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A Minimum Spanning Tree Based Routing Protocol For Multi-hop And Multi-channel Cognitive Radio

Sharmin Sultana
Department of Computer Science and Engineering
Chittagong University of Engineering & Technology
Chittagong, Bangladesh
sharminsultana977@gmail.com

Asaduzzaman
Department of Computer Science and Engineering
Chittagong University of Engineering & Technology
Chittagong, Bangladesh
asad@cuet.ac.bd

***Abstract*— Fixed channel allocation technique, used in traditional wireless network implies to assign planned set of frequency channels to each node of the network. Alternately, Cognitive Radio Network (CRN) permits dynamic spectrum access in multiple channels. Hence, CRN is a lot more efficient in bandwidth utilization than the traditional network. CRN is characterized by the selection of channels for every secondary user from available set of channels at each point in the route. A route is feasible only when there is at least one common channel between each pair of nodes in the route. Theoretical graph methods are utilized in traditional multi-hop networks. However, it fails to model multi-hop Cognitive Radio Networks efficiently and to capture required information for optimal routing. For this reasons, a multi-edge planer graph has been designed where conventional routing protocol like AODV, DSDV can be implemented. In multi-edge graph representation, along with the increased number of nodes and edges in the network, more bandwidth is required to update and maintain the routing table. Hence, the overhead for updating and maintaining these tables will increase and degrade the performance of the network. In this paper, a Minimum Spanning Tree (MST) based routing protocol is employed on the planer graph model which is useful to eliminate redundant links and to prevent possible network loops. In this case, the performance of the network will not be affected with increasing number of nodes. This MST based protocol is validated through simulations. The simulation result depicts the improved percentage of successful routes for single radio and multi radio CRN. It also reduces time complexity than earlier conventional routing protocols.**

Keywords—Cognitive Radio Network (CRN), Multi-Hop CRN (MHCRN), Minimum Spanning Tree (MST).

I. Introduction

In Cognitive radio (CR) communication system, a transceiver can identify which channels are engaged and which are not, and immediately selects accessible channels while avoiding occupied ones. The cognitive radio network (CRN) is an opportunist network that facilities secondary user to use available spectrum. The licensed proprietor of a frequency band is called a primary user and the one who utilizes spectrum opportunities for communication is called a secondary user [1].

For multi-hop CRN, it is essential to analyze routing for dynamic spectrum access system by taking into consideration the properties of the cognitive environment. Once the receiver isn't within the transmission range of the sender, information is forwarded through many hops forming a Multi-Hop Cognitive Radio Network (MHCRN). Every node in a MHCRN, has single or multiple radio or interface. Every radio is capable of fixing a needed frequency (channel) to speak. In MHCRN, dynamic nature of spectrum necessitates the introduction of a spectrum aware routing algorithm. So the final challenge for multi-radio, multi-channel cognitive radio network is to assign channels in such a way that might lead an optimum routing algorithm. This paper proposed a Minimum Spanning Tree (MST) based routing protocol for the multi-edge planer graph model [2]. The proposed scheme keeps its performance almost same even if the network size (i.e., number of nodes and number of channels) increased. This protocol also is validated by considering the share of productive routes through simulations which evaluates the percentage of successful routes for CRN.

II. Related Work

The traditional routing algorithms AODV, DSDV and DSR were presented in [3], [4] and [5]. These algorithms provide best result for traditional network. However, in cognitive radio network, performance decrease as a result of the dynamic nature of spectrum. In MHCRN, the channel is selected based on primary user's traffic pattern. So, to discover routes in such networks, a series of steps have to be followed like scanning for untaken channels at every node, electing a typical channel for every pair of neighbors. Optimal channel needs to be chosen if there contains more than one common channel between a pair of nodes based on various criteria.

A layered graph model was projected as an answer to the current drawback in [6]. In this graph model, every channel or frequency of operation is diagrammatically represented by a layer of the graph. Every layer may be a sub-graph containing nodes that representing users. The nodes in every sub-graph are connected if they are within the transmission range of each other. Communication among the nodes across layers is feasible through inter-layer links. Using this graph model, a routing strategy was proposed to search out optimum route. The disadvantages of this graph based routing algorithm is that this layered graph model is complex to represent.

In [2] a new graph-based model was proposed against layered graph model and it embeds the dynamic behavior of a MHCRN into its edge weights. Such a model is easier and additionally correct because numerous radio channel-related parameters are taken into consideration in decisive edge weights. Distance Vector Routing protocol is used here for routes discovery. It is seen that success rate for multi-radio CR (around 90%) is higher than single radio CR. The limitation of this work is, with the increase in number of nodes, time complexity of the whole system also increased i.e. it takes much time to discover routes. In the context of cognitive radio networks, both centralized approaches and distributed approaches are presented and analyzed in [7] an [8] respectively and in the references herein. Most of them assume that every node has only single radio which might switch among multiple channels. A spectrum aware channel assignment algorithm was presented in [9] that considers any routing algorithmic program would provide optimum result supported channel choice.

III. Proposed System Description

In multi-edge graph model, unlike the normal graph models utilized in routing, has multiple edges between nodes [2]. This feature of the graph accounts for the modeling of additional characteristics of multi-hop CRNs like available channel set, potential routes to different nodes through varied channels and neighbor set of every channel. This section explains the proposed model in details.

A. Graphical Reresentation of Cognitive Radio Network

In MHCRN, routing depends on the available channels that successively rely upon the primary user's traffic pattern. This implies that for best alternative of the route, the routing layer ought to be given information regarding the available set of channel at every node. In addition, the overall variety of interfaces accessible at every node is additionally necessary for designing a useful routing algorithm. For example, if an intermediate node within the route has more than one interface, it will select two completely different channels for incoming and outgoing communication, so that the interference is reduced and throughput is accumulated. It's assumed that the information regarding the overall variety of interfaces and obtainable channels at every node is provided to the routing layer of the nodes. In the multi-edge planer graph model, every user is modeled as a Node within the graph and every common channel between two nodes is represented by an Edge.

A multi-edged graph G is considered here as [2] where N denotes the set of nodes and C denotes the set of all channels. Thus a pair of nodes will have more than one edges if they use completely different channels for communication in contrast to standard graph models where every pair of nodes has only one channel in common. For example, if nodes A and B have three channels to communicate, then it is graphically represented in Fig. 1. Node A and B can communicate through channel 1, channel 2 & channel 3. Therefore, node A and B are connected by three edges. W1, W2 and W3 represent the weights of the edges in each channel. The weights can be simple distance or a complex combination of different factors like interference, fading, energy, etc. Every channel is assigned a channel ID. For example, Channel 1 is assigned '1' as channel ID. On the contrary, in traditional networks, every node in a graph has fixed channel allocation. Since all the nodes communicate via one channel in such networks, there's just one edge between each pair of nodes which might communicate with each other.

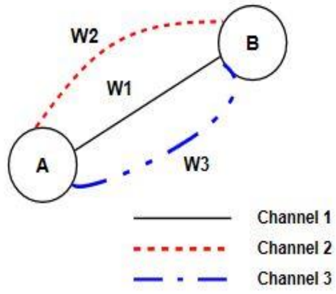

Fig. 1: Two nodes linked with different channels

Fig. 2 considers a multi-edge graph G which is a representation of MHCRN, consists of 5 nodes by occupying four channels. Each node is considered as the users of network. In this graph, the pairs A – B. D – E have common channels 1 and 2. Similarly, channels 1, 3 and 4 are assigned between B–D and so on. In this paper, the same weights are given to all edges between each pair of nodes.

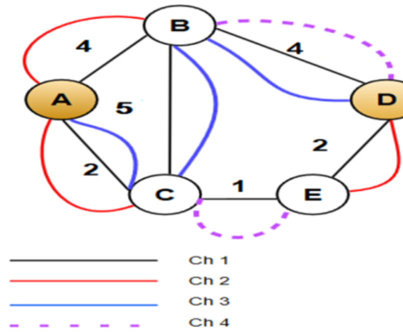

Fig. 2: Graphical Representation of Cognitive Radio Network

B. Channel Assingment based on weight

All graph based routing protocols, find a route based on the weights of the edges of the graph. If the weights of the edges represent the distance between the nodes, then any graph based protocol would select the shortest path route. If the weights are a function of interference, then the route with lowest interference is chosen. Thus weight assignment could be a crucial step in building a graph-based model.

Each radio (interface) of a node is capable of adjusting to a needed channel to communicate. Switch the interface between channels is possible in an exceedingly classical wireless network, though it needs fine synchronization between neighboring nodes and introduces overhead. However, the channels in a cognitive network are distributed across a large spectrum and also the channels are separated with a large band of frequency. In this paper, we consider a system where nodes can switch between interfaces. However, minimization of such switching is required to minimize corresponding overheads. A technique to capture the change in interface is introduced in [2] to minimize this overhead by considering a constraint on interface changing or switching between channels. Let an Interface constraint $IC = | X - Y | \infty$ in the weight similar to [2] as

$$W = |X - Y|\infty + D \quad (1)$$

where, W is the Weight of the edge, X is the Channel ID of the incoming channel, Y is the Channel ID of the outgoing channel and D is the Distance Metric.

Since X and Y area unit channel ID's, if a same channel is chosen for incoming and outgoing communication, then the value of X and Y will be equal and their difference is zero. As a result, the interface constraint term is zero and also the weight, W of the edge can simply be distance, D. Suppose completely different channels has chosen for the incoming and outgoing communications, then mod of the difference of X and Y are a positive non-zero value. The interface constraint term will now be infinity and also the final weight, W would even be infinity. Hence, this selection won't be thought of as a successful route.

Now consider the topology of Fig. 2 and assume that node B has a single radio and it cannot communicate over two different channels. The routing protocol can choose either channel 1 or 2 from node A to node B. So according to [2], the weights for the next hop would be ∞ and 3 respectively. If node A chooses channel 2, weight (W1) seems to be infinite i.e. since node B has no outgoing path using channel 2. That's why, for single radio network it is mandatory to have one common channel from source to destination. So, by adding an IC term to the weights of outgoing edges of the single radio nodes which cannot switch, the possibility of choosing two different channels by the protocol at that node is avoided.

Algorithm 1: Channel Assignment based on weight

1. Add a node N_i to the graph $\boldsymbol{G}$ for each user in Multi-Hop CRN.
2. Add an edge between node N_i and node N_j if they are potential neighbors through channel C_i for all $N_i, N_j \in N$ and $C_i \in C$.
3. Assign the weight for the edge connecting nodes N_i and N_j for all $N_i, N_j \in N$
4. Generate $G(v, E)$.
5. Check $G(v, E)$ whether it is a single radio or multi-radio network.
6. If $G(v, E)$ is single radio network
   i. Add the Interface constraint term (IC) to outgoing edges of nodes N_i if N_i has a single radio and cannot switch for all $N_i \in N$
   ii. $IC = |X - Y|\infty$
   iii. $W = |X - Y|\infty + D$
7. Else
   Channel switching is possible if a node has multi-radio based on channel cost.

Algorithm 1 is proposed to construct the Multi-Edged planer graph model and assign channels based on weights. Here, G defines the projected network model consisting of N number of users. Each user is represented with vertex, V and connection between a pair of users is denoted via edge, E. Weights on each edge represents distance. The index i and j denotes the communicating nodes and C_i symbolizes channel's ID.

C. Topology Reformation Using MST

To return with an ascendable resolution for eliminating redundant neighbors of every node, an algorithm is introduced to stay a minimum of *k* neighbors. The chosen neighbors have high chance to be the consecutive hop of the node in transmissions. In order to keep the best neighbors of every node in terms of minimizing the entire link cost, special case is taken into account by calculating the weights of links.

Consider a network model represented at Fig. 2. Let, source node is A, destination node is D and Node B and C are adjacent to node A. So neighbors of node A are kept in a priority queue and shortest weighted node C is expanded. Now all the neighbors of node C is added to the queue and extract the minimum weight edge among all. This process continue until all the nodes in the topology is visited. If insertion of an edge creates loop, then it is discarded. Finally, reconstructed topology is shown in Fig. 3.

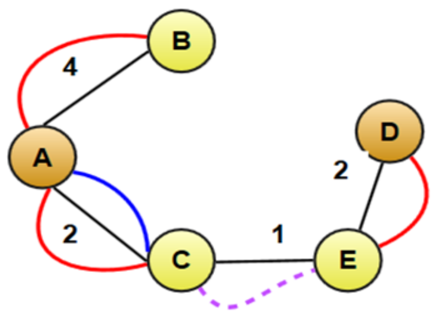

Fig. 3: Reconstructed topology via MST

After formatting topology via MST, it is seen that there exists a single active path from source to any other destination. But sometimes it does not provide shortest distance from source to destination because MST only cares about least resources it can use during routing.

Algorithm 2 proposed a procedure that creates single path from one node to all other nodes by reducing redundant links in the network. The concept of MST is used to develop this procedure. To discover route, it takes input *G(V,E)* and reconstruct new topology which is defined as *G*(V*,E*)*. Here, *S* denotes the source node from where routing starts, *d[i]* keeps track of the current shortest distance and *p[i]* contains the parent of vertex *i*.

Algorithm 2: Topology Reformation Via MST

Input: *G(V,E)*

Output: Topology for the routing phase, *G*(V*, E*)*

1. For every $V \neq S$ initialize $d[s]=0$ and $p[s]=0$ where $d[i]$ contains the current shortest distance from *s* to vertex *i* and *p[i]* contains the parent of vertex *i*.
2. Let *Q* be a priority queue.
3. *Q*←*V*.
4. while *Q* not empty do
5. begin
6. *u* ← *ExtractMin(Q)*

```
mark u as visited.
for each vertex v in Adj[u] do
begin
  if v is not visited and d[v] > weight(u,v) then do
  begin
      d[v] = weight(u,v)
      p[v] = u
       end
    end
end
Return G*(V*, E*)
```

IV. Performance Analysis

A. Simulation Results

A customized simulator developed in C is employed to simulate the multi edge graph. A grid topology is taken into account with variable variety of nodes from a pair to a hundred. The channels available at every node are arbitrarily selected. Maximum number of channels (channel set) at every node is varied from a pair to ten. Each point on the Figs. 4 and 5 is an average of 100 simulations. The first set of simulations assume that all the intermediate nodes in a route are able to switch between channels to communicate with their two neighbors. In the second set of simulations, we assume no intermediate node will switch between channels in the very communication. Although these assumptions are unrealistic, they serve two purposes. Firstly, they assist to verify the planned model intuitively. Secondly, they act as upper and lower bounds on performance. In practical cases, results can consist between these results.

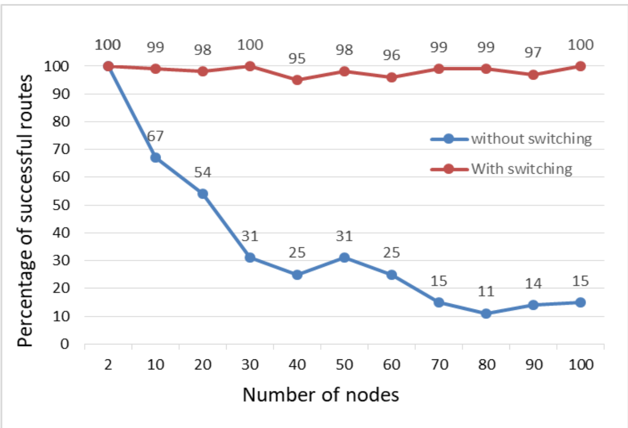

Fig. 4: Graphical representation of successful routes with nodes varying from 2 to 100 and fixed number of channel assuming 5

It is observed from Fig. 4 that there is a hit rate between 95-99% with switching between channel is enabled. Once switching isn't allowed, a node cannot communicate in two completely different channels at the same time. This constraint, limits all nodes within the route to communicate using the same channel. Because it is less probable that all nodes in the route have a common channel, the success rate is lower in such a network. Once switching is feasible, a route is possible if there's at least one common channel between each pair of nodes on the route. As a result, the proportion of successful routes is way higher with switching than without switching.

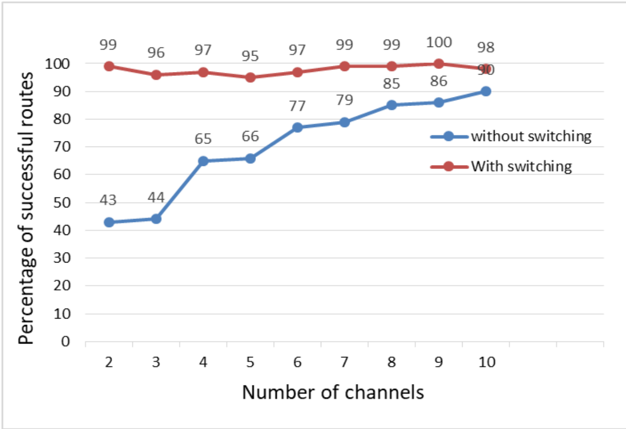

Fig. 5: Graphical representation of successful routes with channels varying from 2 to 10 having fixed number of nodes assuming 10.

It is seen from Fig. 5 that with an increase in the number of channels, the success rate of the routes increases to nearly 100% with switching. This is obvious from the fact that the probability of finding at least one available channel between a pair of nodes increases with the number of channels. Whereas, the probability that a common channel is found among all the nodes with increase in the number of channels also increases significantly.

B. Analytical Study

To verify the simulated result, an analytical model is proposed that determine the probability of successful routes with the variation in number of nodes and number of channels. The value of probability, p is assumed to be 0.5. Consider a topology with n nodes in the route. The probability that there exists a path between the first node and the final node if a channel is available at a particular node with a probability of p is derived by allowing the total number of channels be c.

According to existing algorithm of [2], analytical equation for the network is derived. The probability that one common channel exists between two nodes = p^2. Hence, the probability that a common channel does not exist between 2 nodes = $1 - p^2$. Accordingly, the probability that no common channel exists between two nodes along c possible channels = $(1-p^2)^c$ and the probability that at least one common channel exists between two nodes = $1-(1-p^2)^c$. Finally, the probability that at least one common channel exists between every hop is given as

$$P = (1-(1-p^2)^c)^{n-1} \quad (2)$$

In single radio CRN, a route is possible only if all nodes in the path have at least one common channel and given as,

$$P = 1 - (1-p^n)^c \quad (3)$$

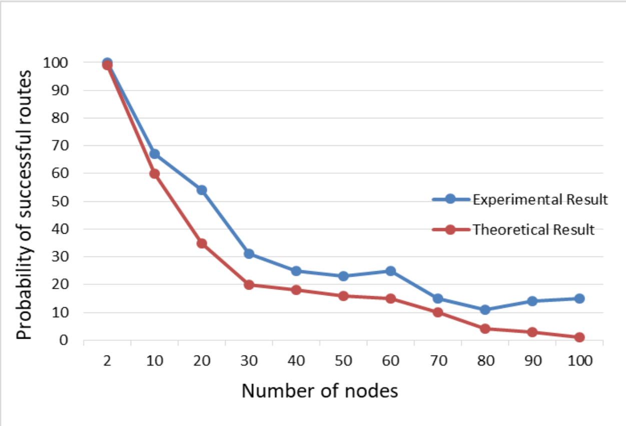

Fig.6: Comparison between experimental result & theoretical result for single radio network

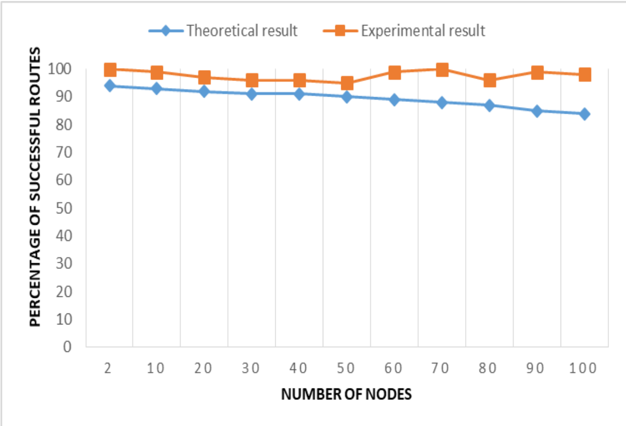

Fig.7: Comparison between experimental result & theoretical result for multi radio network

Fig. 6 and Fig. 7 show the comparisons between the analytical and simulation result. Since grid topology was employed in simulation the analytical results are the lower bound of the performance. Both the Figs confirm that the simulation and analytical resells are in similar shape to validate our analysis.

C. Complexity Analysis

Complexity of a routing algorithm is very important performance criterion. In this subsection the time complexity of the proposed algorithm is compared with the existing ones. The time complexity for the proposed MST based routing algorithm is $O\ (n \times (E\ log\ n)\ \times C)$. Here, *n* is that the range of nodes, *E* is that the range of edges and C is that the range of channels. On the other hand, in existing algorithm of [2], the time complexness is $O\ (n\ \times (m \times n) \times C)$. Here *n* indicates range of nodes, *m* is that the range of neighbors and *C* is that the range of channels. It is simply observed that the complexness of the existing protocols of [2] is much larger than the proposed algorithm. On the contrary, the protocol in [2] is based on DSDV which needs to maintain two routing tables for every nodes. The majority of the complexness in DSDV is generating and maintaining these tables. The updates are transmitted to neighbors periodically. As growing of quality and range of nodes within the network, update the large scale of the information measure and also the routing tables. As a result, the overhead for change and maintaining these tables will increase. It is natural that high routing overhead can degrade the performance of the network.

D. Performance Evaluation

Fig. 8 shows that the percentage of successful routes for single radio network is better in proposed model using MST than existing model of [2] using DSDV where nodes number are varying from 2 to 100. It is observed that percentage of successful routes by using MST protocol is about 10-20% more than DSDV based protocol of [2].

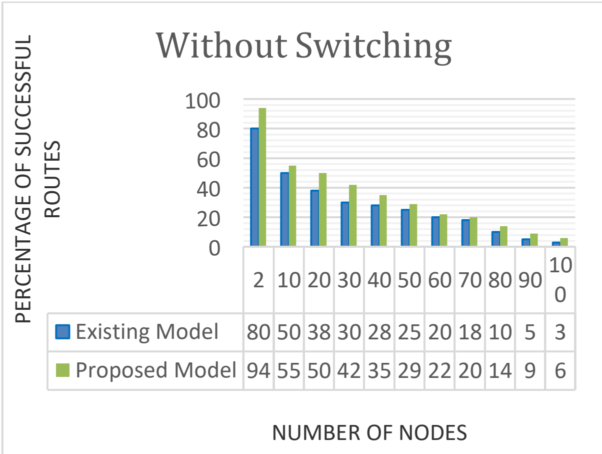

Fig.8: Comparison between existing model and proposed model for single radio CRN

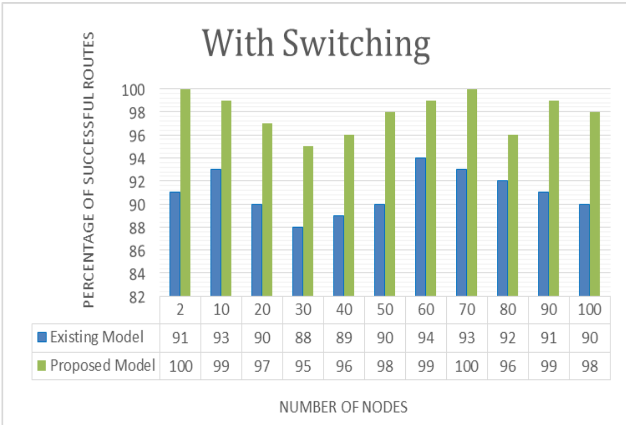

Fig.9: Comparison between existing model and proposed model for multi radio CRN

The percentage of successful routes for multi radio network is also better in proposed model than existing model where nodes number are varying from 2 to 100. It is observed that there is a success rate of 90% with switching in the existing model [2] whereas it is nearly 98% in the proposed model as shown in Fig. 9. Hence, the proposed Minimum spanning tree based protocol outperforms the existing protocol in terms of both the complexity and the performance.

V. CONCLUSION

In this paper, a route finding protocol based on Minimum Spanning Tree (MST) is applied on multi-edged graph which represents a Multi-Channel Cognitive Radio Network. The MST based routing protocol builds a loop-free topology for CRN. It also prevents routing loops and allows a network architecture to include backup links if an active link fails. One important property of the proposed protocol is that the performance of the network does not decrease in spite of increasing number of users. On the other hand, traditional routing protocol like DSDV based scheme limits the performance in the number of nodes that can join in the network when the network topology changes. MST solves this scalability and stability issues of the network. Finally, the routing performance and the time complexity of MST based protocol is better than DSDV based protocol.

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