A New Enhanced TCP-CRAHN: Transmission Control Protocol in Cognitive Radio AdHoc Networks

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Abstract— Cognitive Radio (CR) networks allow users to opportunistically transmit in the licensed spectrum bands, as long as the performance of the Primary Users (PUs) of the band is not degraded. Consequently, variation in spectrum availability with time andperiodic spectrum sensing undertaken by the CR users has a pronounced effect on the higher layer protocol performance, such as at the transport layer. This paper investigates the limitations of TCP CRAHN in a CR ad hoc network environment, and proposes TCP rate adapting protocol. Our approach incorporates service interruption losses as a secondary user try to handoff the channel to the primary user. Transport layer protocol's performance of an SU could be degraded significantly as it tries to handoff channel due to the arrival of PU. This paper presents a study of the challenges of spectrum handoff as PUs in CR networks appears in the course of an on-going transmission by the SUs. A TCP rate freezing algorithm that ensures seamless spectrum handoff as PUs appear is proposed.

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Index Terms— Cognitive radio, Congestion control, Flow control, Spectrum sensing, Service interruption, Spectrum handoff

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1 INTRODUCTION

The emerging field of Cognitive Radio (CR) networks attempts to alleviate the problem of spectrum scarcity in the ISM band by opportunistically transmitting on other vacant portions of the spectrum, such as frequencies licensed for television broadcast and public services. 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. For these reasons, protocol development at the higher layers of the network stack for CR ad hoc networks, involving end-to-end communication over multiple hops, is still in a nascent stage. In this paper, we propose a window-based, TCP spectrum handoff transport layer protocol for CR ad-hoc networks.

The concept of Cognitive Radio (CR) which enables a wireless device to sense the environment and adapt itself accordingly, though has been with us for some time now, still remained elusive because most its expected functionalities/potentialities are yet to be fully explored.
This concept could alleviate the radio resource shortage if carefully and efficiently deployed. The need to guarantee smooth transmission of delay-sensitive multimedia data in the presence of licensed primary users is a challenging research area.

The prospect of having a CR network in which a secondary user (SU) can take advantage of DSA to use primary users' (PU) channels when available introduces a different type of packet loss called the service interruption loss. The service interruption loss arises as secondary users try to handoff the channel to the legitimate users of the channels, the primary user. This new type of loss is different from losses as a result of network congestion and channel errors, experienced also by conventional wireless networks. Transport layer protocol's performance of a SU could be degraded significantly as it tries to handoff channel due to the arrival of a PU. The need to investigate SU's TCP performance during this period of sensing the presence of a PU, handing-off of channels due to the arrival of a PU, and looking for an alternative channel to continue transmitting serves as a motivation for this project.

In this paper, we investigated some of the research challenges of CR technology and identified notable problems which make TCP implementation in CR networks different from that of the conventional wireless network.

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In Fig 1 Consider a chain topology formed by the source S, destination D, and intermediate forwarding nodes. If the node 2 is performing spectrum sensing, then for that duration, it is unable to send or receive packets, resulting in a virtual disconnection of the path. Consequently, the data packets in node 1 and moving toward D, and acknowledgments (ACKs) in node 3 for the source S both experience greater queuing delays. If a timeout indeed occurs, the source is immediately penalized and the rate of sending data is drastically reduced. Similarly, consider the case in which the spectrum used by node 4 is reclaimed by the PUs, and it must immediately cease transmission. There is a finite time duration in which node 4 must identify a new spectrum, switch its transceivers, and coordinate this choice with its neighbors.

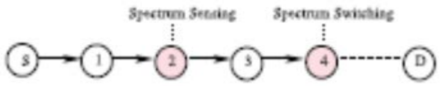

Fig.1. A multiple Hop CR-AdHoc Network

Thus, in both the above cases of spectrum sensing and switching, the source may mistake the increased RTT (or timeouts caused by this increase) for congestion. In TCP CRAHN, we rely on the intermediate nodes periodically piggybacking their spectrum information on the ACKs, or in times of a sudden event like a PU arrival, explicitly notifying the source. While several works have focused on spectrum sensing algorithms in the last few years, the integration of the channel information collected at the nodes and the performance study of these approaches from the viewpoint of an end-to-end protocol remains an open challenge. TCP, in general, is a well-researched area and several theoretical models exist that explain and predict its behavior in wireless networks. It is also implemented at the transport layer for commercially available devices. In addition, the ad hoc network may ferry user traffic to and from the external infrastructure network, receiving configuration commands from remote stations.

We propose a TCP rate adapting algorithm with the aim of ensuring seamless spectrum handoff of channels by SUs as PUs appear in order to transmit their data. The rest of this article is organized as follows. A concise survey of the CR networks is first presented, with an objective to highlight the characteristics of the CR networks, its capabilities, and architectural taxonomies. A detailed study on transport layer research issues and challenges in CR networks is then presented. This helps to identify the spectrum handoff challenges and present the proposed rate adapting algorithm to handle this problem. We conclude with the highlights of some of the algorithmic design issues that need to be considered in order to implement the proposed algorithm and future research direction.

2 ACCESS METHODS OF CR NETWORKS

Broadly speaking, two types of access methods exist for CR networks:

2.1 Overlay CR Networks: this approach is otherwise known as the interference-free approach. The secondary/unlicensed users only access part of the spectrum that is not occupied by the licensed/primary users.

2.2 Underlay CR Networks: in this configuration (otherwise called, interference-tolerance approach), unlicensed or secondary users operate below the noise level of primary users by spreading their signals over the available spectrum. The unlicensed users could interfere with licensed users to a certain tolerable extent.

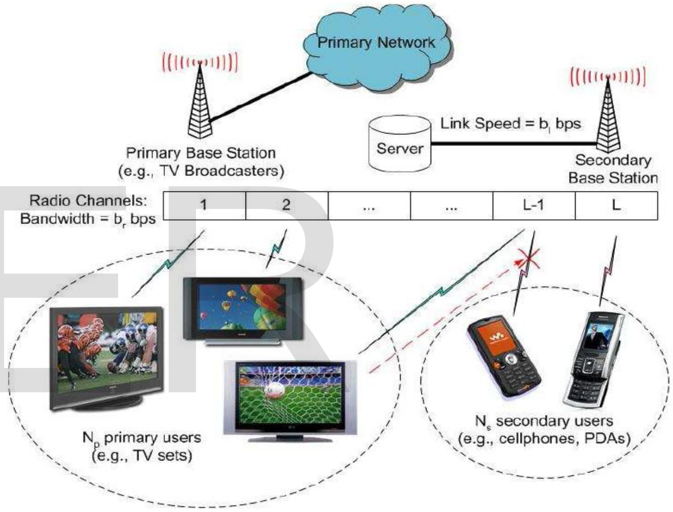

Fig. 2. System model of CR network

3 Architectural Taxonomies of CR Networks

Two generalized architectural taxonomies exist for CR networks:

3.1 Centralized CR Network Architectures

These consist of two main entities namely, the base station that schedules user's data transmission; and the spectrum broker or a dedicated entity dealing with spectrum allocation that allocates the radio resources to users of the CR networks. In this architecture, the sensing functionality is done by the spectrum broker or secondary users.

3.2 Distributed CR Network Architectures

This is similar to the conventional wireless *ad hoc* networks with the exception of the presence of secondary network users. It does not have a central agent (spectrum broker or base station) coordinating secondary users' spectrum access. This type of architecture brings about the concept of service interruption.

4 Challenges of Cognitive Radio Networks

4.1 Cognitive Radio Network Application Challenges

The emergence and the eventual dominance of CR networks along with vast application potentials brought a huge amount of challenges that are intense in their complexities and concern. For instance, utilizing unused spectrum involves discovering the spectrum hole. This process might be misguiding in the sense that primary user absence is only determined by SNR to indicate availability of spectrum. It was believed that any large or small scale fading could cause a dip in the signal strength that may lead to a wrong conclusion. If primary user's presence is detected through collaborative effort of secondary users, this will impinge on the power consumption of secondary users. It is no gainsaying that power management is a very crucial factor in CR network. Identifying the exact transition time when a secondary user needs to hand over the spectrum to the primary user could also be very challenging.

Evaluating the suitability of a new available spectrum for usage and selecting the best channel among available multiple channels could also be very challenging. The channel's parameters in terms of channel width, bandwidth, rate, etc. needs to be evaluated before such a decision is taken and this could be a complex process. Should a secondary user grab as many channels as are available and use them for transmission or should he judiciously selected a certain amount are some of the challenging issues that need to be addressed in CR networks.

Another challenging issue was the power level control of each user in the presence of multiple concurrent users over the same band (such as multiple users on ISM band), to mitigate undesired interference. The need to address and protect privacy through encryption and encoding techniques in such a scenario was also emphasized .

Charging the SU for spectrum usage is a topic that seems intractable as well. The licensed spectrum services are provided to the consumers through a pre-established pricing mechanism. In order to avoid unnecessary exploitation of secondary spectrum and to eliminate unfairness to the licensed owner, some pricing mechanism needs to exist for secondary usage.

- Summarizing the above mentioned challenges, the following open research issues that need to be examined for the full deployment of the CR networks are identified:
- Reliably detecting primary user signals through spectrum sensing.
- Spectrum capacity estimation and different QoS requirements necessitates new adaptive spectrum decision models.
- New mobility and connection management approaches need to be designed to reduce delay and loss of information during spectrum handoff.
- Novel algorithms are required to ensure that applications do not suffer from severe performance degradation when they have to be transferred to another available frequency band due to the appearance of a primary user.

4.2 Service Interruption Loss in CR Networks

Most of packet losses in wireless network can be attributed to channel errors due to fading, interference and shadowing or packet collisions due to simultaneous access of the channel by more than one mobile user. The concept of DSA introduces another type of loss experienced by secondary users due to the intervention of primary users while transmitting the data. This is regarded to as the service interruption loss for the secondary users of an overlay CR network Solutions to improve TCP performance in the presence of losses due to channel errors and packet collisions have been studied extensively and grouped as end-to-end solutions, split-connection solutions, or link-layer solutions.

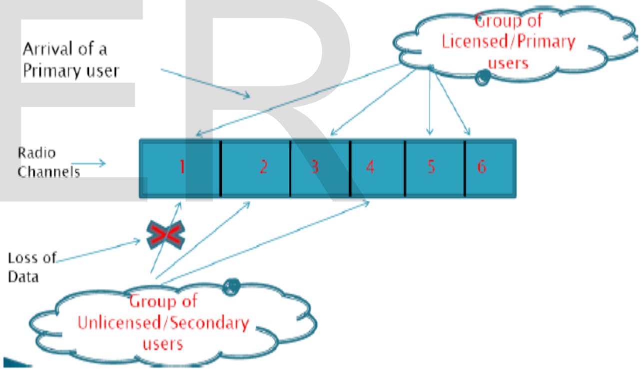

Fig. 3. Service interruption loss

4.3 Proposed TCP Rate Adaptive Algorithm for Spectrum Handoff in CR Networks

To provide seamless communications, spectrum mobility gives rise to a new type of handoff, the so-called spectrum handoff, in which users transfer their connections to an unused spectrum band. New mobility and connection management approaches need to be designed to reduce delay and loss of information during spectrum handoff. Novel algorithms are required to ensure that applications do not suffer from severe performance degradation when they have to be transferred to another available frequency band due to the appearance of a primary user. In order to allow *cwnd* in TCP to scale appropriately to meet the new channel conditions periodic spectrum sensing, channel switching operations, and the awareness of the activity of the primary users (PUs), the

TCP rate control algorithm is proposed so that these features could be integrated into the protocol design.

Spectrum handoff can be implemented based on two different strategies. In reactive spectrum handoff, CR users perform spectrum switching after detecting link failure due to spectrum mobility. This method requires immediate spectrum switching without any preparation time, resulting in significant quality degradation in on-going transmissions. On the other hand, in proactive spectrum handoff CR users predict future activity in the current link and determine a new spectrum while maintaining the current transmission, and then perform spectrum switching before the link failure happens.

The proposed TCP rate adapting algorithm was designed to handle spectrum handoff using proactive spectrum handoff strategy. This ensures that the current transmission is maintained while searching a new spectrum band and the spectrum switching is faster.

TCP rate is frozen or reduced during the period that the SU senses the current channel for the arrival of a PU as well as when it senses an alternative channel to move its transmission to when the PU eventually arrives. With this implementation, the service interruption loss is reduced significantly and the TCP cwnd is maintained in such a way that it could take the advantage on any sudden increase in bandwidth, as well as reducing its rate when there is lower bandwidth without significant data loss. This design will also ensure that the network stays connected throughout the handoff procedure.

4.4 TCP Rate Adaptive Algorithm

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Periodic sensing for PU arrival
Reduce TCP rate
Is PU about to arrive?
If yes
    Freeze the TCP
    Buffer on-going transmission
    Scan for available free channels
    Is free channel available?
    If yes
        Based on parameters select channel
        Handoff present channel to arriving PU
        Switch to newly discovered channel
        Resume TCP normal operation
    Else signal route failure
Else
    Scan for available channels
    Record ON and OFF time of sensed
    channels
    Resume TCP normal operation
```

For this improved TCP protocol to be functional, the design must capture the frame error information provided at the lower level layer protocols of a CR Network so as to assist packet level error recovery at the higher level protocol (e.g. Transport layer). This will help to avoid unnecessary packet dropping due to spectrum mobility enable the users to exploit benefits offered at the lower layers of the CR network thereby observing, reacting, learning and adapting to the environment.

4 CONCLUSION

In this paper, we have elaborated on the different performance problems that engender as a result of using TCP over Cognitive Radio networks. We presented the effect of the new type of loss, called the service interruption loss, which is introduced by the concept of Dynamic Spectrum Access. TCP performance under this loss in a CR Network is different from that of conventional Network. There is a need to redesign TCP to meet with this new challenge. A TCP rate adapting Algorithm that ensures seamless spectrum handoff as PUs appears is proposed. Algorithmic design issues that need to be considered for its successful implementation were copiously analyzed.

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