DARCAH: Distributed Approach to Rendezvous Channel Setup in Cognitive Radio Ad Hoc Networks

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Abstract

In this paper, we propose a solution to the problem on how cognitive radios can find each other. The easiest and common practice to address this problem is to have a dedicated control channel on which the nodes can rendezvous with each other. However, a dedicated Common Control Channel (CCC) has severe drawbacks. As a solution to this drawback, we propose a rendezvous channel (RC) setup scheme called Distributed Approach to Rendezvous Channel Setup in Cognitive Radio Ad Hoc Networks (DARCAH) in which, one of the free channels is chosen as RC rather than having dedicated CCC. Besides, instead of deploying a dedicated central entity, one of the nodes from the Secondary Users (SUs) is in charge of transmitting the RC. Extensive MATLAB simulations were performed to study the effectiveness of DARCAH.

Keywords: Rendezvous Channel, Distributed approach, Cognitive Radio

1. Introduction

In CR technology, users which are not licensed to use the spectrum (also called Secondary Users (SUs)) are able to use the spectrum opportunistically when the licensed users (also called Primary Users (PUs)) are not using it. In order to detect the idle channels, SU node has to sense the spectrum continuously over all the channels using its spectrum sensing mechanisms. As result of the sensing, the SUs may have different list of available channels making the problem of finding a common channel to communicate on difficult. A simple solution to this problem is to dedicate a control channel which each SU is aware of beforehand. However, a dedicated CCC is vulnerable to saturation, has low resource utilization and is susceptible to jamming [1]-[3].

In this paper, we propose a scheme in which instead of dedicating a control channel, one of the free channels is chosen as a Rendezvous Channel (RC). In DARCAH, SUs are tuned to a common RC broadcast by a Head Node (HN) which is one of the SU nodes.

The rest of this paper is organized as follows. In section 2, discusses our proposed scheme in detail. We will show our performance evaluation and simulation results in section 3. We will finally draw our conclusions in section 4.

2. Proposed scheme

Motivated by the drawbacks of EX and RAN [1] schemes in which a dedicated central entity is in charge of informing the SU of the current RC, we propose a modified scheme called Distributed Approach to Rendezvous Channel Setup in Cognitive Radio Ad Hoc Networks (DARCAH) which is used for distributed CR networks. The main objective of the proposed scheme is to establish a RC which all SUs are tuned to get control messages. In DARCAH, an ordinary SU called Head Node (HN) is in charge of broadcasting the RC rather than a dedicated central entity. Once acquired by the SUs, the RC is used as a control channel as far as it is not reclaimed by PU network.

2.1. System Model

The primary network has N channels. SU nodes are aware of the range of the primary spectrum over which they operate opportunistically. They are also aware of the channel mapping and the size of the bandwidth of the primary spectrum. There is at least one common idle channel between two SU nodes that want to transfer data between one another. Similarly, there must be at least one common channel
between the head node and normal node that wants to join the network. There should not be a significant offset between the timing of the timers of the different nodes.

In DARCAH there are two kinds of nodes with different roles. One out of the SUs will be referred to as Head Node (HN), and the rest of the nodes are called Normal Nodes (NNs). The HN is in charge of choosing and transmitting the current RC to inform the NNs. Each SU node (whether HN or NN) is equipped with two half-duplex transceivers. One of the transceivers, named Transceiver for Scanning and Beaconing (TRSB), is used for scanning the primary channels and transmitting beacons on the channels available in the HN. In NNs, on the other hand, it is used only for sensing the primary channels and listening beacons from HN. The second transceiver, which is abbreviated as TRRD for Transceiver for Rendezvous and Data, is used for data transmission, and tuning to a rendezvous channel in both type of nodes. It is also used for scanning when a node joins a network.

2.2. Working principles of DARCAH

Upon turning on, each SU scans the spectrum starting from the lowest frequency using its TRSB and starting from the highest frequency using its TRRD. If a channel is free, it listens (tunes) for a period of \( T_b \) on that channel to get beacon. Otherwise it scans the next channel. If beacon is received on a channel, the SU node reads the beacon message. The second transceiver (TRRD) will then stop scanning and is tuned to the RC indicated in the beacon message. The node will continue scanning (to sense active PUs) using TRSB. This node will become a NN. In order to avoid collision with a beacon of a HN, a NN does not perform beaconing.

Nonetheless, if \( T_b \) expires before a beacon is received, the node senses the next channel. If no beacon is received after visiting all the channels, the SU node declares itself to be the HN of the network. It assigns randomly one of the free channels as RC. Using its TRSB, it transmits the beacons messages on idle channels for a period of \( T_b \) seconds. It also continuously listens to the current RC using its TRRD to observe the activities of other nodes, and to send or receive data to or from neighbor nodes. Moreover, using its TRSB radio, a HN unceasingly senses the primary spectrum and transmits beacon message on an idle channel (except on the RC) to inform NNs of the current RC and other control messages. In order not to make the RC busy, the HN does not transmit beacon message on the current RC. The flowchart shown in Figure 1 describes the activities performed by SU nodes in DARCAH protocol.

If a node wants to transmit data to a neighbor node, it contends to use the RC following IEEE 802.11 DCF through its TRRD. The two nodes will negotiate to communicate using any of the common idle channels which is different from the RC. Other nodes listening to the communication of the two nodes will defer, for a period as specified by DCF, not only contending to use the RC but also using the channel the two nodes agree to share their data on. When data transmission is complete, the nodes tune back to the RC they have been tuned to before they were engaged in data transmission. If the RC is no more idle, they execute the algorithms shown in Figure 2 based on their roles.

2.2.1. Rendezvous Channel Setup time \((R_s)\) and Time to Rendezvous \((R_t)\)

When a SU node wants to initiate communication in a network where there is no HN yet (in the start of the network), the node will spend \( T_b \) seconds on each idle channels to get a beacon. Because there is no HN, the SU node will not receive a beacon and hence it will become the HN of the network. A node in DARCAH has to be tuned \( N(T_b + \alpha) \) seconds to ensure that a beacon is received on a channel. We define the amount of time that it takes for a node to be HN as the rendezvous channels setup time \((R_s)\). Clearly, \( R_s \) will have minimum value when there is only one idle channel. So, the best case scenario value of \( R_s \) is \( N(T_b + \alpha) + (N-1)\alpha \), where \( (N-1)\alpha \) is the amount of time the node spends to sense the N-1 active channels. The maximum value of \( R_s \) occurs when all primary channels are idle in the vicinity of the HN. In this case, a HN will take a worst case scenario of \( NT_b = N^2(T_b + \alpha) \). Similarly, the time to rendezvous \((R_t)\) is the time it takes for NN to find a HN. The best case \( R_t \) occur in the lowest frequency in the first trial. The time required to rendezvous with the HN will be only the sum of the sensing time and the beacon transmission duration of the HN, i.e. \( R_t \) is equal to \( T_b + \alpha \). The maximum \( R_t \) for a NN occurs when all the primary channels are idle as sensed by the NN but only the middle channel in the case of odd numbered channels or the two middle channels in the case of even numbered channels are idle on the vicinity of the HN in addition to the current RC. Therefore, the worst \( R_t \) is equal to \( (N-1)/2 \ (N(T_b + \alpha)) \) for odd numbered channels and \( (N/2 - 1)N(T_b + \alpha) \) for even numbered channels.
2.2.2. When RC is reclaimed by PUs

If HN observes that the current RC is reclaimed by PUs, it will immediately erase the RC from the beacon message. Instead, the BC is used as RC and the HN chooses another BC out of the free channels. If the BC is also active, it chooses new RC and BC out of the idle channels it has at its disposal. Then, it informs the NNs about the current RC and the new BC on the next beacon transmission. All the NNs which get the new beacon message will be tuned to the current RC. Any one or more of the NNs can observe the repossession of the RC by PUs. In this case, the TRRD of the NN is tuned to the BC. The TRSB scans and tunes to the next idle channel which is common with the HN. The algorithms in Figure 2 show how RC is released when it is reclaimed by the PUs.

3. Performance evaluation

An extensive simulation was conducted using MATLAB to test the effectiveness of DARCAH as compared to EX and RAN protocols. The following simulation setup was used: The number of channels was varied from 1 to 50. The points on the graphs are the mean value of 1000 simulations. To compensate the PU traffic, the probability of the channel availability ($\gamma$) was chosen to be 0.5. The probability of channel availability is defined as the probability of a channel to be idle. According to [1], a node and its neighbor will have the same channel status with high probability. Hence, it is assumed that if a channel is
free on NN, it is also free on HN with probability of 0.8 and vice versa. The beaconing time, \( T_b \), is chosen to be 200ms, and the time taken by a node to shift to and sense a channel, \( \alpha \), is 100ms.

### 3.1. Results

Figure 4 (a) shows the simulation results of the joining \( R_t \) of DARCAH as compared to the simulation results of centralized schemes such as EX and RAN protocols [1]. From the graph, we can understand that DARCAH has slightly less time to rendezvous than EX and RAN protocols. However, the \( R_t \) shown in Figure 3 (a) is the time it takes for a node to join a network for the first time. In other words, it is the time it takes for a NN to get a beacon from the HN. Once it joins to the network, a node which executes DARCAH will be tuned to the RC. If it wants to initiate communication, it only contends to use the RC. The time to rendezvous is 0 seconds. On the other hand, nodes which execute the EX and RAN schemes need to do all the network initialization processes like a newly joining node. This clearly shows DARCAH is superior to EX and RAN protocols as depicted in Figure 3. (b).

![Figure 3. Time to Rendezvous simulation results of DARCAH, EX and RAN schemes](image)

### 4. Conclusion

In this paper, we have proposed a solution to the problem on how CR nodes can find each other. The proposed DARCAH scheme avoids the reliance on dedicated central entity of previously proposed schemes. Simulation results show that DARCAH has slightly less time to rendezvous. For an already joined node, the time to rendezvous is zero since the node will be tuned to the current RC. This shows DARCAH improves the time to rendezvous significantly even with the absence of dedicated central controller.

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### 6. References