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Design and Evaluation of Cognitive Radio Ad hoc Networks Over TCP

Ashish Manusmare, * Ritu Chauhan
Electronics and Communication TIT, Bhopal ashishmnsmr@gmail.com
Assistant Professor, Electronics and Communication TIT, Bhopal
ritu_chauhan82@rediffmail.com

ABSTRACT—
Cognitive radio networks have emerged as a promising solution to the ever-growing demand for additional spectrum resources and more efficient spectrum utilization. Cognitive radio (CR) technology used for the vacant licensed frequency band, for improvement of the spectrum utilization. CR operation does not interfere with transmission of the licensed or primary user and this is getting by incurring a trade-off in the CR network performance. A key novelty of CRP is the local interference observation to packet observations to a packet forwarding delay over the control channel and mapping of spectrum selection metrics. This will allow the route formation to undertake over a control channel to capture the environmental and spectrum information for all the nodes, which reducing the computational overhead at the destination. The result of wireless network is unguaranteed. We can't say that the output of the wireless network always comes, because it depends on the connectivity of the network. On the other hand wired network gives the result because all the devices are connected with wired line. In this paper we are going to add TCP (Transport Control Protocol) to the CRP.

Keywords— Cognitive Radio, Transport Control Protocol, Optimization, Routing, Spectrum.

I. INTRODUCTION

The continuously increasing number of Wi-Fi devices has resulted in growing congestion in the crowded ISM bands, putting a potential limit on the evolution of Wi-Fi networking. On the other hand, some licensed bands, e.g., TV broadcast frequencies, remain largely underutilized. In order to satisfy the ever-growing public demand for additional spectrum resources, in November 2008 the FCC issued a ruling permitting unlicensed users (secondary users, SUs) to operate in the so-called white spaces, i.e., unused portions of the TV broadcast frequency band, as long as they do not interfere with licensed users (primary users, PUs). This ruling marks the arrival of cognitive radio networks (CRNs).

In CRNs, SUs have the ability to sense a wide spectrum range, dynamically identify currently unoccupied spectrum blocks, and choose the best available block to transmit, ensuring non-interfering coexistence with PUs [1]. While research on CRNs was initially focused on PHY/MAC layer issues (e.g., [2], [3], [4], [5]), soon the research community realized the great potential of multi hop CRNs. By exploiting the unoccupied frequency resources, the cognitive radio technology is expected to largely increase the capacity of multi hop wireless networks [6].

The main goal of Cognitive Radio (CR) technology is to enhance the spectrum utilization in the licensed frequencies and also alleviate the congestion in the 2.4 GHz ISM bond. As we above mansion recent research in this area has mainly focused on spectrum sensing and sharing issues in infrastructure based networks that relies on the presence of a centralized entity for collecting the spectrum information, allocating transmission schedule and deciding the best possible spectrum for use to the CR users served by it. Such architectures are generally singlehop, with each CR directly communicating with the central entity as a end destination. Thus, the application of CR technology is distributed scenarios is still in a nascent stage, and several open research challenges are outlined. This paper presents the combine architecture for CR with TCP protocol. These gives the advantages of the TCP protocol in the CR technology and create a new architecture for the mobile transmission network.

The goal of TCP CRAHN is to retain the window-based approach of the classical TCP, and at the same time introduce novel changes that allow its applicability in CR ad hoc networks. We would like to mention that the main merit of this paper lies in the theoretical design of a transport layer. The actual implementation on real software defined radios is currently limited by the lack of implementations for link layer and end to end network layer protocols. Thus, there are many practical issues that exist today, which make it difficult for demonstrating TCP CRAHN running on such radios, but we are hopeful that rapid advances will soon make this feasible.

II. RELETED WORK

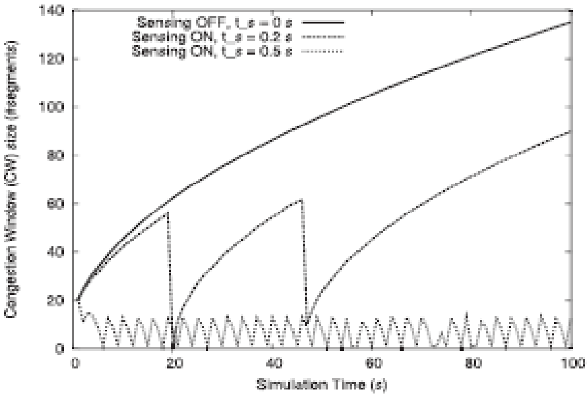
A. TCP (Transport Control Protocol)

TCP is an adaptive transport protocol that controls its offered load (through adjusting its window size) according to the available network bandwidth. It additively increases its congestion window in the absence of congestion and throttles down its window when a sign of congestion is detected. In the wired Internet, congestion is identified by packet loss, which results from buffer overflow events at the bottleneck router. However, it is unclear how well such TCP mechanisms work in a multihop wireless network.

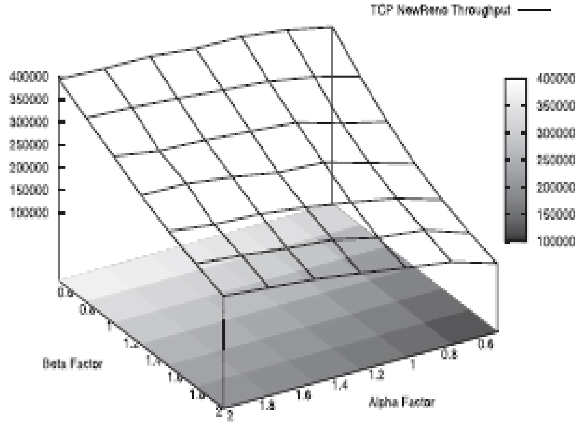
TCP, in general, is a well-researched area and several theoretical models exist that explain and predict its behavior in wireless networks [7]. TCP protocol is also implemented at the transport layer for the commercially available device. In addition to that, ad hoc network also uses ferry user traffic to and from receiving configuration commands from remote stations, the external infrastructure network. TCP is have very high standard in the wired world and have a very high compatibility with existing infrastructure useful from the network management perspective. Transport protocol is well known topic in traditional ad hoc network, but it is quit unexplored in the CR networks. It is also well known that traditional TCP implementation which runs over the internet (e.g. TCP SACK [8], new Reno [9] and TCP Vegas [10]) perform poorly over wireless links because of the additional data losses caused by node mobility or by bad channel conditions, which are may misinterpreted as indicator of network congestion. Because of this there are several transport protocol have been proposed for wireless ad hoc networks by using cross-layer or layered approach. Example of first approach of this is, The Ad Hoc TCP protocol (ATCP) [11] leverages network feedback from intermediate nodes to distinguish packet losses caused by bad channel errors or by mobility rather than by network congestion.

In TCP network protocol network feedback and cooperation among layer of protocol model are also used by Sundaresan et al [12]. In this layer approach, the source nodes does not depend on feedbacks from intermediate node but it is analyzes the correlation between TCP events to find the cause of data packet loss. This is also caused the TCP-RTO [12] protocol and TCP-DOOR [13] protocol. There is lots of literature on how to enhance the performance of TCP by designing novel solution of the MAC or link layer without modifying the existing TCP standard [13]. We also highlight that all these protocols are not suitable for CR network because they not consider the special characteristic of the CR network.

There are some works investigating the performance of classical TCP over CR network and some of them addressed the design of novel transport protocol solution. Sligerland et al [14] and Kondareddy and Agrawal [15] provide insight on effect of dynamic spectrum access (DSA) links over TCP performance.



(a)



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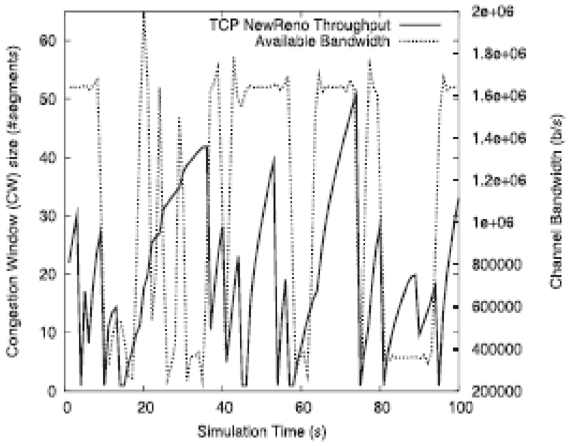


(c)

Fig. 1. (a) A study of the cwnd size as a function of the varying sensing time. (b) The impact of different PU activity on TCP throughput is investigated.(c) The effect of changing channel bandwidth on cwnd. All simulations are undertaken in ns-2

B. GENERAL AD HOC NETWORK

In the multi-hop single-transceiver CR routing protocol (MSCRP) [19], analogous to the classical AODV, the RREQ is forwarded over all the possible channels to the destination. The latter then decides on the spectrum selection for the shortest path based on analytical estimates of the time for spectrum switching, channel contention, and data transmission. Similarly, the best routing paths are first identified and *then* the preferred channels along the path are chosen in [20]. In both these works, the sequential path selection and spectrum allocation does not guarantee that spectrum is available along the path optimized for classical metrics, such as latency or hop count. Moreover, the flooding of the RREQ in all the channels of the spectrum or using the RREQ packet transmitted over the CCC to carry information of the entire spectrum [20] raises concerns of scalability. The protocol proposed in [15] uses a combination of routing and link scheduling to reduce intra- CR interference and spectrum switching costs. A multi-agent learning approach named adaptive fictitious play is described in [13]. The CR users exchange their channel selection information periodically that also provides information of the extent to which the different classes of traffic (delay sensitive or otherwise) on a given channel is affected. The fictitious play algorithm learns the channel decision strategies of the neighboring CR users over time to identify the channels that are likely to be used by them. However, it is not clear how long the network would take to converge on the optimal solution, with the assurance of a stable operating point in the presence of varying PU activity.

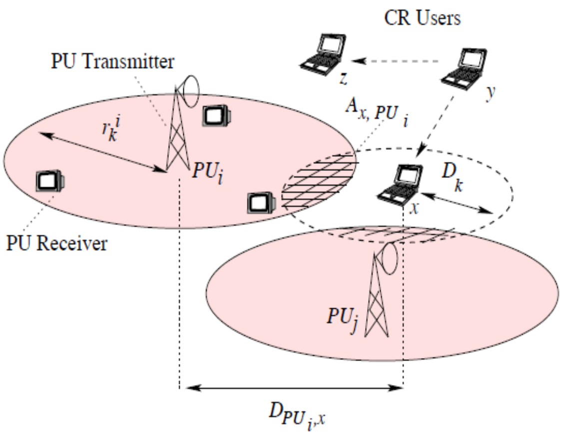


Fig. 2. General Ad hoc Network, Choosing next hop forwarding nodes based on spectrum selection.

C. TCP CRAHN: A TRANSPORT PROTOCOL FOR CR AD HOC NETWORKS

TCP CRAHN comprises of the following 6 states, as shown by the state diagram in Fig. 2. They are

1. Connection establishment,
2. Normal,
3. Spectrum sensing,
4. Spectrum change,
5. Mobility predicted, and
6. Route failure.

Each of these states addresses a particular CR network condition and we describe them in detail as follows.

1. Connection establishment

TCP CRAHN modifies the three-way handshake in TCP newReno so that the source can obtain the sensing schedules of the nodes in the routing path. First, the source sends out a Synchronization (SYN) packet to the destination. An intermediate node, say i, in the routing path appends the following information to the SYN packet: 1) its ID, 2) a timestamp, and 3) the tuple (t_i^1, t_i^2, t_i^3). Here, t_i^1 is the time left before the node starts the next round of spectrum sensing, measured from the timestamp. t_i^2 is the constant duration between two successive spectrum sensing events, and t_i^3 is the time taken to complete the sensing in the current cycle. On receiving the SYN packet, the receiver sends a SYN-ACK message to the source. The sensing information collected for each node is piggybacked over the SYN-ACK and thus, the source knows when a node in the path shall undertake spectrum sensing and its duration. The final ACK is then sent by the source to the destination completing the handshake.

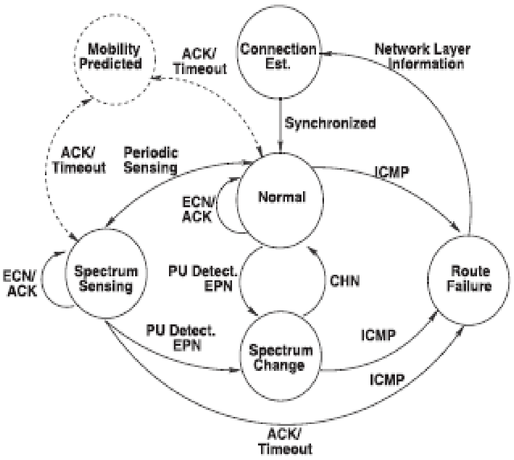


Fig. 3. Finite state machine model of TCP CRAHN.

The calculation of the sensing time t_i^s by a node i is undertaken locally. Based on the bandwidth of the channel (W), the external signal to noise ratio (γ), and the probabilities of the on period (P_{on}) and the off period ((P_{off}), a framework to calculate this time is given as follows :

$$t_i^s = \frac{1}{W\gamma^2}[Q^{-1}(P_f) + (\gamma+1)Q^{-1}(\frac{P_{off}P_f}{P_{on}})]^2$$
(1)

Equation (1) gives the sensing time t_i^s that minimizes the probability of missed primary user detection P_f, i.e., incorrectly stating the channel is vacant when indeed there is an active PU and Q is the standard Q function.

2. Normal State

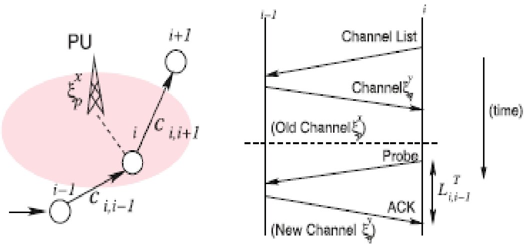
The normal state in TCP CRAHN is the default state and resembles the classical functioning of the classical TCP newReno protocol. Our protocol enters this state when 1) no node in the path is currently engaged in spectrum sensing, 2) there are no connection breaks due to PU arrivals, and 3) no impending route failure is signaled. Thus, the path to the destination remains connected and ACKs sent by the latter are received at the source.

3. Spectrum Sensing State

This describe how TCP CRAHN adapts to spectrum sensing through 1) flow control, which prevents buffer overflow for the intermediate nodes during sensing and 2) regulating the sensing time to meet the specified throughput demands.

4. Spectrum Change State

In the ideal case, the effective bandwidth of the TCP connection is dependent on several factors, such as contention delays and channel errors at the link layer, apart from the raw bandwidth of the channel. In this section, we show how TCP CRAHN scales its cwnd rapidly, say from point B to a different value B', in Fig.4 (b), accounting for these factors, so that the available spectrum resource is most efficiently utilized.



(a) **(b)**

Fig. 4. (a) The PU interference scenario and (b) the link layer total delay estimation.

5. Mobility Predicted State

In order to address the problem of delayed route failure notification, the mobility prediction framework based on Kalman filter-based estimation [17], which uses the Received Signal Strength (RSS) information from the link layer. We construct the set of Kalman equations similar to the disposition for calculating sensor location in [18], but for a simpler, scalar case of a single dimension of the received power value. Formally,

$$x^K = Fx^{K-1} + Gu^{K-1} + Bw^{K-1}$$

describes the transition between the states for the system used for predicting the new RSS value (i.e., x^K) at the K_{th} iteration, using the previous prediction (i.e., x^{K-1}), and current control input or observed RSS value (i.e., u^{K-1}), and the variable wk represents discrete random changes owing to fading or multipath.

6. Route Failure State

The node i sends a destination unreachable message in the form of an ICMP packet if 1) the next hop node i + 1 is not reachable based on link layer retries, 2) there is no ongoing spectrum sensing based on the last known schedule, and 3) no EPN message is received at node i signaling a temporary path disconnection due to PU activity. At this stage, the source stops transmission and a fresh connection needs to be formed over the new route by TCP CRAHN.

III. PROPOSED METHOD

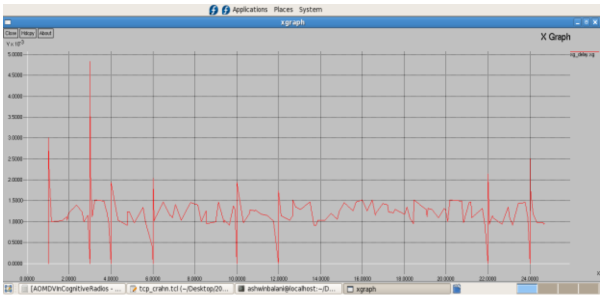
Cognitive radio (CR) technology enables the opportunistic use of the vacant licensed frequency bands, thereby improving the spectrum utilization. However, the CR operation must not interfere with the transmissions of the licensed or primary users (PUs), and this is generally achieved by incurring a trade-off in the CR network performance. In order to evaluate this trade-off, a distributed CR routing protocol for ad hoc networks (CRP) is proposed that makes the following contributions: (i) explicit protection for PU receivers that are 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.

In this paper we proposed a method to collaborate the Cognitive radio (CR) technology with the TCP Ad hoc network. This gives a method TCP CRAHN (Transport Control Protocol for Cognitive Radio Ad Hoc Network). This proposed method acquired the all advantage of the wired network in the CR wireless network. In this paper, we consider CR Ad Hoc Networks (CRAHNs) that do not have a centralized entity for obtaining the spectrum usage information in the neighborhood, or external support in the form of a spectrum broker that enables the sharing of the available spectrum resource. Thus, compared to infrastructure-based networks, relying on local decisions makes the problem of node-coordination and end-to-end communication considerably more involved. While the mobility of the intermediate nodes and the inherent uncertainty in the wireless channel state are the key factors that affect the reliable end-to-end delivery of data in classical ad-hoc networks, several additional challenges exist in a CRAHN. The periodic spectrum sensing, channel switching operations, and the awareness of the activity of the Primary Users (PUs) are some of the features that must be integrated into the protocol design.

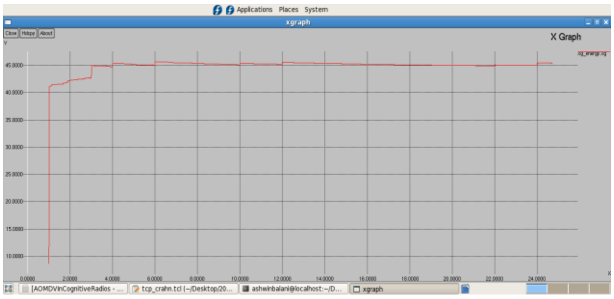
IV. EXPERIMENTAL RESULTS

Following results are obtained if we do not apply Cognitive Radios on TCP based networks,

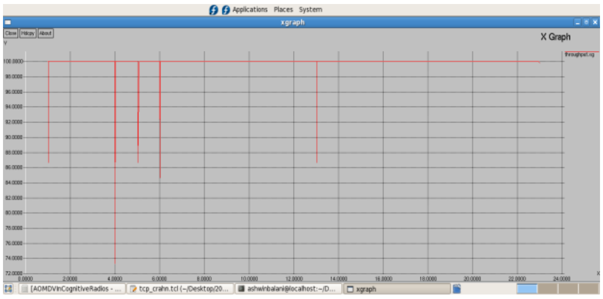
The graph for delay is shown as follows, it indicates that we are getting a communication delay of about 5 milliseconds if we do not apply CRAHN on TCP



The graph for energy is shown as follows, it indicates that the network consumes about 45 mJoules of energy if we do not apply CRAHN on TCP

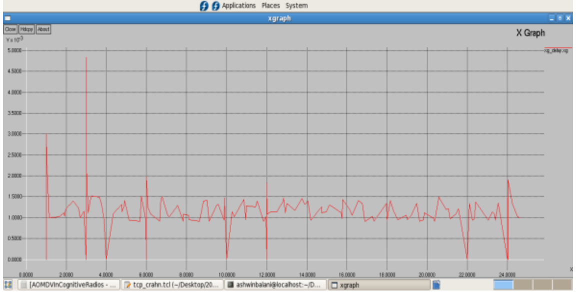


The graph for packet delivery ratio is shown as follows, it indicates that we are getting a minimum pdr of 60% if we do not apply CRAHN on TCP

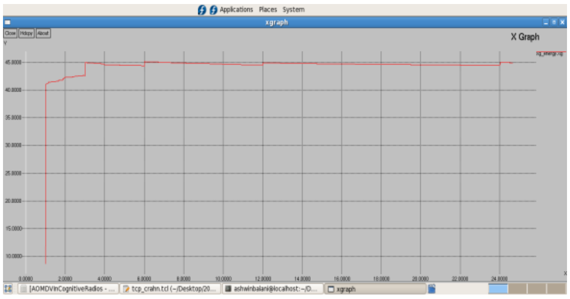


After application of CRAHN on TCP we get the following results,

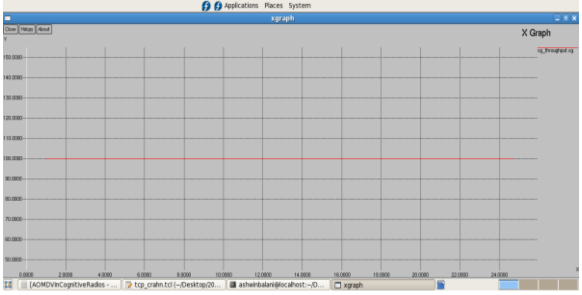
Delay is similar to TCP networks



Energy is reduced by 1 mJoules, which can be considered approximately same



Packet delivery Ratio with CRAHN has increased to 100%, and is maintained at 100% due to proper spectrum utilization in Cognitive Radio networks



V. CONCLUSION

TCP networks give a very good delay and energy efficiency with or without the cognitive radio concept, but after application of cognitive radios we get a tremendous increase in the packet delivery ratio, which is due to proper spectrum utilization. In CR, the spectrum is properly allocated thus there are minimal packet losses, and the network efficiency increases, thereby we conclude that Cognitive radios can increase the packet delivery rate of the current TCP systems and thereby reduce packet retransmissions

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