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ENHANCED HYBRID COGNITIVE RADIO AD HOC NETWORKS (CRAHNs) FOR MOBILE NETWORK

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ABSTRACT:

In sensor networks, a very crucial aspect of the maintenance of the communications of secure data is the data, which is the most difficult of all tasks. The sensor network consists of hierarchical elements like the Base Station (BS), the Cluster Head (CH) and the Sensor Nodes (SNs), and this will have three different keys, which are the public and private, the cluster and the master keys. Through the opportunistic use of the currently available wireless spectrum, cognitive radio (CR) technology is intended to address the issues in wireless networks brought on by the limited amount of range accessible and the inefficient use of spectrum. With the inherent capabilities of cognitive radio, CR networks will offer the most advanced spectrum-aware communication paradigm in wireless communications. However, the significant spectral fluctuation and various quality-of-service (QoS) requirements faced by CR networks provide unique difficulties. The distributed multihop design, the dynamic network topology, and the time- and location-varying spectrum availability are essential differentiating elements in cognitive radio ad hoc networks (CRAHNs).

1.1 INTRODUCTION

Current wireless networks are based on a fixed spectrum assignment policy that governmental agencies regulate. Although the spectrum is licensed long-term over vast geographical regions, recent research has shown that significant portions of the assigned spectrum are utilised, leading to a waste of valuable frequency resources [Ian Akyildiz et al.,2006]. The FCC recently approved using unlicensed devices in

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licensed bands to address this critical problem. To this end, cognitive radio (CR) technology is envisaged to identify and use vacant spectrums, known as spectrum holes or white space [Ian Akyildiz et al.,2006].

Since most of the spectrum is already assigned, a key challenge is to share the licensed spectrum without interfering with the transmission of other licensed users (also known as primary users or PUs). If this band is found to be occupied by a licensed user, the CR user moves to another spectrum hole to avoid interference.

CR is considered the enabling technology of the Dynamic Spectrum Access (DSA) paradigm, which is envisaged to solve the current spectrum scarcity problem, thus facilitating the accommodation of new wireless services and providing an effective solution to the ever-increasing user demand. In this chapter, we first introduce the DSA paradigm and explain the underlying reasons for its deployment. Then, we describe the characteristics of CR technology and its application in wireless networks. In CRAHNs the distributed multihop architecture, dynamic network topology, diverse quality of service (QoS) requirements, and time and location-varying spectrum availability are key factors that must be considered in network design. These challenges necessitate novel design techniques that simultaneously address a wide range of communication problems spanning several protocol stack layers.

In CRAHNs CR users are mobile and can communicate with each other in a multihop manner on both licensed and unlicensed spectrum bands, as shown in Fig. 1a. Furthermore, due to the lack of central network entities, CRAHNs necessitate each CR user having all the spectrum related CR capabilities, and determining its actions based on local observation, leading to distributed operation [Akyildiz et al.,2009]. In order to adapt to the dynamic spectrum environment, the CRAHN requires spectrum-aware functions, which form a cognitive cycle [Ian Akyildiz et al.,2006]. As shown in Fig. 1b, the steps of the mental cycle consist of four spectrum management functions: spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility. To implement CRAHNs, each process needs to be incorporated into the classical layering protocols, as shown in Fig. 2. The following are the main features of spectrum management functions:

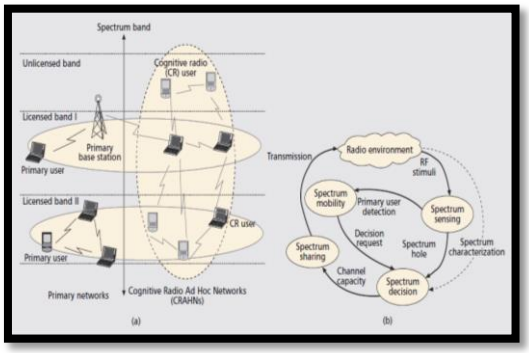

Figure 1. The overview of CR ad hoc networks: a) network architecture; b) CR cycle.

- **Spectrum Sensing:**

A CR user should monitor the available spectrum bands, capture their information, and then detect spectrum holes. Spectrum sensing is basic functionality in CR networks and hence closely related to other spectrum management functions and layering protocols to provide information on spectrum availability.

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- **Spectrum Decision:**

Once the available spectra are identified, CR users must select the best available band according to their QoS requirements [Akyildiz et al.,2009]. Especially in CRAHNs, spectrum decision involves jointly undertaking spectrum selection and route formation.

- **Spectrum Sharing:**

The transmissions of CR users should be coordinated by spectrum-sharing functionality to prevent multiple users from colliding in overlapping portions of the spectrum. Spectrum sharing includes channel and power allocations to avoid interference caused to the primary network and a CR medium access control (MAC) protocol along with spectrum sensing.

- **Spectrum Mobility:**

If a PU requires the specific portion of the spectrum in use, the communication must be switched to another vacant part of the spectrum. This requires spectrum handoff and connection management schemes coupled with spectrum sensing, neighbour discovery in a link layer, and routing protocols.

Each spectrum management function relies on exchanging information between CR users over a Common Control Channel (CCC), which we describe in the next section.

2 COOPERATION AND COMMON CONTROL CHANNEL (CCC)

The interaction between CRAHN users leading to cooperation and the use of the CCC in spectrum management are essential topics explained first.

2.1 Cooperation

CRAHNs lack centralised support and must rely on local observation of each CR user to determine its actions. All spectrum management functions are based on cooperative operations to overcome the drawback caused by the limited network topology and spectrum availability knowledge. CR users determine their actions based on observed information exchanged with their neighbours. For example, CRAHNs require the assimilation of details during sensing from several users to improve accuracy and for fair sharing of the detected spectrum resource through cooperation. Some spectrum management functions, such as spectrum decision and mobility, need reliable route formation and packet delivery over multiple hops in CRAHNs. For this, information regarding the likely PU interference over the length of the path and sensing schedules of the intermediate nodes needs to be available at the source node. In summary, cooperation is theoretically more advantageous in CRAHNs since the uncertainty in a single user's observation can be minimised through collaboration [Akyildiz et al.,2009].

2.2 CCC

A CCC is required to exchange spectrum information and coordinate spectrum access to enable cooperation among CR users. A brief classification of the possible approaches for the CCC is provided in this section [Akyildiz et al.,2009].

2.3 In-Band CCC

The control messaging occurs in the licensed channels used for data transfer. As spectrum availability changes with time, the in-band CCC is generally in effect for

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comparatively smaller durations. For example, spectrum sensing is periodic and may occur at well-defined epochs, during which the surrounding CR users may need to be silenced by informing them via the CCC. Moreover, the physical extent of the CCC is limited (local coverage), as the spectrum resource that may be used is different based on the users' location. Although this approach has the advantage of using a single transceiver, it is subject to periodic disruptions and the associated overhead of new task-specific CCC formation.

2.4 Out-of-Band CCC

Here, a separate channel is used for the CCC that does not overlap with the licensed media. The best performance results if a CCC has global coverage as new users joining the network can conveniently broadcast their presence on it without knowing the current state of the CR network. In addition, cluster-based architectures may use local coverage where the CCC is defined differently for each cluster of users and reflects the specific PU activity in their respective locations. However, as the data and control signalling are separate, more than one transceiver may be needed for dedicated CCC monitoring. For single radio devices, the cost of switching between the data band and the CCC and the associated deaf period when the CCC is not sensed must be accounted for in the protocol design.

3 SPECTRUM SENSING

A CR is designed to be aware of and sensitive to the changes in its surroundings, making spectrum sensing an essential requirement for realising CR networks. As shown in Fig. 2, the CRAHN necessitates the following functionalities for spectrum sensing.

3.1 PU Detection

PU detection is a capability to determine the presence of PU transmissions through the location observations of a CR user and identify the current spectrum availability accordingly. In CRAHNs, energy and feature detection methods are the most commonly used for PU detection [Cabric et al.,2004]. In the energy detector CR, users sense the presence/absence of the PUs based on the energy of the received signals. While the energy detector is easy to implement, it cannot differentiate signal types. Thus, the energy detector often results in false detection triggered by unintended signals in CRAHNs. Furthermore, its performance is susceptible to uncertainty in noise power.

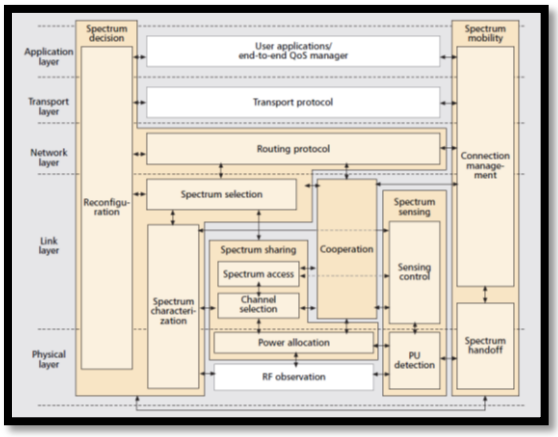

Figure 2. Spectrum management framework for CRAHNs.

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Feature (or cyclostationary) detection determines the presence of PU signals by extracting their specific features, such as pilot signals, cyclic prefixes, or modulation type, from its local observation. The main advantage of feature detection is its robustness to the uncertainty in noise power. Furthermore, it can distinguish the signals from different networks. Thus, this method allows the CR user to perform sensing operations independently on its neighbours without synchronisation. Although feature detection is the most effective scheme for CRAHNs, it is computationally complex and requires a significantly long sensing time.

Furthermore, in CRAHNs, spectrum sensing necessitates an efficient cooperation scheme to prevent interference to PUs outside the observation range of each CR user and mitigate multipath fading and shadowing effects.

3.2 Sensing Control

The PU detection functionality is controlled and coordinated by a sensing controller, which considers two main issues:

- How quickly a CR user can find the available spectrum band over a wide frequency range for their transmissions
- How long and how frequently a CR user should sense the spectrum to achieve sufficient sensing accuracy during the transmission and detect the presence of communication in primary networks to avoid interference

For fast and efficient spectrum discovery in CRAHNs, the out-of-band sensing scheme should have a coordination scheme to optimise its searching sequence and decide on the stopping rule for out-of-band sensing [Kim and Shin.,2008]. Furthermore, in in-band sensing, a longer sensing time leads to higher sensing accuracy and less interference. Conversely, a longer transmission time increases access opportunities but causes higher interference due to the lack of sensing information [Lee and Akyildiz.,2008]. Thus, how to select the proper sensing and transmission periods in a distributed manner is an essential issue in CRAHNs.

4 SPECTRUM DECISION

CRAHNs require capabilities to decide on the best spectrum band among the available bands according to the QoS requirements of the applications. This notion is called spectrum decision and constitutes a rather essential yet unexplored topic. The prominent uniqueness of spectrum decision in CRAHNs lies in the end-to-end route consisting of multiple hops with heterogeneous spectrum availability. The following are the main functionalities required for spectrum decision (Fig. 2).

4.1 Spectrum Characterisation

Through RF observation, CR users characterise the available spectrum bands by considering the received signal strength, interference, and the number of users currently residing in the spectrum. Unlike classical ad hoc networks, each CR user observes heterogeneous spectrum availability that varies over time and space due to the PU activities, which should also be considered in the spectrum characterisation.

4.2 Spectrum Selection

CR users allocate the best spectrum band to satisfy QoS requirements according to observed spectrum availability. Since the entire communication session consists of multiple hops with heterogeneous spectrum availability, spectrum allocation is closely coupled with routing protocols to determine the best combination

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of route and spectrum. However, since numerous varieties of paths and ranges between the source and destination, it is infeasible to consider all possible links for spectrum decisions. Thus, in recent research, route selection is performed independent of spectrum allocation [Wang and Zheng.,2006]. Although this method is quite simple, it cannot provide an optimal route because spectrum availability on each hop is not considered during route establishment. Thus, a joint spectrum and routing decision method is essential for CRAHNs.

4.3 Routing Protocol

Current on-demand routing protocols, using CCC for the setup phase and the shortest route metric, need modifications before they can be used in a multichannel CR environment. First, new metrics and optimisation functions need to be devised to capture the collective spectrum opportunity for each candidate forwarding node. One such example metric is the bandwidth-footprint product, which measures the extent of the physical region unusable because of possible interference to the PUs in a given spectrum bandwidth. By minimising this metric, the routes can be chosen so that the CR users in the path avoid the regions where large sections of the licensed spectrum are rendered unusable.

The main decision undertaken during route setup is choosing between allowing the path to circumvent the affected PU activity region or switching the spectrum while maintaining the current direction toward the destination. In addition, the type of channel access technology and underlying physical layer capability may also strongly influence routing choices. For example, if a CR user device is equipped with a secondary ultra-wideband (UWB) radio, the routes may pass through the PU-affected regions without changing the spectrum. The UWB transmission is seen as noise by the PUs, but the limited transmission range increases the number of hops.

4.4 Reconfiguration

The protocols for different network stack layers must adapt to the channel parameters of the operating frequency. Once the spectrum is decided, CR users must select the proper communication module such as modulation types, error control schemes, and upper layer protocols adaptively to application requirements and spectrum characteristics, and reconfigure their communication system accordingly. For example, the spectrum bands used by CR users may not have uniform bandwidths. When the spectrum is changed on a given link, it may become a bottleneck or exhibit a significant capacity increase. Both these conditions affect the end-to-end delay and, in turn, the transmission rate of the source decided by Transport Control Protocol (TCP). Thus, the congestion window (CW) needs to immediately reflect the bandwidth conditions of the spectrum on the link.

5 SPECTRUM SHARING

Spectrum sharing provides the capability to maintain the QoS of CR users without causing interference to the PUs by coordinating the channel access and allocating communication resources adaptively. Thus, spectrum sharing is performed in the middle of a communication session and shares some functionalities with spectrum sensing, and figure 2 depicts its functional blocks for CRAHNs.

5.1 Resource Allocation

Based on local observation, CR users must perform channel selection and power allocation while choosing the best channel constrained by interference to other

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CRs and PUs. Cooperation among neighbours helps enhance the spectrum-sharing performance, especially in power allocation, which should be aware of the PU activities in the transmission range.

Game theoretical approaches have been exploited to determine the communication resources of each user in CRAHNs. Each CR user has a common interest in using the spectrum resources as much as possible. However, CR users have competing claims to maximise their share of the spectrum resources (i.e., one CR user's activity can impact others' activities). Furthermore, the rational decisions of a CR user must be undertaken while anticipating the responses of its rivals. Game theory provides an efficient distributed spectrum-sharing scheme by describing the conflict and cooperation among CR users, allowing each to decide rationally on its best action. Although the game theoretical approaches can achieve the Nash equilibrium, they cannot guarantee the Pareto optimum, leading to lower network capacity.

5.2 Spectrum Access

Sensing and transmission intervals, determined by sensing control, influence the performance of spectrum access, as explained previously. This functionality forms the core of the MAC protocols [Cormio and Chowdhury.,2009]. However, in CRAHNs, the sensing schedules are independent due to a lack of synchronisation over all users. Furthermore, CR ad hoc users may adopt periodic or on-demand sensing triggered by only spectrum-sharing operations (i.e., when CR users want to transmit or are asked for their spectrum availability by neighbour users). Based on the different spectrum access techniques, the design approaches for MAC protocols in CRAHNs can be classified as random access, time-slotted, and hybrid. In random access schemes, the channel may be opportunistically captured by any CR user for control and data exchange. In time-slotted protocols, the control and data are assigned fixed durations, preventing simultaneous transmission by multiple CR users. Finally, a hybrid scheme may have a specified time duration for control packets followed by random access for capturing the channel before data transfer. The MAC layer has the following key considerations to aid CR users in properly accessing the spectrum and communicating with each other.

5.3 Time Synchronization

Some MAC protocols need rigid synchronisation for control and data channels (slotted), while others have assigned slots for control signalling alone (hybrid). Slotted protocols may need network-wide synchronisation and have different places in the beaconing period for each CR user. This is difficult to achieve due to the distributed operation in CRAHNs and incurs scalability issues. In addition, in some slotted protocols, CR users hop over the channels broadcasting hello messages in a pseudo-random manner similar to Bluetooth. This results in an extensive coordination time and lowers spectrum utilisation efficiency. As the spectrum is available only for short durations, periodic hopping without data communication wastes the resource. Thus, we believe that random access is best suited for CRAHNs if there is an accurate spectrum sensing mechanism supporting it.

5.4 Spectrum Sensing Support

To improve the accuracy of spectrum sensing, PU transmission must be distinguished from other CR users in the same neighbourhood. If energy detection is used, one approach may involve establishing a silence zone up to two hops from the

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CR user currently performing sense. Another method uses multiple radios assigned distinctly to the control, data, and busy tone band, respectively [Ma et al.,2005]. Whenever a node transmits or receives data on a given channel, it also emits a busy signal in the uniquely mapped active tone band. Thus, during spectrum sensing, a CR user may check the busy tone to verify that the channel is genuinely unused by other CR users. In carrier sense multiple access (CSMA)-based protocols, a CR user undergoes a back-off for a small duration when the channel is sensed busy due to transmission by other users. This time could be utilised for spectrum sensing since the CR user is idle as it counts down its back-off timer. Moreover, in CR ad hoc mesh networks, the devices connected to the mesh router (MR) may piggyback their sensing results on the data packets and allow the MR to decide based on the collected information.

6 CONCLUSIONS

The examination work proposed a cross-breed zone-based steering convention for CRAHNS with a zone-building organiser technique utilised to develop the zone. Additionally, to figure out wellness angle to recognise better zone head hubs in the system. To perform directing utilising zone disappointment system, way disclosure, a decrease of excess communicates and course upkeep components. By effectively and opportunistically using frequencies set aside for licensed users of the bands, CR networks are intended to address the issue of spectrum scarcity. The spectrum sensing, spectrum decision, spectrum sharing, and spectrum mobility features must be incorporated into CR devices to achieve the objectives of entirely ubiquitous spectrum-aware communication. CRAHNs' primary problem is integrating these functions
into the various layers of the protocol stack so that the CR.

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