Energy Efficient Collaborative Spectrum Sensing in Cognitive Radio Networks

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Abstract

Depending on trust management, an energy efficient collaborative spectrum sensing (EE-CSS) protocol is put forward. In contrast to the traditional collaborative spectrum sensing (T-CSS), here we are attaining energy efficiency by limiting the overall count of sensing reports exchanged between the honest secondary users (HSUs) and the secondary user base station (SUBs). In EE-CSS, it is concluded that the least total count of sensing reports needed to fulfill a target global false alarm (FA) and missed detection (MD) probabilities in T-CSS is more. We are calculating steady-state average SU trust value and total count of SU sensing reports transmitted in both T-CSS and EE-CSS. Derivations are made for the global FA and detection probabilities Qf and Qd for a data fusion method. The effect of link outages on Qf and Qd are also examined. The output tells that the energy consumption in T-CSS is comparatively higher than in EE-CSS for long range communications where the transit energy is dominant.
Keywords- EE-CSS Protocol T-CSS, Data Fusion Techniques

I. INTRODUCTION

The radio frequency spectrum is a limited natural resource to enable wireless communication between transmitter and receivers. Licenses are usually required for operation on certain frequency bands. The entities of an incumbent network are called primary users (PUs), while the entities of a CRN are called secondary users (SUs). Each SU is equipped with one or more cognitive radios which are capable of identifying available channels (i.e., not occupied by PUs) and hopping between them. In addition, SUs should locate each other via a “rendezvous” process.

In the process of rendezvous, SUs meet and establish a link (i.e., exchange control information) on an available channel, so that data communication can be carried on. However, implementation of rendezvous is challenging because SUs are not aware of the presence of each other before rendezvous and available channels sensed by each SU may be different Common control channel is probably the most well-known approach for rendezvous.

A dedicated channel is chosen to exchange control information as it is named. However, maintaining common control channel in CRNs is not easy. The availability of dedicated control channel may change over time. Once a PU continuously occupies the common control channel for a long time, all of the control message exchange will be “blocked” during the long duration, called CR longtime blocking problem. Although a new common control channel can be chosen and established according to channel availability updating channel availability information causes a considerable overhead. Moreover, a single control channel usually becomes a bottleneck and causes the control channel saturation problem in high-node density or high-traffic-volume environments.

II. PROBLEM STATEMENT

A S.Esakki Rajavel et al. [6] energy efficient spectrum sensing is proposed. The protocol achieves energy efficiency by reducing the total number of sensing reports exchanged between the honest secondary users (HSUs) and the secondary user base station (SUBS) in a traditional collaborative spectrum sensing (T-CSS) protocol. It is shown that the minimum total number of sensing reports required to satisfy a target global false alarm (FA) and missed detection (MD) probabilities in T-CSS is higher than that in EE-CSS. Expressions for the steady-state average SU trust value τ and total number N of SU sensing reports transmitted are derived, as is an expression for the energy consumption, in EE-CSS and T-CSS. The global FA and detection probabilities Qf and Qd are obtained for a commonly used decision fusion technique. The impact of link outages on τ, N, Qf, and Qd is also analyzed. The results show that the energy consumption in EE-CSS can be much lower compared to that in T-CSS for long range communications where the transmit energy is dominant. The system model is shown in Fig 1.We assume that there are H HSUs and M MSUs for a total of N=H+M+1 sensing entities (including the FC) in the CRN. Without loss of generality, we assume that the HSU are numbered from 1 to H and the MSUs are numbered from H+1 to H+M, i.e., h∈{1,2, . . . ,H} and m∈{H+1,H+2, . . . ,H+M}. There is one SUBS and one primary user base station (PUBS). The PUBS communicates with the PUs using the licensed band and the SUBS communicates with SUs via the unlicensed and licensed bands. SUs can only communicate with the SUBS. We assume that the PUBS and SUBS can communicate so that the PUBS can send the band-state matrix (BSM) to the SUBS periodically; this matrix includes the state of the licensed band for the past R time slots. The licensed band is divided into V sub-bands, Bv, v=1,2, . . . ,V, and each SU can only sense one band at any given time. The FC may allocate one or more SUs to sense a band in each time slot in EE-CSS. Hereafter, we assume that the FC requests all SUs to sense one band. EE-CSS can be generalized to the case in which the FC allocates subgroups of SUs to sense different sub-bands. The BSM allows the FC to calculate the accuracy of its own reports in addition to the accuracy of the reports from SUs. The FC uses the accuracy value calculated from the past reports of an SU to weight future reports from the SU.

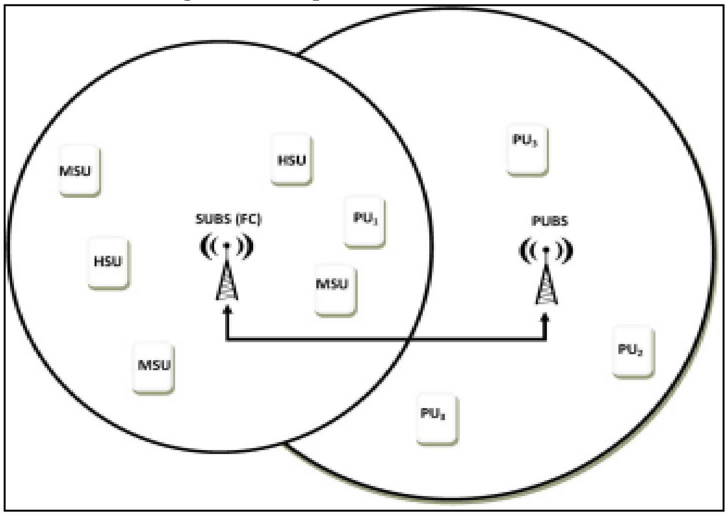

Fig. 1: System model of CRN

The main contributions of this paper are summarized as follows:
1) It proposes an energy efficient CSS protocol, namely EE-CSS, based on a TRMS, and derive expressions for the steady-state average trust value and the steady-state average total number of sensing reports transmitted by the SUs in the CRN.
2) It formulate energy consumption models for EE-CSS and T-CSS and use the models to show the scenarios in which EE-CSS is more energy efficient than T-CSS.
3) A method to evaluate Qf and Qd is proposed and closed form expressions for Qd and Qf in the case with no MSUs are derived. It also analyzed the impact of link outages between the FC and the SUs while exchanging sensing reports on the expressions derived.
4) The numerical results show that, for given target global FA and MD probabilities, detection EE-CSS can reduce the number of reports transmitted by HSUs and thus, the energy consumption (compared with a T-CSS technique).

A. Sensing Methods and Collaborative Spectrum Sensing
CR SUs are chosen to scan band(s) of the licensed spectrum and to find spectrum holes. Several sensing methods can be used to detect the state of a spectrum band. The main sensing methods are matched filtering, cyclo-stationary detection, and energy detection. The most commonly used method is energy detection as it does not require any a priori knowledge of the PU signal. This is an important factor because the signaling scheme used by PUs may be unknown to SUs. Sensing reports provided by SUs for a given licensed band may differ due to differences in channel fading gains, locations of SUs and primary network transmitters, number of signal energy quantization levels used at the sensing SU, and sensing errors. Sensing reports are gathered for a collaboration process.

B. Data Fusion Techniques
The final decision about the state of the spectrum usage can be made at one or more nodes based on the infrastructure of the network. In a centralized CRN, an entity at the secondary user base station (SUBS), namely the fusion center (FC), receives the sensing reports from SUs and produces a final decision on the state of each band. In data fusion (DF) techniques such as AND/OR Rule, Ki Rule and Majority Rule the FC rules that the PU channel is busy when all/one, i out of K, and at least half of sensing entities report busy channels, respectively. Other techniques which are based on a Bayesian criterion and Neyman-Pearson test require the knowledge of some a priori probabilities.

C. Attacks in Collaborative Spectrum Sensing
Differences in the geographical locations of SUs and PU network transmitters, channel fading gains, and sensing errors are not the only causes of the variations among the sensing reports. An MSU can also attempt to influence the FC's final decision to gain

unfair access to the spectrum holes or to interfere with PUs by manipulating its sensing report. MSU attacks in CSS can be divided into two classes: dynamic spectrum access attacks (DSAA) and Malicious Behavior Attacks (MBA), also known as spectrum sensing data falsification (SSDF).

D. Trust and Reputation Management

Trust and reputation management systems (TRMSs) have been proposed to combat malicious behaviors in CRNs, TRMSs record the accuracy of previous sensing reports sent by SUs and compute a trust value for each SU which is taken as the trustworthiness of its future sensing reports. There are several methods which are used to compute trust values: beta distribution (in conjunction with Laplace smoothing), beta distribution with the concept of uncertainty and suspicious value and consistency.

E. EE-CSS

The main component of the proposed EE-CSS is the media access control (MAC) protocol. We use a contention-free MAC protocol.

F. MAC Protocol

EE-CSS attempts to reduce the number of transmitted reports from HSUs, based on the observation that HSUs agree on the spectrum usage more often than they disagree. EE-CSS uses mini time slots in two phases as shown in Fig. 2:

1) Phase I

Based on the SU trust values, the FC chooses a set of SUs which are to sense the band and transmit their report to the FC in the mini time slots. The FC will broadcast a message containing the list of chosen SUs. The FC fuses the reports from the chosen SUs with its own local decision and broadcasts the intermediate decision to all SUs.

2) Phase II

If an SU disagrees with the intermediate decision or it does not receive the broadcast message reliably, it can so indicate via a transmission in its designated mini time slot; otherwise, the SU remains quiet.

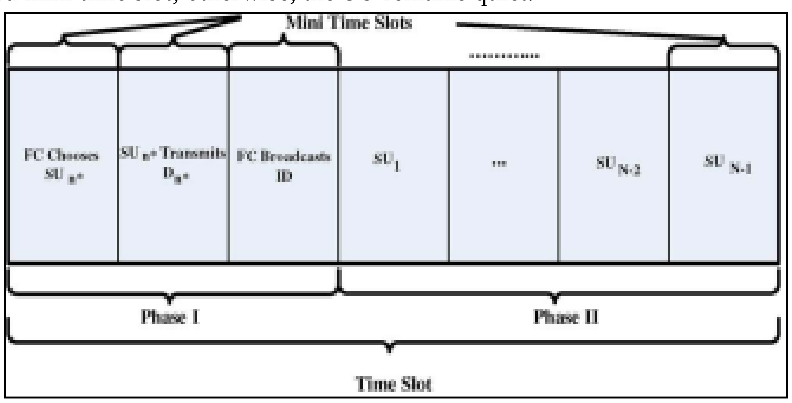

Fig. 2: Phases I and II in EE-CSS

III. RESULTS AND DISCUSSION

The average steady-state total number, NH, of sensing reports in T-CSS and EE-CSS are shown in Fig.3. The flat line at low SNR is the result of reaching the maximum number of available SUs in the CRN. It can be seen that EE-CSS requires a lower NH than T-CSS at low SNR and a similar number at high SNR. We expect the same average number of sensing reports in EECSS for higher SNR values. This is because the FC in T-CSS and EE-CSS requires less than or equal to 2 explicit sensing reports.

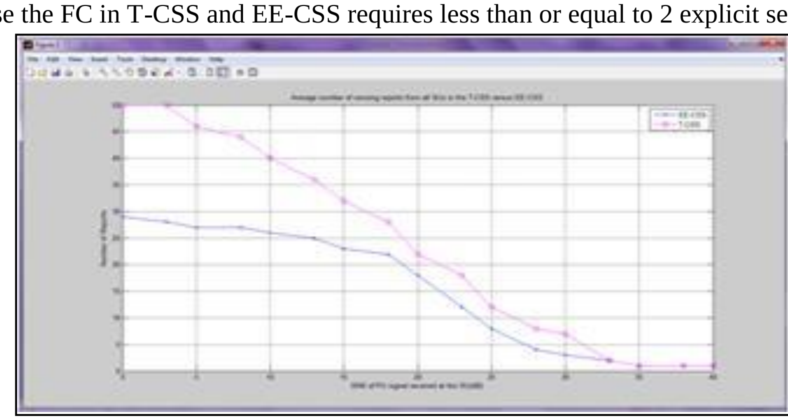

Fig. 3: Average number of sensing reports from all SUs in the T-CSS versus EE-CSS

For long range wireless communication (e.g., Kilometers or more), θ ~ 0 and for short range wireless communications θ ~ 1.When the difference between the number of reports in T-CSS and EECSS is large in Fig.4, EE-CSS consumes less energy than TCSS for 0 < θ < 1.2. However, when the difference between the number of reports in T-CSS and EE-CSS is small in Fig.4, T-CSS consumes less energy than EE-CSS for 0.5 < θ. This is due to the fact that the energy consumed in receiving packets in EE-CSS offsets its efficiency in transmission energy. For SNR values which T-CSS and EE-CSS require only 2 reports (or less), the energy consumption are the same because T-CSS and EE-CSS are identical.

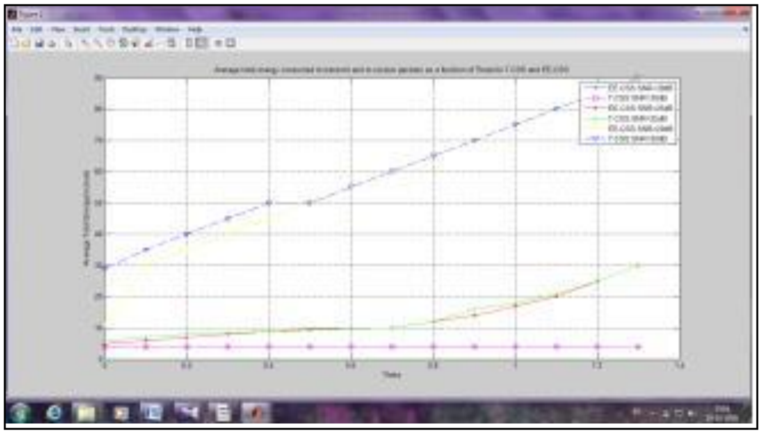

Fig. 4: Average total energy consumed to transmit and to receive packets as a function of θ for T-CSS and EE-CSS

IV. CONCLUSION

A collaborative spectrum sensing (CSS) protocol is proposed which aims to improve the energy efficiency of traditional CSS (T-CSS) protocols by reducing the number of sensing reports from SUs to the FC. Expressions for the steady-state SU average trust values and the steady-state average total number of sensing reports transmitted for each band state evaluation were derived. Expressions for the global missed detection probability, Qmd, and false alarm probabilities, Qf, for a commonly used decision fusion technique were also obtained. Outages on the FC and SU links affect the reception of sensing reports at the FC. The effect of such outage on steady-state SU average trust values and average number of reports were analyzed. The effect of outage on Qmd and Qf for scenarios with no MSUs in the network were also analyzed. For a given Qmd, and Qf target values, it is found that EE-CSS requires a smaller steady state average total number of sensing reports. It is shown that EE-CSS can greatly reduce the energy consumption in EE-CSS compared to that in T-CSS for long range communications where the transmission energy is dominant. We also found that outages generally have a smaller impact on Qmd, and Qf for EE-CSS than for T-CSS.

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