primary user.

b. **Reconfigurability:** Once radio environment gets captured, reconfigurability helps cognitive radio to program dynamically according to radio environment [5].

![Figure 1: Cognitive radio cycle [5]](image)

To exploit under-utilized portions of the spectrum, known as white spaces or spectrum holes, the report motivates the need for a new generation of smart, programmable radios that are capable of interference sensing, channel state learning, and dynamic spectrum access. In the most common design considered today, cognitive radios (CRs) must transparently coexist with licensed users having obviously more priority on the licensed spectrum bands. In fact, CR can exploit the licensed bands either during the absence of their legacy users or by judiciously computing their transmission power in order to benefit from the underutilized portion of the spectrum [5].

The main idea behind this work is to use an appropriate routing protocol for cognitive network which becomes a major necessity now days. As the available radio frequency for wireless communication gets lesser day by day because of licensing, so we need to have some way to use these frequencies in a more efficient manner. But since the topology of ad-hoc network changes dynamically so our cognitive ad-hoc network should be capable to cope up with dynamic network topology as well as diverse quality of service. And also proper routing protocol should be there so that an efficient routing can be done apart from maintaining QoS. On local observation of CR users but also on statistical behavior of the Pus [5].

2. **Literature Survey**

Nie Nie et al. [6] (2006) proposed a game theoretic framework to analyze the behavior of cognitive radios for distributed adaptive channel allocation. They defined two different objective functions for the spectrum sharing games, which capture the utility of selfish users and cooperative users, respectively. Based on the utility definition for cooperative users, they shown that the channel allocation problem can be formulated as a potential game, and thus converges to a deterministic channel allocation Nash equilibrium point. Alternatively, a no-regret learning implementation is proposed for both scenarios and it was shown to have similar performance with the potential game when cooperation was enforced, but with a higher variability across users. The no-regret learning formulation was particularly useful to accommodate selfish users. Non-cooperative learning games have the advantage of a very low overhead for information exchange in the network. Lijun Qian et al. [7] (2007) considered the scenario where the cognitive radio network was formed by secondary users with low power personal/portable devices and when both systems were operating simultaneously. A power control problem was formulated for the cognitive radio network to maximize the energy.
efficiency of the secondary users and guarantee the QoS of both the primary users and the secondary users. The feasibility condition of the problem is derived and both centralized and distributed solutions are provided. Because the co-channel interference were from heterogeneous systems, a joint power control and admission control procedure was suggested such that the priority of the primary users was always ensured.

Hicham Khalife et al. [8] (2008) presented a novel routing approach for multichannel cognitive radio networks (CRNs). Their approach was based on probabilistically estimating the available capacity of every channel over every CR-to-CR link, while taking into account primary radio (PR). Their routing design consist of two main phases. In the first phase, the source node attempted to compute the most probable path (MPP) to the destination (including the channel assignment along that path) whose bandwidth has the highest probability of satisfying a required demand D. In the second phase, they verify whether the capacity of the MPP was indeed sufficient to meet the demand at confidence level δ. If that is not the case, they judiciously add channels to the links of the MPP such that the augmented MPP satisfies the demand D at the confidence level δ. Kaushik R. Chowdhury, et al. [9] (2011) proposed CR routing protocol for ad hoc networks (CRP) that makes the following contributions: (i) explicit protection for PU receivers that were generally not detected during spectrum sensing, (ii) allowing multiple classes of routes based on service differentiation in CR networks, and (iii) scalable, joint route-spectrum selection. A key novelty of CRP is the mapping of spectrum selection metrics, and local PU interference observations to a packet forwarding delay over the control channel. This allows the route formation undertaken over a control channel to capture the environmental and spectrum information for all the intermediate nodes, thereby reducing the computational overhead at the destination.

Matteo Cesana et al. [10] (2011) said that cognitive radio networks (CRNs) were composed of cognitive, spectrum-agile devices capable of changing their configurations on the fly based on the spectral environment. This capability opens up the possibility of designing flexible and dynamic spectrum access strategies with the purpose of opportunistically reusing portions of the spectrum temporarily vacated by licensed primary users. On the other hand, the flexibility in the spectrum access phase comes with an increased complexity in the design of communication protocols at different layers. This work focuses on the problem of designing effective routing solutions for multi-hop CRNs, which is a focal issue to fully unleash the potentials of the cognitive networking paradigm. They provided an extensive overview of the research in the field of routing for CRNs, clearly differentiating two main categories: approaches based on a full spectrum knowledge, and approaches that consider only local spectrum knowledge obtained via distributed procedures and protocols.


3.1 An Efficient Location Server for an Ad Hoc Network

In [11] three current location service, Grid Location Service (GLS), Simple Location Service (SLS), and Reactive Location Service (RLS) are introduced. Grid Location service: In GLS, a node chooses a set of node in the network (i.e., location servers) to maintain the node’s current location. Nodes that require the location of a node query the node’s location servers [5].

Simple Location Service: In SLS, a node periodically transmits its location table to its neighbors. Thus, a node in the network learns the location of all other nodes in the network. Here each location packet (LP) updates location tables, contains the location of several nodes, the speed of each of nodes, and the time the LP was transmitted. The rate a mobile node transmits LPs adapts according to location change [5]:

$$\left(\frac{\text{Trange}}{\alpha}\right) \cdot \left(\frac{1}{v}\right) = \frac{\text{Trange}}{\alpha \cdot v}$$

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Where $Trange$ is the transmission range of the node, $\alpha$ is the average velocity of the node, and $\beta$ is a constant optimized through simulation is a scaling factor.

Reactive Location Service: RLS is a reactive location service that queries location information on an as-needed basis.

### 3.2 An improved Map-based Location Service for Vehicular Ad Hoc Networks

In [12], a distributed hierarchical location service called Density aware Map-Based Location Service (DMBLS) for Vehicular Ad Hoc Networks. DMBLS makes use of the street digital maps and the traffic density information to define a three-level hierarchy of locations servers. The location service uses a density aware server selection policy which selects servers at high density regions of a city. DMBLS, for vehicular urban environments, based on the traffic density. In this, they have assumed that each vehicle knows its own geographic position and the use of the Global Positioning System (GPS).

Updating Location Information: Due to the high mobility, the vehicles positions keep changing very fast and therefore, the location server should be informed to update the information it stores. The location information are valid for a period $T$ equal to the time required for the vehicle to reach the next waypoint plus a threshold time $Tc$ and it can be predicted by the following formula: $T = \frac{D_{int}}{S_{avg}} + Tc$

Where $D_{int}$ is the distance between the current intersection and the next intersection and $S_{avg}$ corresponds to the average speed of the vehicle. $Tc$ represents the time spent by the vehicle near the intersection before it moves away with a distance $R$ equal to the transmission range [5].

### 3.3 SEARCH Protocol - Spectrum Aware Routing Protocol

The SEARCH protocol uses the geographic forwarding. This protocol jointly considers the path and the channel selection to avoid the regions of the Primary User activity during the route formation. Minimization of hop count to reach the destination is done by using the optimal path found by geographic forwarding [13]. The idea of the geographic forwarding is used in this protocol. It is able to deal with reasonable levels of PU activity changing rate. Also, a mechanism for disseminating the destination location both at the source and at each intermediate node is required.

The protocol assumes the primary users” activities in an ON/OFF process. The functions followed by the protocol are (1) Route setup phase (2) Joint Channel – Path optimization phase and (3) Route Enhancement, in order to improve the route during its operation.

SEARCH mainly works on following two concepts
- PU activity awareness: In CR network, route must be constructed to avoid region affected by active PU. When PU activity affect region, SEARCH provides hybrid solution, it first uses greedy geographic routing on each channel to reach destination by identifying and circumventing PU activity region [5]. The path information from different channels is combined at destination in series of optimization steps to decide on optimal end-to-end route in a computationally efficient way.
- CR user mobility: Cognitive user mobility results into frequent route disconnections. Thus for each node, through periodic beacons, updates its one-hop neighbors about it current location SEARCH ensures performance as well as less interference in cognitive radio network.

### 3.4 SER - Spectrum and Energy Aware Routing Protocol

The main aim of this protocol to establish a bandwidth guaranteed QoS routes in small CR networks where the topological changes are low. The protocol uses Time Division Multiple access [14]. The QoS requirement considered here is the number
The SER is an on demand routing protocol proposed for multihop CR networks. The basic operation of SER includes route discovery, data transmission and route maintenance.

- **ROUTE DISCOVERY:** The route request (RREQ) broadcast procedure is based on Dynamic Source Routing Protocol (DSR). When the source CR user, say S, has packets to send to the destination CR user, say D, then S will start the route discovery process by broadcasting a spectrum aware RREQ message on the Common Control Channel (CCC). The RREQ message will be received by all of its neighbors. An intermediate CR user, e.g. V, which uses a timer, once it receives the first RREQ for each received RREQ from the neighbor, say U, before the timer expires, V runs the communication segment assignment algorithm to find the feasible communication segments between the link, i.e. \( l = (U,V) \). If the feasible communication segment is not found, V drops the corresponding RREQ. Else, the link attaches itself to the current partial path, updates the other information and rebroadcast it. Simultaneously, the Cognitive user increases the value of the hop count and the time to live [14].

The destination user waits for more RREQs to arrive at its side. The destination user also sets up a timer on its side, in order to monitor the multiple RREQs. The destination will use the same technique followed by the source node, to select the optimal path. It computes the route by using the utility route of the path and selects the one which is used to the maximum.

Destination replies the source CR user with route reply (RREP) packet through the same control channel. The communication segment of each link for the path is used especially only for the data transmission, which is a reserved one. When the RREP is forwarded towards the source CR user, all the intermediate users reserves the same communication segment mentioned in the reply packet. There may be problem of intersecting path from other communication segment too. Therefore, instead of finding a new route, the communication segment assignment algorithm coordinates the conflicting users with it s one – hop neighbors scheduling to recover the route reservation.

- **DATA TRANSMISSION:** After receiving the Route Reply by the destination, the data transmission begins. The data will be forwarded by the source to the destination via the intermediate CR users.

- **ROUTE MAINTENANCE:** The route maintenance is re constructed automatically by using route recovery (RREC) and route error (RERR) messages. This phase is important as the users are mobile.

### 4. Conclusion

Cognitive radio (CR) technology is introduced to solve the problem of spectrum underutilization in wireless networks by opportunistically exploiting portions of the spectrum temporarily vacated by licensed primary users. In this paper, we present a survey of recent routing protocols in Cognitive Radio Networks (CRNs).

### References


