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Implementation of relay based collaborative spectrum sensing using coalitional games in wireless cognitive radio networks ☆

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ABSTRACT

Collaborative spectrum sensing is used by Secondary Users (SUs) in Cognitive Radio Networks to improve spectrum detection performance. To study its performance, Normal Collaborative Spectrum Sensing (NCSS) based on coalitional games is designed and implemented in *Wireless Open-Access Research Platform*. The SUs which detect weak signal from Primary Users collaborate with Cluster Head (CH) to improve the overall sensing performance indicated by sum-utility of the system. However, the test-bed implementing NCSS shows that under poor reporting channel conditions, the coalition splits and the 'weaker' SUs exhibit inefficient sensing performance. The proposed Relay based Collaborative Spectrum Sensing (RCSS) solves this problem by using neighboring SU with low error prone relay path to share sensing results between affected SUs and CH. Test-bed results reveal that RCSS performs better than all other collections of coalitions and it improves sum-utility by 20%, as compared to NCSS at the cost of minimal 2.3% loss in energy efficiency.

1. Introduction

In recent years there has been an increasing demand of wireless services. However, traditionally spectrum is licensed to operators and each system has to operate within a limited frequency band. As the unlicensed spectrum is already congested, there is a need to find new ways to exploit licensed radio spectrum. Recent studies have shown that the actual licensed spectrum remains unoccupied for large periods of time [1] termed as 'white spaces'. Cognitive Radios (CRs) [2,3] can be used to sense these 'white spaces' and the opportunistic users who seek idle channels of licensed Primary Users(PUs) are called the Secondary Users (SUs). The SUs can share the spectrum with the licensed PUs without causing harmful interference to them; thereby providing higher data throughput with respect to different applications [4].

The problem of spectrum sensing has been discussed widely [5]. Individual spectrum sensing by SUs is insufficient as CRs experience multipath and shadow fading and may not detect the PU's signal. So, a SU which failed the detection of PU may begin transmission and interfere with the PU. However, it is unlikely that all SUs in a network experience the same amount of fading; most of them would detect the correct PU signal. By cooperating with each other, the sensing results may be communicated to other users. Therefore, cooperative spectrum sensing [6] is an attractive and effective approach to combat multipath fading, shadowing and the receiver uncertainty problem.

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A traditional approach to cooperative spectrum sensing is by relying on a centralized fusion centre [7] (FC). However, SUs belonging to different service providers might need to interact with each other for collaboration without relying on FC. Also, a centralized approach can lead to significant overhead and increased complexity. In [7], Collaborative Spectrum Sensing (CSS) through coalitional games has been shown to provide a distributed alternative to cooperative sensing. In this model, SUs autonomously collaborate and self-organize into disjoint independent coalitions. Based on coalitional game theory, Li et al. [8] investigated cooperative spectrum sharing between multiple operators. The resource allocation problem in a multichannel CR network consisting of multiple PUs and SUs through a coalitional game theoretic approach is studied in [9].In this regard, Hao et al. [10] presents a solution for improving the energy efficiency of co-operative spectrum sensing.

However, most of these works focus on theoretical research and software simulation, which need further validation on practical hardware platform to see the performance in real situation and feasibilities of implementation.*Wireless Open-Access Research Platform (WARP)* developed by Rice University [11] is a currently used hardware platform for CR research. WARP is a scalable and extensible programmable wireless platform, to prototype advanced wireless networks. It provides an ideal platform to setup real cognitive environment. To the best of our knowledge CSS has not been implemented on real wireless cognitive scenario using WARP for experimental verification. In this paper, we have implemented Normal Collaborative Spectrum Sensing (NCSS) in WARP board designing a cognitive radio transmission. Performance analysis of the system has been done and results show that the probability of miss detection decreases at the cost of increased probability of false alarm. A short version of the implementation can be found in our paper [12]. The implementation in this paper differs from [12] in the sense that we have used Neyman–Pearson (NP) technique [13] for sensing whereas [12] discusses the Bayes' technique to implement spectrum sensing based on coalitional games on WARP. In Bayes' approach the individual detection threshold of SUs are determined from a PR activity pattern (in this case exponential ON–OFF distribution) and is used for evaluating the probability of false alarm and probability of detection. However, in NP test the false alarm probability is fixed and the detection threshold and probability of SUs are evaluated. Due to this computational simplicity of NP technique, we redesign our system described in [12] with significant modifications.

In this paper, the behavior of a simple two user CRN performing NCSS using coalitional games has been studied in practical test bed scenario. The effectiveness of NCSS in increasing the detection probability of the SUs at the cost of increasing false-alarm rate has been discussed. Due to varying environmental conditions and SU mobility, a coalition that has been setup can also split. A SU which once enjoyed favorable conditions and formed part of a coalition can experience poor reporting channel conditions having high error probability. Such a scenario does not support cooperative communication. According to the merge-and-split rules discussed in [7], the SU will leave this coalition if it yields a more preferred collection of coalitions based on certain metrics. The SU which leaves this coalition might merge with another suitable cluster. In case there is no other surrounding coalition available for this SU to merge with, it will perform individual spectrum sensing and a miss-detection will cause undue interference to licensed users. This motivated us to take a detailed look into this particular scenario, to see if the removal of the SU from the coalition can be prevented.

Relay based cooperation is an interesting paradigm in which CR radios have the potential of creating tremendous impact. In its simplest form, co-operative communication [14] consists of an intermediate node, which relays data between the transmitter and receiver located far away from each other, in case of a weak direct communication link between them. It result in an improvement in the link quality and in turn the system capacity. Communication using multi hop relays not only helps in overcoming path loss and achieve power gain, but also adds multipath diversity, critical to wireless communication over fading channels. Broadly speaking, cooperative protocols are of two kinds [15]: (1) *Amplify-and-forward*(AF) and (2) *Decode-and-forward*. It is shown that the AF protocol [15], in which the relay transmits the signal obtained from the transmitter without any processing, achieves full diversity. The effects of AF protocol on spectrum sensing capabilities of cognitive radio network (CRN) have been studied in [16].

In the second part of this paper, we introduce relay based cooperation into coalitional games, to prevent SUs from leaving a coalition when they do not benefit from the splitting. We name this system as Relay based Collaborative Spectrum Sensing (RCSS). In this paper, we show through WARP implementation that, neighboring SUs which provide a low error prone path within a coalition can be used as relays to share individual detection bits within a cluster. RCSS can be a better alternative as compared to normal merge-and-split operations. Hence two primary objectives of this paper are:

(1) To analyze the performance of NCSS in real CR environment using WARP nodes as trans-receivers.
(2) To justify the effect of introduction of relay based sharing of detection bits in the coalitional game based CSS framework for a CR environment using WARP test-bed.

The organization of the paper is as follows: In Section 2, a brief overview of NCSS is provided, the significance of the terms used throughout the paper are discussed. The proposed RCSS is also explained. Section 3 provides the implementation of both NCSS as well as RCSS in WARP test-bed to observe its performance in real wireless cognitive radio scenario. Section 4 discusses the exhaustive test bed results. The importance of coalitional game based CSS and its drawbacks revealed by the results are studied. The effect of incorporation of relay based cooperation within the existing framework is studied against all scenarios possible for RCSS, and the improvement in sum-utility is shown. The energy efficiency of RCSS with respect to NCSS is also experimentally evaluated. Finally, in Section 5, the conclusion of the paper is presented.