Vicious Cycle of MAC Protocols of Cognitive Radio Ad Hoc Networks: Problem Statement

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ABSTRACT

In cognitive radio ad hoc networks, secondary users need to exchange control information before data transmission. This task is not trivial in cognitive radio networks due to the dynamic nature of environment. This problem is sometime called rendezvous problem of cognitive radio network. The rendezvous problem is normally tackled by using two famous approaches: the use of common control channel (CCC) and using channel hopping (a.k.a sequence-based protocols). However, these two famous solutions form a vicious cycle while solving the rendezvous problem. The main purpose of this paper is to point out how and why this vicious cycle is formed.

1. INTRODUCTION

Cognitive radio technology allows the secondary users (SUs) to access the licensed channels in opportunistic fashion without causing any interference to primary users (PUs). All SUs find and detect the free channels (i.e., the channels not being used by PUs) and access the channels [1]. The availability of the channel is highly dependent on PU activities which change dynamically in frequency, space and time. Therefore, the sets of available channels for each SU might not be the same. However, if a pair of SUs wishes to communicate with each other, they need to rendezvous on a channel which is commonly available to them and exchange control information. This task is more challenging in CR ad hoc networks since there is no centralized coordinator and SUs may operate on different channel independently. This is call rendezvous problem of CR networks.

2. SOLUTIONS

Many medium access control (MAC) protocols for CR networks have been proposed to address this problem. Nonetheless, we categorize the existing solutions into two major groups as follows.

Common Control Channel Approach: Any protocols that enable rendezvous by using dedicated control channel are included in this category.

Channel Hopping Approach: In this category, any protocols that enable rendezvous without using common control channel are included.

This research was supported by the MKE(The Ministry of Knowledge Economy), Korea, under the ITRC(Information Technology Research Center) support program supervised by the NIPA(National IT Industry Promotion Agency)" (NIPA-2012-(H0301-12-1004). Dr. CS Hong is corresponding author.

2.1 Common Control Channel Approach

The most efficient way to solve the rendezvous problem is using predefined common control channel (CCC). Most of proposed medium access control (MAC) protocols for cognitive radio networks were designed by assuming the existence of CCC and it is available for every secondary user [1]. In this approach, necessary control information is exchanged among SUs via CCC. When a SU wants to initiate any communication, it switches to CCC first and attempts to negotiate with the intended receiver or neighbor. After negotiation has been done on CCC, data communication can be accomplished in other available channels known as data channels [2].

Fig.1 illustrates the normal operation of a network with a common control channel. In contention phase, all users attempt to negotiate on CCC. After negotiation has been done on CCC, users move to selected channels and perform data communications simultaneously.

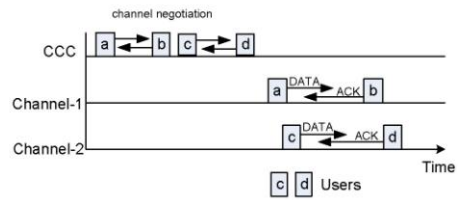

Fig.1. Process of channel negotiation and data communication with a common control channel

Obviously, using CCC makes MAC protocols simple and efficient. However, the use of CCC is not feasible in some senses due to the following reasons.

1. Lack of availability of CCC: The main drawback of this approach is it cannot robust to primary user activities. When a PU appears on CCC, all SUs must defer their transmissions on CCC and vacate the channel immediately. Moreover, the available channel sets in CR networks are dynamically changing including the CCC. Therefore, an ever-available control channel for all SUs is unlikely to exist.

2. Control channel saturation problem: The principle of CCC approaches forces the SUs to transmit all control packets on CCC. Thus, the collision rate of control packets is high when the number of users in the network is large as all users use only one control channel for negotiation.

2.2 Channel Hopping Approach

Many sequence-based protocols have been proposed to compensate the problems of CCC approach. In channel hopping approaches, SUs generate their own channel hopping sequences. When a SU (let say sender) needs to communicate with its neighbor (receiver), it switches one channel after another by following predefined hopping-sequence and finds its neighbor [3][4]. The basic procedure of neighbor discovery is as follows. When a SU switches to a channel, it senses the channel for the presence of PUs and other SUs' transmission. If it senses the channel is free, it will broadcast a beacon message [5]. If the intended receiver is on current channel and receives the beacon, it will reply acknowledgement (ACK) and it can be assumed that rendezvous has occurred between these two users. Then they can perform negotiation for data communication on current rendezvous channel. Otherwise SU will switch to another channel by following the hopping sequence and broadcast beacon message again. This process is repeated until the SU (sender) meets with its intended receiver. When two SUs (sender and receiver) rendezvous on a common channel, they exchange control packets and negotiate for data communication [6].

Fig.2 illustrates the operation of a channel hopping protocol. In Fig.2, user *a* and *b* find each other by following their own hopping sequences. When they rendezvous on channel 3, they perform negotiation for data communication.

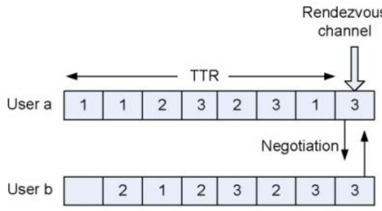

Fig.2. Operation of a channel hopping protocol

The main advantage of these approaches is SUs can rendezvous on any available channel. It overcomes control channel saturation problem and tolerates long term blocking of primary users. Moreover, channel hopping protocols consider only pair-wise rendezvous (only a sender and a receiver), so these do not need global available common control channel. However, channel hopping approaches also introduce some major problems.

1. Channel access delay: In sequence-based protocols, when a user wants to communicate with its neighbor, it will switch one channel after another by following hopping sequence and find its neighbor. So user needs significant amount of time to meet with its neighbor and it is normally called channel access delay or time to rendezvous (TTR).

2. Complexity: The next one is complexity of generating channel hopping sequences. When users generate channel hopping sequences, any pair of these sequences should overlap at least once within a sequence period, so that any pair of users that needs to communicate can rendezvous. Moreover, the TTR values between any pair of sequences should be reasonable.

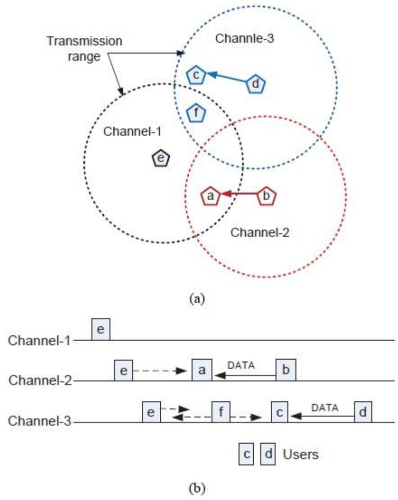

Fig.3. (a) Users are operating on different channels independently and (b) multichannel hidden terminal problem

3. Lack of network status information: The most important drawback of sequence-based protocols is lack of information of neighbors' communications. Consider the scenario of Fig.3 (a). As shown in Fig.3 (a), there are three available channels and users are operating on different channels independently, and there is no centralized coordinator. A user may have knowledge of communications on the current operating channel, perhaps, by overhearing. But it has no idea about current transmissions on other available channels. Suppose user e wants to communicate with user f, but it has no knowledge of ongoing transmissions between users a and b, and c and d. User e attempts to find user f by following its hopping sequence. Let the hopping sequence be {1, 2, 3}. When e switches to channel 2, it will sense the channel as free because it is out of transmission range of current transmission which is data communication between user a and b. So it will broadcast preamble message, and it is going to interfere data receiving of user a, as shown in Fig.3 (b). This is nothing else but *multi-channel hidden terminal problem* [8].

When a SU generates its hopping sequence, all available channels should be included in the sequence. This is mandatory for all channel hopping algorithms. Otherwise, it cannot guarantee the rendezvous between a pair of users. Thus, when a SU wants to find its neighbor, it may need to switch all available channels and broadcast preambles. As a consequence, neighbor discovery of a pair of users might interfere most of current transmissions of the network. Best of our knowledge, almost all sequence-based protocols suffer this multichannel hidden terminal problem.

The multichannel hidden terminal problem has been well studied in decades. As we have found so far, the best solution for multichannel hidden terminal problem is using common control channel (CCC) [7]. The reasons of why CCC can simplify this problem are as follows. According to principle of CCC approaches, all users must negotiate on CCC before any data communication begins. All neighbor information can easily be broadcasted on CCC and users can gather the information by overhearing. Moreover, neighbor discovery process can be eliminated by using CCC. When a SU wants to communicate with its neighbor, it simply switches to CCC and attempts to negotiate.

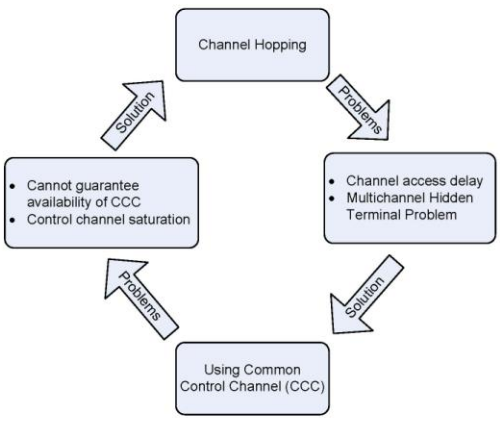

Fig.4. Vicious cycle of rendezvous problem

3. VICIOUS CYCLE

As we mentioned above, two famous solutions for rendezvous problem of CR networks form a vicious cycle. Fig.4 illustrates the vicious cycle of CCC approaches and sequence-based protocols. CCC approaches can make protocols simple and efficient, but it cannot guarantee the availability of CCC. If CCC is broken in case of primary user appearances, it can lead the network to the single point of failure. Sequence-based protocols can compensate problems of CCC due to the PU activities. So it can be more tolerable primary user activities than CCC approaches. However, sequence-based protocols suffer the multichannel hidden terminal problem. The best solution so far for multichannel hidden terminal problem is using predefined CCC. Moreover, using CCC can eliminate the neighbor discovery processes. So, it provides less channel access delay.

4. CONCLUSION

We have presented the vicious cycle of rendezvous problem of CR networks and, how and why it is formed. As we all know, rendezvous problem should not be overlooked. Nonetheless, as best of our knowledge, there is no perfect solution so far for this problem. Almost all of the proposed solutions suffer one or both of these problems, lack of availability of CCC and multichannel hidden terminal problem. As a future work, we are developing a hybrid MAC protocol that is immune from this vicious cycle.

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