Cooperative Neighbor Discovery in Dynamic Spectrum Access Networks

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Abstract

In dynamic spectrum access networks, neighbor discovery is one of the most challenging tasks and, it becomes more critical when there is no centralized coordinator. Neighbor discovery in a DSA network is normally done by using a common control channel or channel hopping. Since both methods introduce their own drawbacks, in this paper, we propose a cooperative neighbor discovery mechanism without using channel hopping techniques or control channel. In this mechanism, neighboring secondary users collaboratively involve in neighbor discovery process of a pair of users and, thus it can provide relatively small delay.

1. Introduction

Dynamic spectrum access (DSA) or cognitive radio technology is one of the most promising wireless technologies. In DSA networks, secondary users (SUs) access the licensed spectrum in an opportunistic manner without causing any interference with primary users' (PUs) transmission. Normally, SUs sense the free channels or idle portions of a channel and access the channel [1].

Assume that there are m number of channels,$M = \{CH_1, CH_2, \dots, CH_m\}$ and *n* number of secondary users $N = \{SU_1, SU_2, \dots, SU_n\}$ in a DSA network. The availability of channel is changing dynamically in frequency, space and time; thus, SUs may operate on different channels independently at any given time. Nonetheless, if a pair of SUs wishes to communicate with each other, they need to operate on the same channel at the same time. Imagine that an SU ($SU_1\ on\ CH_1$) wants to communicate with a neighbor SU which is currently dwelling on a different channel ($SU_2\ on\ CH_3$), how could the SUs find its neighbor for communication?

Neighbor discovery in a DSA network can be achieved by using a common control channel (CCC) [2]. However, this method is not reliable since the CCC can be unavailable at any time because of PUs. Another famous method is using channel hopping (CH), but this mechanism suffers long channel access delay [3, 4]. In this paper, we propose a cooperative neighbor discovery mechanism without using CCC or CH mechanisms.

2. Cooperative Neighbor discovery

We assume that network type is ad hoc without a centralized coordinator and n number of SUs are randomly distributed on the available channels. Every SU in the network is equipped with a single transceiver. SUs are within transmission range of each other, i.e., there is no hidden terminal, and SUs dwell only on PU-free channels. All message transmissions follow the principle of the Distributed Coordination Function (DCF) of IEEE 802.11[5].

When an SU (source) needs to communicate with one of its neighbor, it chooses one of the available channels, CH_i , and it will broadcast the neighbor discovery message (NDM). The NDM includes the destination's ID, the host channel information and the source ID. If the destination SU currently resides on CH_i and receives the NDM, it can simply reply the neighbor discovery acknowledgement (ND-ACK) message and the neighbor discovery has been accomplished between these two SUs. The SU then continue data communication on CH_i . If the source node does not receive any ND-ACK on CH_i, it will switch to host channel and wait for the destination SU. Neighboring SUs on CH_i can conclude whether the neighbor discovery has been accomplished by overhearing the ND-ACK. If an SU receives a NDM and does not overhear any ND-ACK on CH_i, it can infer the destination SU is not on CH_i and the SU will collaborate in the current neighbor discovery process.

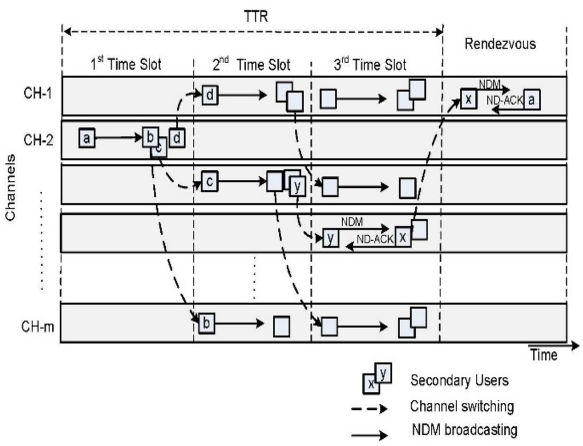

Fig.1 Cooperative neighbor discovery message dissemination.

If an SU has to collaborate in neighbor discovery of a pair of SUs, it will choose one of the available channels $CH_j, i \neq j$, and switches to CH_j . The SU senses the CH_j and if it is PU-free, it will attempt to rebroadcast the NDM of the source SU. If the destination SU is currently on CH_j, it will reply the ND-ACK. Then, the destination SU switches to the host channel, the channel that the source SU currently dwelling on, and broadcasts the NDM with the source ID. On successful receiving of the NDM, the source SU can reply confirmation message and the rendezvous can be achieved. If more than one SU chooses the same channel, they need to contend for transmission. If an SU successfully transmits the NDM, the other waits and checks whether the rendezvous is successfully achieved or not. If neighboring SUs overhear the ND-ACK, they will abort the rendezvous process. Otherwise, they will choose one of the available channels and perform the same procedure as mentioned. All SUs in the network involve in the neighbor discovery process and rebroadcast the NDM exactly one time.

Figure 1 depicts the cooperative rendezvous procedure. As shown in the figure, the SU_a is the source, and it initiates neighbor discovery process to meet the neighbor, U_x . SU_a chooses CH_1 as host channel and broadcasts NDM on CH_2. Neighboring SUs on CH_2 participate on rendezvous process by rebroadcasting the NDM on selected CHs. When SU_x receives the NDM via the U_y , it switches to CH_1 (host channel of SU_a) which is the channel that SU_a is currently dwelling on. Then SU_a and SU_x can rendezvous on CH_1 .

3. Time to Rendezvous

The major goal of all neighbor discovery algorithms is to meet with intended neighbor as soon as possible. In this section, we present the performance of cooperative neighbor discovery mechanism in terms of time to rendezvous (TTR). Fig. 2 shows the maximum TTR value of proposed cooperative neighbor discovery (Co-ND) mechanism, jump-stay (JS) and enhanced jump-stay (EJS) algorithms of [6]. Normally, TTR values are dependent on number of available channels, i.e., the more number of available channels in the network, the larger the TTR values. However, the proposed mechanism disproves this concept. As shown in the figure, when the number of available channels increases, the maximum TTR (MTTR) of JS and EJS also dramatically increase while that of cooperative mechanism increases slightly. For the simulations, we set the total number of SUs as n=100.

The results are more obvious in Fig. 3, which represents the average TTR (E [TTR]) values of JS, EJS, CO-ND and orthogonal sequence based (OSA) algorithm of [7]. Note that simulations are performed under the best scenarios for the JS, EJS and OSA, i.e., JS and EJS are simulated under the symmetric model and OSA is evaluated with the best channel condition. As shown in figure 3, the E[TTR] values of Co-ND is much smaller than that of other approaches. More interesting result is, as mentioned before, the TTR values of Co-Red do not depend on number of available channels. Thus, even when the number of available channel increases, Co-Red provides relatively small E[TTR].

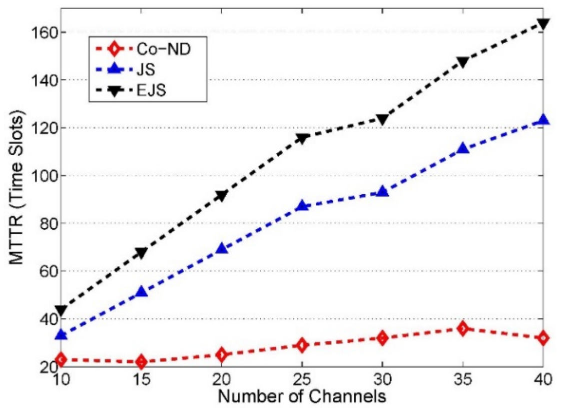

Fig. 2 Maximum time to rendezvous versus total number of channels.

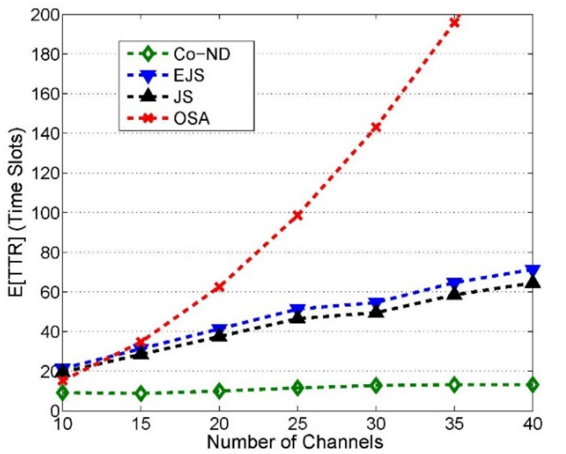

Fig.3 Average time to rendezvous versus total number of channels.

4. Conclusion and Discussion

An alternative way of rendezvous mechanism for dynamic spectrum access networks, without using any control channel or channel hopping, has been presented. It provides relatively small TTR values and also provides upper bound of TTR. More important fact is the TTR values are not dependent on number of available channels. However, since it exploits the benefit of cooperative communication, it requires enough population to perform cooperative neighbor discovery i.e., there should be at least two SUs on each channel which is $n \geq 2$.

5. Acknowledgement

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