A survey on broadcast protocols in multihop cognitive radio ad hoc network

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***Abstract*— In the traditional ad hoc network, common channel is present to broadcast control channels between the nodes. This cannot be achieved in cognitive radio ad hoc network where different cognitive users acquire different channels based on the spatial and temporal usage of the primary users. Broadcasting of control signals to all the nodes of the cognitive radio ad hoc network with high success rate while minimizing the broadcast delay is difficult. Broadcast collision occurs when a node receives multiple copies of broadcast message in multi hop cognitive radio ad hoc network. This survey helps to understand different schemes used for broadcasting the control information with high success rate and low broadcast delay by eliminating the broadcast collision in multi hop cognitive radio ad hoc network.**

***Index Terms*—Cognitive Radio (CR), Broadcasting, Channel Assignment.**

I. INTRODUCTION

Current wireless network uses Fixed Spectrum Assignment (FSA) policy. In FSA wireless devices operate in ISM bands between 900 MHz and 2.4 GHz. Due to enormous growth of wireless applications there occurs spectrum scarcity. At the same time, according to FCC (Federal Communications Commission) the licensed bands in range of 400 – 700 MHz are underutilized. Thus to increase the spectrum efficiency FCC approved the unlicensed (cognitive) users to use the licensed (primary) bands.

Cognitive Radio (CR) network is a new paradigm that provides the capability to share or use the spectrum in an opportunistic manner. Cognitive radio improves spectrum utilization satisfying spectrum shortage for emerging wireless applications. Cognitive radio changes its transmission or reception parameters based on interaction with its environment in which it operates and communicates efficiently avoiding interference with licensed or unlicensed users. Cognitive user senses and uses the idle channel and hops to another idle channel when primary user returns to its idle channel. The idle channel formed at particular time and location due to non-utilization of primary users is referred as the spectrum holes or white spaces. The process of utilizing the spectrum holes by cognitive user when the primary user is not available and returns the channel again when it is needed by the primary user is referred as the Dynamic Spectrum Access (DSA) as in Fig. 1. The objective of the cognitive network is to use the available idle spectrum efficiently without causing interference to the primary users.

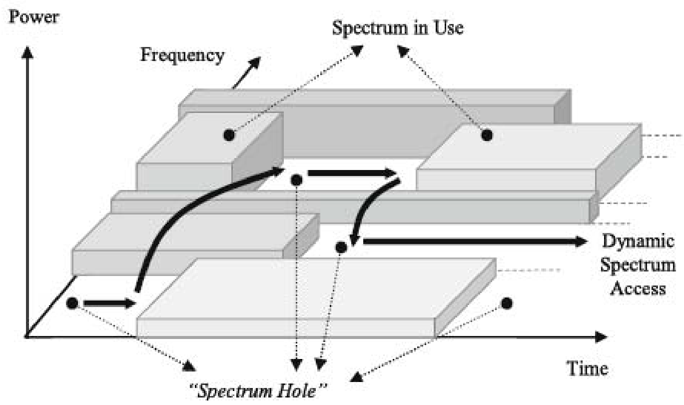

Fig. 1 Principle of Cognitive Radio network

In wireless ad hoc network control information is broadcasted to destination node through intermediate nodes. In traditional ad hoc network as in Fig. 2a, broadcast is achieved by using common channel due to the presence of single spectrum. In Cognitive Radio (CR) ad hoc network as in Fig. 2b, primary user have licensed channels, if the work is completed by the primary user within a time period, then the channels are free for the use of secondary user. In single hop scenario, the broadcasting at single time slot is difficult due to the presence of different channels. So it is not possible for the neighboring nodes to receive information at same time.

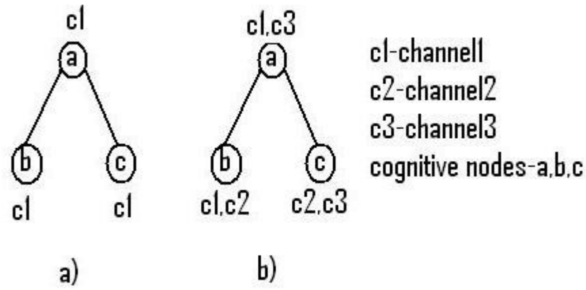

Fig. 2 Single hop scenario a) Traditional ad hoc network b) CR ad hoc network

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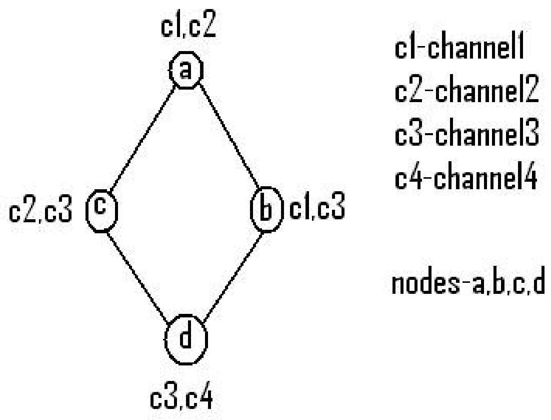

Fig. 3 Multi hop CR network

The multi hop scenario of the Cognitive Radio ad hoc network consists of broadcast collision problem as in Fig. 3.If two nodes c and d trying to send same packet at same time to single destination node d then broadcast collision occurs in multi hop CR ad hoc network. Due to the absence of Collision Detection (CD) scenario in CR ad hoc network, it is difficult to handle the broadcast collision, since the network topology information is not known for the user. This survey helps to understand different schemes used for broadcasting the control information with high success rate and low broadcast delay in multi hop cognitive radio ad hoc network.

II. BROADCAST TECHNIQUES

A. Flooding scheme

In traditional MANET (Mobile Ad hoc NETwork) due to dynamic change of topology caused by mobility of nodes broadcasting message to neighboring nodes using single hop scenario is not possible. In multi hop scenario broadcasting achieved by one straightforward solution known as flooding demonstrated by Ni et al [1]. In flooding a node receiving broadcast message immediately forwards to all of its neighbors. Thus control information passes to all nodes of network using broadcast solution of flooding.

Flooding leads to problem of redundancy, contention and collision due to blind rebroadcasting of messages. When mobile node decides to rebroadcast a message to its neighbor while all of its neighbor already received message causes redundancy. Due to redundant rebroadcast these transmission may contend with each other. Because of lack of RTS/CTS dialogue, collision detection and back off mechanism collisions are more likely to occur and causes damages.

To overcome the problems of flooding the rebroadcast is limited using several schemes namely probabilistic, counter-based, distance-based, location-based and cluster-based schemes.

B. Self-pruning scheme

Broadcasting in ad hoc network through self-pruning proposed by Wu et al [3], consists of selecting small subset of forward node set to perform rebroadcast. In a low mobility environment, tree-based schemes such as minimal connected dominating set (MCDS) are better in reducing resource consumption. In a high mobility environment, simple flooding is the only way to achieve the full coverage. When a packet is broadcasted via simple flooding, the packet is forwarded by every node in the network exactly once. Hence, the same packet is received more than once which leads to unnecessary overhead in the network. Simple flooding ensures the coverage, but it also has the largest forward node set and may cause network congestion and collision.

Self-pruning helps in reducing the forward node set and minimizes the network congestion and collision. Forward node set is selected based on neighborhood coverage conditions namely neighbor connectivity and history of visiting nodes. Due to difficulty of gathering the global network topology based on local details such as k-hop neighborhood information the forward node set is selected through distributed and local pruning process. The forward node set is constructed using proactive (up-to-date) or reactive process (on-the-fly).

C. Random Broadcast Scheme

In the random broadcast scheme proposed by Song et al [4], the Cognitive User (CU) is unaware of the channel availability information of other cognitive users before broadcasts are executed. Thus the straightforward action for a CU sender is to randomly select a channel from its available channel set and broadcasts a message on that channel till the allocated time slot expires. Broadcasting is successful if both CU sender and receiver are in the same channel as in Fig. 4.

Tx	1	3	4	1	5	4	3	4	5	3	5	2
Rx	3	1	2	4	3	2	1	2	4	3	2	1

Fig. 4 Random broadcast scheme

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D. Full Broadcast Scheme

In full broadcast scheme proposed by Song et al [4], each Cognitive User (CU) visits all the available channels in the spectrum. Unlike the random broadcast scheme where the channel in each time slot is randomly selected by the CU, in the full broadcast scheme, the CU sender broadcasts on all its available channels sequentially. Similarly, the CU receiver is made to listen to its available channels sequentially. In addition, three different channel-hopping sequences are used for the full broadcast scheme: 1) the channel-hopping sequence under which the order for each CU to visit all the available channels is random (denoted as Full broadcast I); 2) the channel-hopping sequence under which each CU visits all the available channels sequentially (denoted as Full broadcast II); and 3) the jump–stay channel-hopping sequence (denoted as Full broadcast III).

The jump–stay channel-hopping sequence can be constructed under blind information with guaranteed rendezvous. Blind information is the practical scenarios that 1) the network topology is not known; 2) the channel information on the other SUs is not known; 3) the available channel sets of different SUs are not assumed to be the same; and 4) tight time synchronization is not required. Furthermore, similar to the random broadcast scheme, each CU sender also broadcasts for a finite number of time slots S.

E. Selective broadcasting scheme

The cognitive radio ad hoc network provides the efficient sharing of the radio spectrum. Control signals used for communication are broadcasted to the neighbors in their respective channel. If the number of channels is more in the Cognitive Radio ad hoc network then it leads to higher delay for allocation of channels which in turn leads to unsuccessful broadcasting. Thus selective broadcasting scheme demonstrated by Kondareddy et al [5] is used to reduce the higher delay in which control information is transmitted to a pre-selected set of channels. Neighbor graphs and minimum node graphs are used to select a set of channels.

In neighbor graph the nodes are plotted as the cognitive users and the edges are plotted as the common channels between two nodes. Minimal node graph is the method of attaining minimum number of edges by which all the nodes in the graph are connected.

In Fig. 5, solid edge between node A and B are made to use channel 1. Similarly solid edges between AC and AD are also utilizing channel 1 to complete their work. Channel 2, 3 and 4 are described to represent the use of different channel by Cognitive Users. Fig. 6 represents the minimal node graph in which the number of channels is reduced which minimize the delay for the utilization of common channels.

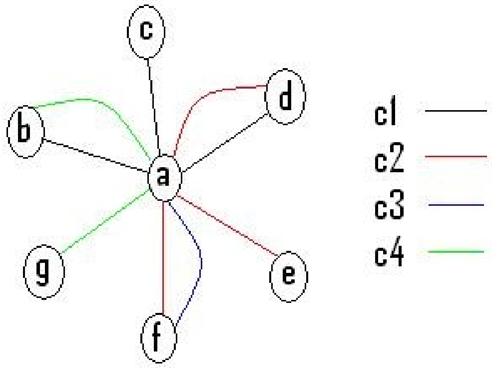

Fig. 5 Cognitive radio node graph

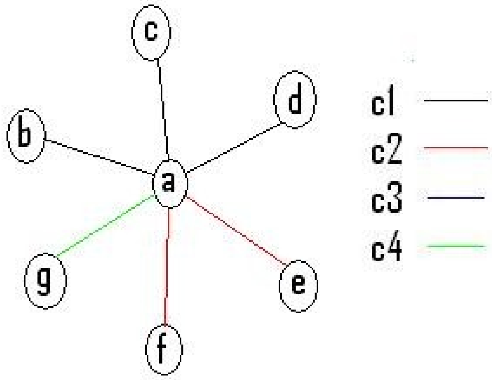

Fig. 6 CR Minimum node graph

Selective broadcasting starts in the steady state where all the nodes collect information about neighbor nodes. Selective broadcasting is an efficient way to broadcast a message to all its neighbors. It uses a selected set of channels to broadcast the information instead of broadcasting to all the channels. When a node enters the network for the first time, it has no information about its neighbors. So, initially, it has to broadcast over all the possible channels to reach its neighbors. This is called the initial state of the network. Then it can start broadcasting selectively, when it is in steady state. Network steady state is reached when all nodes know their neighbors and their channel information.

F. Spectrum opportunity clustering scheme

In cognitive radio ad hoc network, cluster based architecture for control channel assignment is formed to broadcast a control signal which is referred as spectrum opportunity clustering demonstrated by Lazos et al [6]. In this approach, cognitive users are grouped into clusters if they sense the similar idle channels. Based on space and time varying spectrum availability, different cognitive users acquire different idle channels. So the clustering is formed based on grouping of the cognitive nodes with maximum number of common channels. This helps to eliminate the problem of the frequent reclustering since the possibility of using common channels is more. The cluster design is formulated as the maximum edge biclique problem.

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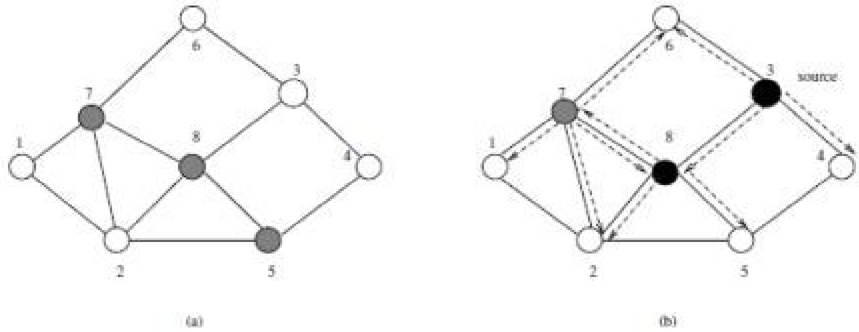

Fig. 7 (a) Forward node set without routing history (static). (b) Forward node set with routing history (dynamic) with node 3 being the source (visited node). Black nodes are visited nodes and gray nodes are forward nodes.

Forward node set without routing history (static) in network is represented in Fig. 7a where unfilled nodes such as 1,2,3,4 & 6 just receive the information and they do not perform rebroadcasting. Nodes 5, 7, 8 rebroadcast the information to the neighboring nodes. Fig. 7b represents forward node set with routing history in dynamic network. Node 3 acts as the source node and visited nodes are denoted as the black color and forward nodes are represented by the gray color. Fig. 7b clearly depicts how routing is performed in the dynamic network.

In spectrum opportunity clustering, cognitive nodes individually need to compute their cluster memberships by solving the maximum edge biclique problem. A cluster membership information are broadcasted to the neighboring nodes and it should be updated accordingly. If there is a change in network topology then new cluster information is rebroadcasted. Cognitive nodes compute the final and unique cluster membership information and broadcast through the final clusters to ensure consistency with their neighbors in cluster and control channel assignments.

G. Novel unified analytical model scheme

In cognitive radio ad hoc network different, cognitive users use different available channels based on the locations and traffic of primary users. This non-uniformity of channel availability leads to several issues in the broadcast protocol which degrades the performance in the cognitive radio ad hoc network. In this model, iterative algorithm is used to decompose a complicated network into few simple networks. Thus calculating successful broadcast ratio for these simple networks reduces the complexity of original larger network.

Under the novel unified analytical model scheme proposed by Song et al [7], at each iteration round, alink that connects to the source node is randomly selected. This is used to verify whether the broadcast over this link is successful or not, the network is decomposed into two simpler networks. If the broadcast over this link is successful, all links that connect to the other node of the selected link will connect to the source node. If the broadcast over this link fails, then it is removed from the network. The successful broadcast ratio over each remaining link is updated accordingly after each iteration. The process terminates when only two nodes are left in the remaining networks.

H. Distributed Broadcast Scheme

Song et al [8-9] proposed the distributed broadcast scheme in which all the SU nodes in the network intelligently select a subset of available channels from the original available channel set for broadcasting. The size of the downsized available channel set is denoted as *w*. The value of *w* needs to be carefully designed to ensure that at least one common channel exists between the downsized available channel sets of the SU sender and each of its neighboring nodes.

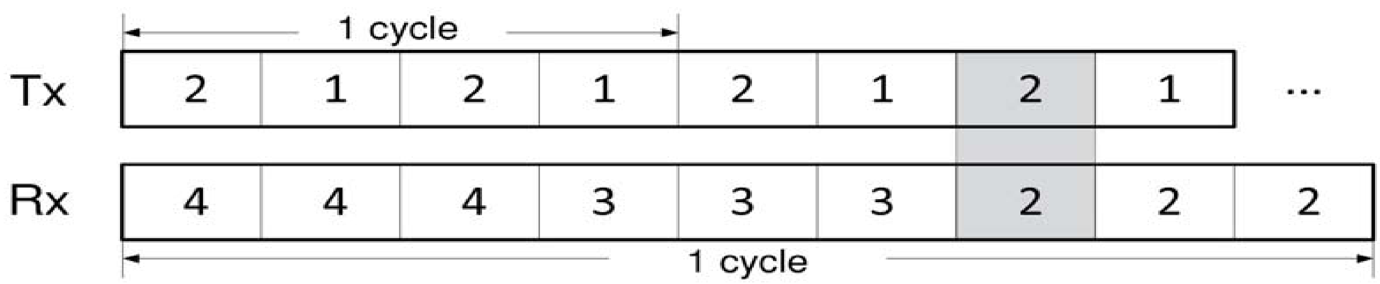

Fig. 8 Distributed broadcast scheme

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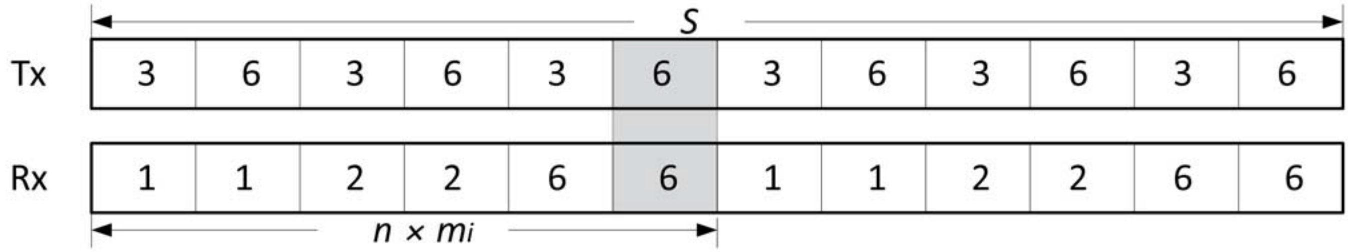

Fig. 9 QoS-based broadcast scheme

Fig. 8 gives an example of the broadcasting sequences of the distributed broadcast scheme. For a SU sender, it hops periodically on the *w* available channels for *w* cycles (one cycle consists of *w*2 time slots). For each receiver, it stays on one of the *w* available channels for *w* time slots. Then, it repeats for every channel in the *w* available channels.

I. QoS-Based Broadcast Scheme

In QoS-based broadcast scheme demonstrated by Song [10], the Cognitive User (CU) sender broadcasts on a subset of its available channels in order to reduce the broadcast delay. The main objective of this protocol is to achieve high success rate with minimum delay. Success rate is defined as the probability that all the nodes receive message successfully. Average broadcast delay refers to time duration between the start and end of the broadcasting operation. Broadcast collision is eliminated when the parent nodes do not select the same channel in multi hop scenario. In addition, the channel hopping sequences of both the CU sender and the CU receiver are designed for guaranteed rendezvous, given that the CU sender and the CU receiver have at least one channel in common in their hopping sequences.

The interference between the primary and secondary (cognitive) users is avoided by limiting the transmission coverage of each cognitive user than the sensing coverage area. For each CU sender, it randomly selects n channels from its available channel set. Then, it hops and broadcasts periodically on the selected n channels for S time slots. The values of n and S are determined by the QoS requirements of the network (i.e., the successful broadcast ratio and the average broadcast delay). On the other hand, for each CU receiver, it first forms a random sequence that consists of its every available channel with a length of n time slots for each channel. Then, it hops and listens with this sequence periodically.

III. CONCLUSION

In this paper the different schemes for the broadcast of control information in multi hop cognitive radio ad hoc network are discussed. Due to the non-uniform channel availability in CR networks, several significant differences and unique challenges are introduced when analyzing the performance of broadcast protocols in CR ad hoc networks.
The main objective of this paper is to achieve high success rate with low delay in multi hop Cognitive Radio network. Many research studies have been focused on eliminating the broadcast collision in CR. It is important that the effective channel assignment is the primary need in the field of CR network which is achieved by using different broadcasting protocols. Future work of this paper is to provide security while assigning channels to cognitive users.

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