

STBH: a Spectrum-tree-based Hybrid Routing Protocol for Cognitive Network

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Abstract

This thesis proposes a spectrum-tree-based hybrid routing protocol STBH for cognitive network. By proposing ideas of architecture, we introduce the model of STBH, route metric and the algorithm for forming a spectrum tree. Then we propose the route discovery and recovery strategy for Cognitive Networks both in single spectrum and among several spectrums. At last, with simulating by NS2, the effectiveness and robustness of STBH will be proved with the comparison with CTBR.

Keywords: *STBH, spectrum tree, cognitive network*

1. Introduction

The Cognitive Radio (CR) technology, which refers to a smart radio, was proposed by Joseph Mitola III^[1]. This kind of technology as he mentioned could percept the external environment in some level, by learning from the historical records, and then making intelligent decisions to adjust its transmission parameters according to the current state of the environment. Besides CR, Thomas proposed Cognitive Network^[2] (CN), which has been known as the next generation communication network or dynamic spectrum access networks.

The recent research work on CN Routing Protocol is focused on the theory and route metric. Lu et al.^[3] defined the policy-based dynamic spectrum access management system framework to simplify the management for co-exist wireless networks. Akyildiz et al.^[4] proposed that there should be four challenges for the design of CN's routing protocol: common control channel, intermittent connection, and rerouting, scheduling management. Zhang et al.^[5] proposed the CTBR protocol, which is a spread of tree-based routing protocol fit for CN. Wang et al.^[6] detailed analyses of the decoupling design and added design method to CN's routing algorithm.

This thesis will propose a spectrum-tree-based hybrid routing protocol STBH for cognitive network. By proposing ideas of architecture, we introduce the model of STBH, route metric and the algorithm for forming a spectrum tree. Then we propose the route discovery and recovery strategy for Cognitive Networks both in single spectrum and among several spectrums. At last, with simulating by NS2, the effectiveness and robustness of STBH will be proved with the comparison with CTBR.

The rest of this thesis will be carried on as follows: Section 2 gives an introduction to the model of STBH, while Section 3 makes a description about the route discovery and route recovery. Section 4 presents the evaluation results. At last, we have a conclusion of all in Section 5.

2. Model of STBH

Through the analyses and research above, we propose the STBH for CN's features. STBH, which is based on tree structures, is a hybrid from active and on-demand routing strategy for CN. STBH build a

Spectrum-Tree (ST) for each feasible spectrum, by which the routing protocol is active kind only the routing is between a node and the root, if not with the root, the protocol is on-demand kind.

2.1. Architecture

In a multi-hop CN, every node has a spectrum agile radio system for route discovery and reconfiguration of transceiver. We defines that the communication between the nodes, which should be static or move slowly physically, would come out by ad-hoc way and the link is full duplex. So the architecture of STBH is as Fig 1.

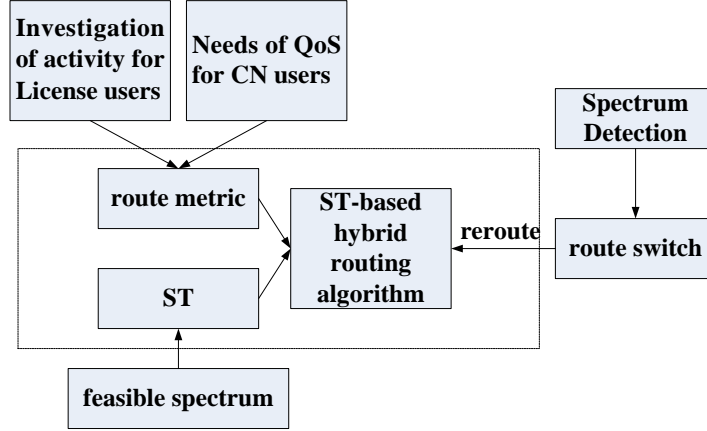


Figure 1. Architecture of STBH

As STBH working, it defines a new route metric by the investigation of activity for license users and also the needs of QoS for CN users. Then it builds a ST, which has been proved to be of great efficiency, flexibility and scalability by CTBR^[5], for each feasible spectrum. By using STBH routing algorithm, it forms the route from end to end based on ST and route metric. When the spectrum between two CN users is switch or missing, STBH will provide a route switch or route recovery algorithm.

2.2. Route metric

The route metric we mentioned is based on the cost of link recourse and the stability of routing. We firstly propose the cost for one link then we can have the total cost of the routing. The cost of link l_i is as Equation (1).

$$C_i = \left[O_{ca} + O_p + \frac{P_{kt}}{r_i} \right] \frac{1}{1 - e_{pti}} \quad (1)$$

O_{ca} is the cost of spectrum access, O_p is the cost of spectrum and P_{kt} is the capacity of packet. And in a certain access technology they are certain amounts. r_i is the speed of access and e_{pti} is the error ratio of packet. The stability of routing can be reflected by duration of a link which can be forecasted by the investigation of activity for license users. Take T_{li} as the duration of l_i , therefore the cost of l_i would be as Equation (2).

$$C_i = \left[O_{ca} + O_p + \frac{P_{kt}}{r_i} \right] \frac{1}{1 - e_{pti}} \cdot \frac{1}{T_{li}} \quad (2)$$

And the total cost of the end to end routing would be as Equation (3).

$$C = \sum_{i=1}^k C_i + \sum_{i=1}^m (D_{switch} \cdot \frac{1}{T_{si}}) \quad (3)$$

k is the number of the links, m is the times the spectrum have switched and D_{switch} is the delay of two CN users while switch between the spectrums.

2.3. Spectrum tree

Every ST only has a single root node by which keeps the topology information for the whole ST. In CN the node may find more than one feasible spectrum, and then some of the nodes would belong to several STs which are known as overlapping nodes. For the routing between root and regular nodes, root will give every CN users an ID, which is organized by a Hash Table for better time complexity. That means every node in a certain ST would have a unique ID and the overlapping ones would have several.

While in CTBR, they make the base stations as the root nodes, but as we know CN is distributed and communicates in ad-hoc way, that implies how to choose a root would be a real challenge. If we suppose Node X is ST_i 's root, and ST_i could only be used by Node X a very short time, then the system would make ST_i dismiss easily, which will consequence to frequently route maintenance and route recovery that means more costs.

Root Node Selection Strategy (BNSS) is proposed to make sure every ST has only one proper root. Firstly, we suppose all nodes as a root, then send root request message (RRM) to the neighbors, and collect the RRM as $\langle N, T_i \rangle$. N would be the number of the feasible spectrums, T_i is the feasible time for a certain spectrum. BNSS is as follow:

```
begin
rooti=X
recvRRM<NY,TiY>
if (NY>NX) then
rooti=Y, send <NY,TiY> to the neighbors
end if
if (NY=NX) then
if (TiY = TiX) then
rooti=Y, send <NY,TiY> to the neighbors
else
delete <NY,TiY>
end if
end if
end
```

At last the node with the largest N or longest T_i would be the root. The construction process of ST is convergent and each ST would have only once. So the cost would be acceptable.

3. Routing algorithm

3.1. Route discovery

STBH routing algorithm is a hybrid from active and on-demand routing strategy for CN. The active routing strategy is shown by ID between the root and normal nodes. In CN we divide the routing into routing in a single channel in the same ST and routing between the channels which is among several STs.

STBH use CRREQ (Cognitive Route REQuest) and CRREP (Cognitive Route REPLY) for route discovery between the nodes. We define them as following:

```
CRREQ< IDS, IDD, metric, intra/inter >
CRREP<IDS, IDD, intra/inter>
```

ID_S and ID_D stand for the source node and destination node, while metric refers to the route metric, and intra/inter shows connection is or not between the channels.

3.1.1. Route discovery in a single channel

When routing in a single channel as Fig 2, all the nodes work in the same channel. We take Node S and D's communication as an example. Node S firstly sends CRREQ, in which ID_D and intra/inter are null, to the root (Node A) by active routing. When the root receives SPPEQ, it will find 2 nodes in the same ST, then puts ID_D into CRREQ, values intra/inter with 1 and sends CRREQ back to Node S. Following, Node S will find the destination in the same ST and broadcast CRREQ. As it broadcasting, every node will calculate the route metric so when Node D gets the message, it could choose the best strategy to send a CRREP back.

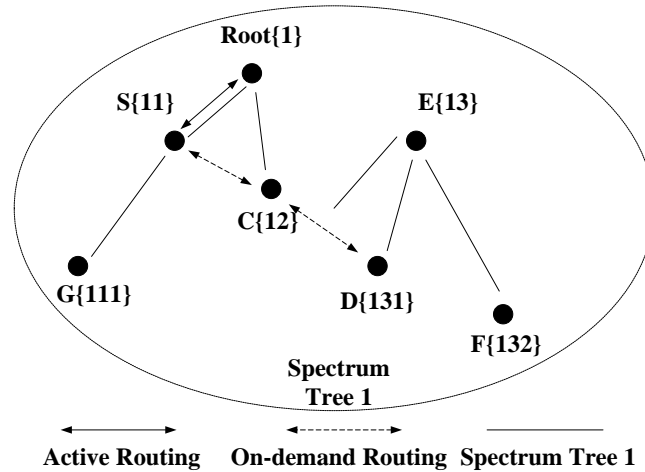


Figure 2. Routing in single ST

3.1.2. Route discovery between the channels

As we can see in Fig 3 and 4, Node A is the root of both ST 1 and ST 2. Like routing in single ST, Node S firstly send CRREQ to the root. When the root finds the destination is in ST 2, it will put ID_D into CRREQ and value intra/inter with 0. Then the root will check the nodes table to find out if there is other overlapping node.

If there is not any other overlapping node, the root will send CRREP to Node S in ST 1. By only active routing, the root will send the packet from Node S to Node D by ST 2, which is to say by the root Node S and D get connection.

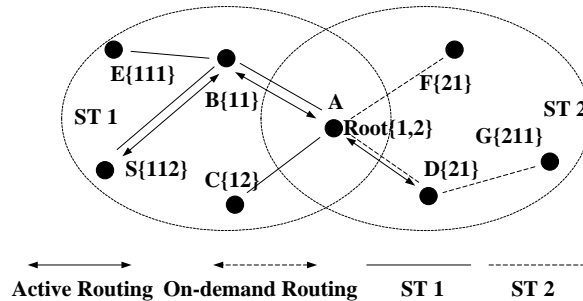


Figure 3. Routing in 2 STs with one overlapping node

If there are other overlapping nodes, the root will make the best overlapping node, which means the

shortest route metric, the gateway node of 2 STs. As we can see in Fig 4, Node B realizes that Node S and D will get connection through it by checking ID_S and ID_D . By active routing, Node B will find the best route to Node S and D. Then by on-demand routing to the Node S from B, the transmission starts from Node S to B, so is the transmission from Node B to D. That is how 2 STs routing from Node S to D by B.

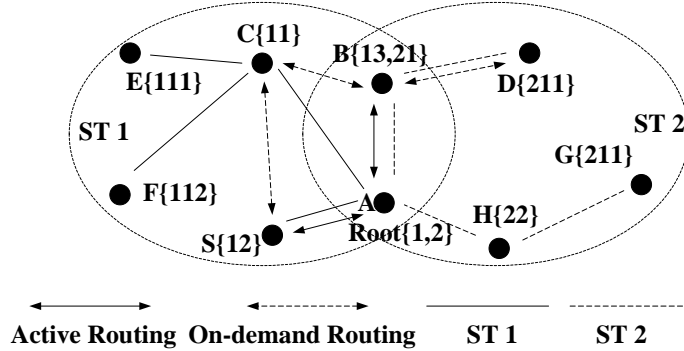


Figure 4. Routing in 2 STs with several overlapping nodes

3.2. Route recovery

Traditionally, in a multi-hop communication system, the movement of nodes is the reason of the failure of connections. But in CN, the failure of the connections always courses by the appearance of the license users.

3.2.1. Route recovery in single ST

Supposing Node S and D is working in the same ST. When license users capture Spectrum 1, the root sends the message to dismiss the whole ST. If there is a feasible spectrum, the root will broadcast the spectrum message before the dismiss message. All the nodes will change the ID. In this situation, the ST doesn't need to be rebuilt. If there isn't any feasible spectrum, all the nodes will join other STs when receive a dismiss message.

3.2.2. Recovery in several STs

Supposing Node S and D are belongs to different STs as Fig 4. When license users capture Spectrum 1, Node A broadcast a dismiss message and Node S realizes Node D work in ST 2. The route recovery algorithm is as follow:

```

if (Spectrum 2 is feasible for Node B)
then join Node S to ST 2; find Node D in ST 2 by on-demand routing
else join Node S to other ST; Node S find Node D by the overlapping nodes
    if (over lapping nodes exist)
    then find the best route between Node S and D
    else Node S start a route discovery between the channels to Node D
    end if
end if
end if
    
```

4. Evaluation

We use NS2 toolkit to simulate a CN environment. The model is as following.

Parameter for CN	Environment
Space	1000m×1000m
Node number	50
Duration	150s
Cover	250m
Type of data resource	CBR
Storage of packet	512 Bytes
Number of data resource	1、 2、 3、 4、 5、 6、 7、 8、 9、 10
Frequency	0.1s

4.1. End to End Average Delay

End to End Average Delay (E2EAD) shows the traffic and QoS of CN by calculate the duration of a packet from the source node to the destination. We make CTBR as a comparison for STBH and change the number of gateway nodes to show the influence of the number of overlapping nodes to STBH. It is the results as Fig 5.

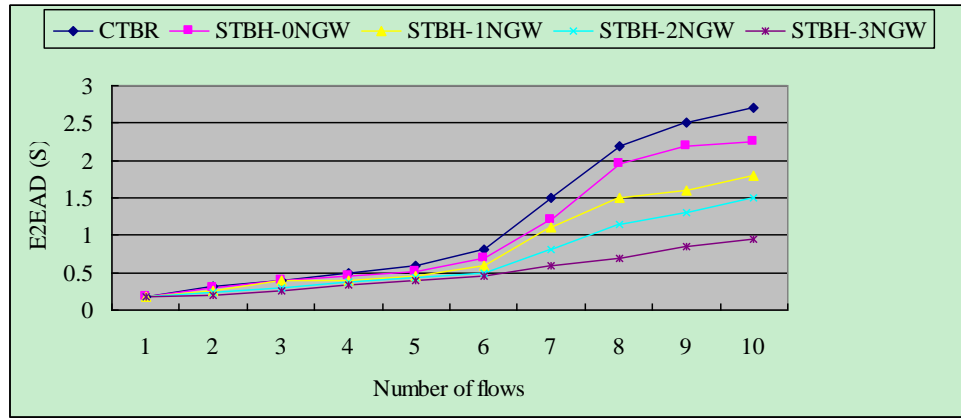


Figure 5. E2EAD of STBH and CTBR

4.2. Route Overhead

Route overhead can be measure by the cost of control. We can define the Normalized Routing Overhead (NRO) as Equation (4).

$$NRO = \frac{N_{control}}{(N_{control} + N_{data}) \bullet N_{flow}} \quad (4)$$

The $N_{control}$ is the storage of control orders, N_{data} is the storage of data, N_{flow} is the number of flows. We also make CTBR as a comparison for STBH and change the number of gateway nodes to show the influence of the number of overlapping nodes to STBH. It is the results as Fig 6.

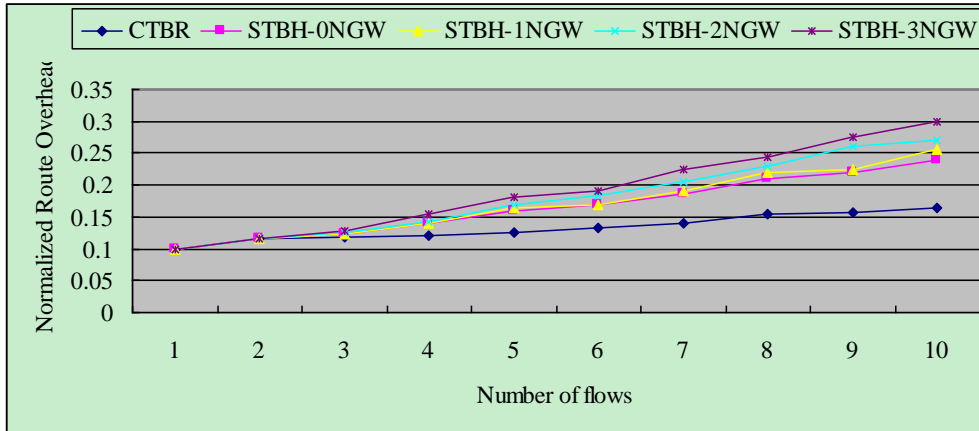


Figure 6. Normalized route overhead of STBH and CTBR

5. Conclusion

By the evaluation results above we could realize that, in average, the performance of STBH is better than CTBR by the consideration of E2EAD. When the load increases, the packets have to use gateway nodes for load balancing, by which could be seen as a sense of decentralization. As the load increasing, both STBH and CTBR's E2EAD would increase, but by the change of number of gateway nodes, STBH have a much better performance.

However, STBH is a hybrid routing protocol. That feature makes it lead to more cost than CTBR does when using on-demand routing. When the number of flows increases, STBH's cost increases more significantly, especially when the gateway nodes number is increasing. However, CN is usually deployment in small area and with few types of equipment in one single ST, and flexibility is the first factor for consideration. So the additional cost from STBH is acceptable, especially considering the performance improved by STBH. But in further research work, the cost of STBH in on-demand routing and the scalability will be our focal point.

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