Journal of Computer Science and Technology Studies
ISSN: 2709-104X
DOI: 10.32996/jcsts
Journal Homepage: www.al-kindipublisher.com/index.php/jcsts

JCSTS
AL-KINDI CENTER FOR RESEARCH AND DEVELOPMENT

| RESEARCH ARTICLE

Advanced Recursive Best-First Search (RBFS) based Routing Protocol for Multi-hop and Multi-Channel Cognitive Wireless Mesh Networks

Md. Zahid Hassan[1] ✉ and Asaduzzaman[2]

[1]Student, Dept. of Computer Science and Engineering, Chittagong University of Engineering and Technology, Chattogram and Bangladesh

[2]Professor, Dept. of Computer Science and Engineering, Chittagong University of Engineering and Technology, Chattogram and Bangladesh

Corresponding Author: Md. Zahid Hassan, **E-mail**: zahidhassan956@gmail.com

| ABSTRACT

Cognitive Wireless Mesh Network (CWMN) is an opportunistic network in which radio channels can be assigned according to their availability to establish connections among nodes. After establishing a radio connection among nodes, it is necessary to find an optimal route from the source node to the destination node in the network. If there remain more channels among nodes, the minimum weighted channel should be taken into account to establish expected routes. The graph theoretic approach fails to model the multi-channel cognitive radio networks due to abrupt failure in finding new successful routes as it can't figure multi-channel networks. In this paper, a multi-edged graph model is being proposed to overcome the problems of cognitive radio networks, such as flooding problems, channel accessing problems etc. A new channel accessing algorithm has been introduced, and optimal routes have been selected using a heuristic algorithm named RBFS. Simulation results are compared with DJKSTRA based routing protocols.

| KEYWORDS

Mesh Network, Cognitive Radio Network, Radio Channel, Flooding Problem, Routing Protocol.

| ARTICLE INFORMATION

ACCEPTED: 12 December 2023 **PUBLISHED:** 01 January 2024 **DOI:** 10.32996/jcsts.2024.6.1.1

1. Introduction

Wireless mesh networks [Ahmed et al. 2013, Kiani 2016, Cong et al. 2009, Asaduzzaman et al. 2011, Alabady et al. 2013] (WMNs) provide high data rate service, scalability and self-healing abilities at reduced cost. As a result, it has emerged as a promising technology for wireless broadband internet access. Traditional wireless networks rely on a small number of wireless hotspots to connect users, where a WMN extends network coverage using wireless mesh routers that communicate with each other via multi-hop wireless communications [Kojic 2010]. There are a lot of difficult environments such as emergency situations, tunnels, oil rigs, battlefield surveillance, high-speed mobile-video applications on board public transport, real-time racing-car telemetry or self-organizing internet access for communities where WMN can be applied.

To improve the system capability and adaptability of mesh networks, cognitive radio performs a great job. To avoid channel interference and congestion, a cognitive radio can be programmed and configured dynamically. There are two types of users [Zhao et al. 2007] in CWMN. Primary or licensed users have a strong right to use the available spectrum. On the other hand, secondary users, also known as cognitive users, just utilize the available radio channels when primary users remain idle. Thus, primary users become the important components of CWMN.

For multi-hop, it is crucial to study routing in a dynamic spectrum access system, taking into account the unique properties of the cognitive environment. Data is forwarded through several hops(nodes), forming a Multi-Hop Cognitive Wireless Mesh Network [Zhao et al. 2007, Akyildiz et al. 2008] when the receiver is not in the transmitting range of the sender. Any two users can only make a connection between them if they have at least one common channel. Each node in a multi-hop cognitive wireless mesh network is capable of changing to a required frequency (channel) to communicate. So, the channel of the multi-radio should be assigned in such a way that would lead a routing algorithm optimal. Two nodes can be connected if there is at least one common channel between them. So, channel assignment is a crucial part of routing. Various dynamic [Zhao et al. 2007, Akyildiz et al. 2008, Kapse et al. 2013] spectrum assignment processes have been proposed earlier. We use a simple methodology to assign available spectra and calculate their weights. Among many [Musznicki et al. 2012] existing algorithms, the RBFS algorithm [Kiani 2016] has been used to find the best route for the convenience of minimum cost, greedy, and memory bounded nature. In Dijkstra based routing protocol, there may exist flooding problems which can be solved by using RBFS based routing protocol. A brief discussion about the contribution is given below:

- A global database which can store the straight-line distances among nodes.
- Gaussian normal distribution has been used to calculate the weights among nodes. As nodes are dynamic, weights are changed according to the changing positions.
- Channel assignment algorithm is being used to find the best channels and creating the topology (random graph).
- RBFS algorithm is being used to find the best route in a dynamic environment, as previous routing protocols are suitable for only static environments.
- RBFS based protocol can solve the flooding problem as it chooses the route based on a heuristic search approach.

The remainder of the paper has been organized as follows. Section 2 presents a brief discussion of the previous works. Section 3 describes the working procedure of our proposed methodology. Simulation results are discussed and analysed in section 4, and section 5 concludes the paper.

2. Literature Review

In the last decade, a lot of work has been done on wireless communication [Cordeiro 2006] for its convenient characteristics. Federal Communications Commission (FCC) handles all effective tasks of promoting competitions, innovations, investment and regulations in the radio spectrum. Cognitive Radio (CR) technology provides an efficient utilization of available radio spectrum.

The traditional routing algorithms AODV, DSDV, Dijkstra and DSR were discussed in [Perkins et al. 2003, Perkins et al. 1994, Johnson et al. 2007]. These scheduling algorithms give the best results for the traditional network topology. But, for cognitive radio networks, performance decreases because of the dynamic nature of the spectrum.

In multi-hop cognitive networks, the availability of a particular channel depends on the primary user's traffic. Due to the dynamic physical layer, characteristics like bandwidth, power constraints and interference levels may vary. If a route discovery has to be initiated in such networks, a series of steps have to be followed, with scanning for available channels and finding the best channel being the most important tasks. If there is more than one common channel between a pair of nodes, then an optimal channel has to be chosen based on various criteria such as interference level, bandwidth, etc.

A layered graph model has been proposed as a solution to the problem [Zhao et al. 2013]. In this graph model, each channel is represented by a layer of the graph. Each layer containing nodes in a subgraph represents users. The nodes in each sub-graph are connected if they are in the transmission range of each other. Communication among the nodes in different layers is possible through inter-layer links. Using this graph model, a routing technique was built to find an optimal route [Zhao et al. 2013].

The disadvantage of this graph model is that it is complex to represent. Traditional routing protocols like AODV [Perkins et al. 2003], DSDV [Perkins et al. 1994] and DSR [Johnson et al. 2007] assume planar structured graphs. As a result, a direct application of these protocols on a layered graph model is not possible.

Y. R. Kondareddy has proposed a 'Multi-Edged Planar Graph Model' for routing in MHCRNs, which is proposed in [Kondareddy et al. 2008]. It embeds the dynamic behavior of an MHCRN. Such a model is simpler and also accurate as it takes into account various radio channel related parameters for determining edge weights. A distance vector routing algorithm is used here, but the success rate is approximately 90%. So, the loss of packets occurs.

In the context of cognitive radio networks, both centralized approaches [Cordeiro et al. 2006] and distributed approaches [Yuan et al. 2007] have been proposed. Most of them assume that each node has only one radio, which can be switched among multiple channels.

Spectrum aware channel algorithm was proposed by [Ahmed et al. 2013], which considers that a routing algorithm would give optimal results based on channel selection.

By considering co-channel interference among primary and cognitive nodes and node mobility, a joint routing algorithm was proposed by [Tang et al. 2016]. The hybrid adapting algorithm used in [Ngo et al. 2016] gives a solution to select neighbouring nodes by using MST. It focused on using all-spectrum by cognitive radio for disaster response networks.

In the Dijkstra based routing protocol [Musznicki et al. 2012], it needs to visit all the nodes in the system to find the optimal route, which is inefficient when the number of nodes will be increased.

In [Kondareddy et al. 2008], channel assignment is done based on the radio of a node. If the node has a single radio, then incoming and outgoing channels must be the same from source to destination. For multiple radio cases, channel switching is possible. So, an appropriate channel is assigned based on cognitive cost function.

The article by [Wang et al. 2015] presents a comprehensive survey of channel assignment schemes based on BFS for multi-radio multi-channel wireless mesh networks. The models described here are only applicable for unidirectional networks. The proposed algorithm degrades performance with the increase of nodes in the topology.

Figure 1: Graphical representation of cognitive wireless mesh network.

3. Methodology

In this paper, available channels between nodes have been assigned. Then, a graph has been formed using these channels. The percentage of successful routes from source to destination has been shown within this randomly generated graph. The algorithm and pictorial representation of the proposed system are focused on in this chapter.

In Fig. 1, a graphical representation of a cognitive wireless mesh network where channels can be assigned to make connections among nodes has been shown.

If a node has more than one interface, then it can assign more channels to reduce the interference among allocated channels. The throughput of the wireless network can be increased with a reduced interference level by assigning more channels.

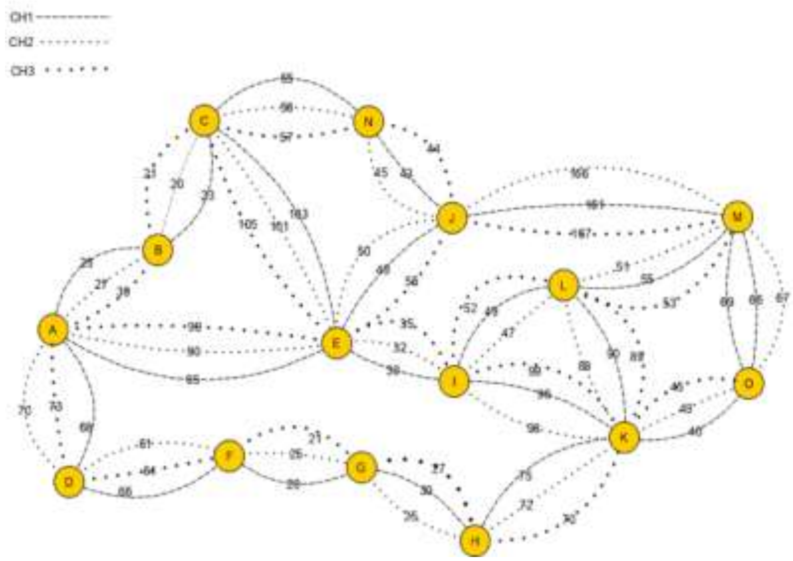

Figure 1: Graphical representation of cognitive wireless mesh network.

3.1 Topology Formation Using Channel Assignment Algorithm

Each node has more than one radio through which it can access the available radio channel to make-up links with other nodes for communication. Two nodes can be connected only when there is at least one common channel. Connection between any two nodes is possible if each node assigns the same channel between them using radio.

$$\mathrm{IF} = |1 - \frac{X}{Y}|\infty \quad (1)$$
$$\mathrm{W} = |\mathrm{X} - \mathrm{Y}|\infty + \mathrm{Q} \quad (2)$$

In the above equation, X and Y represent any two nodes. Any two nodes can be linked if they satisfy Eq. (1). This equation checks whether the two nodes are assigning the same channel or not. If nodes A and D (Fig. 1) are connected by three channel sets, both of them assign the same three channels, which are ch1, ch2, and ch3. Both nodes A and B assign ch1, for example, to represent the same channel. So, according to Eq. (1), we can find the Interface Factor (IF) in Eq. (3).

$$\mathrm{IF} = |1 - (\frac{1}{1})|\infty = 0 \quad (3)$$

So, weight (W) can be calculated for this channel according to Eq. (4).

$$\mathrm{W} = |\mathrm{X} - \mathrm{Y}|\infty + \mathrm{Q} = 0 + \mathrm{Q} = \mathrm{Q} \quad (4)$$

Q is a function that depends on the straight-line distance between any two nodes. If the IF term is zero, that means both nodes of a pair assign the same channel, then the weight of the channel can be calculated by the Q function (Eq. (5)) where D represents straight-line distance, and R represents a random value using gaussian normal probability distribution.

$$\mathrm{Q} = \frac{1}{D} \times \mathrm{R} \quad (5)$$

The channel weight between every two nodes depends on distance. Using Gaussian Normal Probability Distribution, channel weight can be calculated using straight-line distance. So, if nodes are dynamic in nature and change their positions randomly, their assigned channel weight will be changed. If a channel weight satisfies the threshold value, then that channel can be selected to establish a connection. Otherwise, the channel should be rejected.

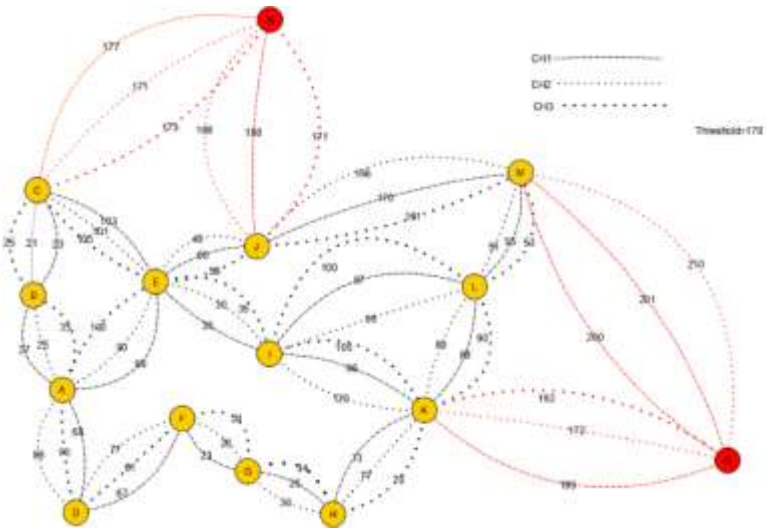

Figure 2: channel weight changes according to node positions.

In the above Fig. 2, it has been shown that nodes are changing their positions dynamically. As the weight of each channel is a complex function of distance, channel weights are also being changed according to their respective positions.

In Fig. 2, all the channels connecting to nodes N and O cross the threshold value. So, these channels should not be considered according to our proposed methodology. As a result, there remain no channels that connect the node N & O with other nodes.

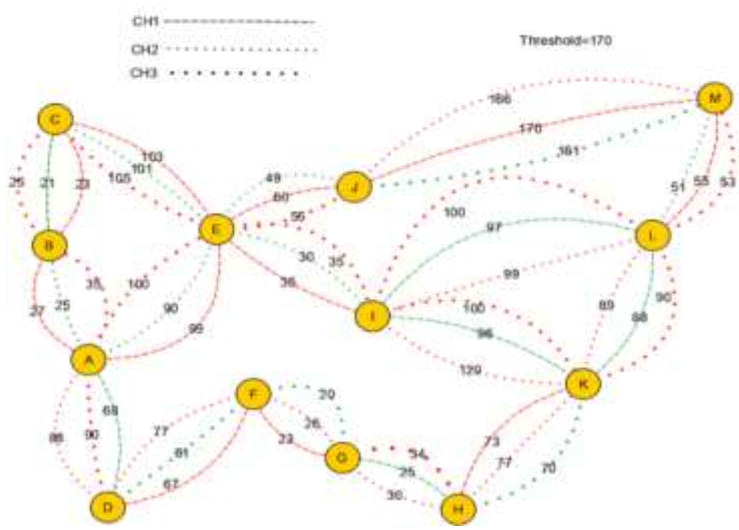

Figure 3: Reconfiguring the graph according to the threshold value.

In Fig. 3, nodes N & O have been disconnected, and a new multi-edged multi-channel graph has been formed. Each node has three channels to connect other nodes. But a minimum weighted channel should be considered to make a connection, making other channels free. Taking the minimum cost channels, the final graph (Fig. 4) was formed.

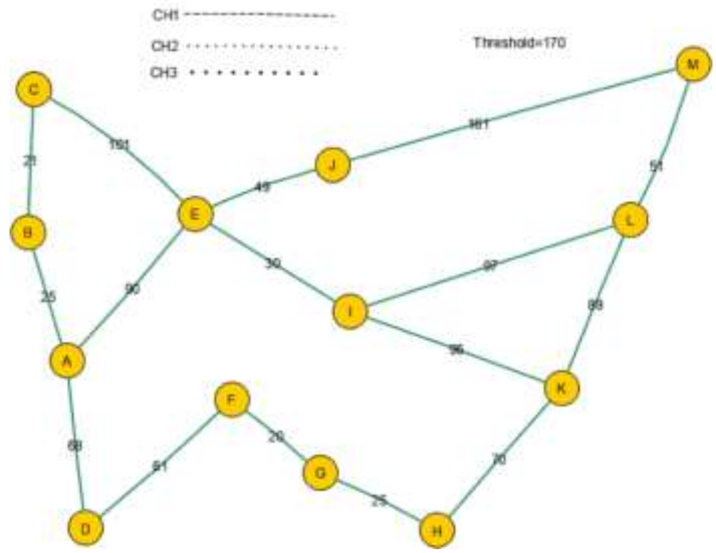

Figure 4: A graph has been formed randomly, taking minimum cost channels.

The channel assignment algorithm is used to assign the best channels and generate a graph. If two nodes allocate the same channel between them, then the Interface Factor (IF) becomes zero (Eq. (4)). So, the weight can be calculated for this channel according to Eq. (5).

After allocating all the available channels for the overall nodes, it is necessary to compare these weights with a threshold value. Those channels can be chosen in the primary stage whose weights are under this threshold value. As a result, a multi-edged graph has been formed (Fig. 3).

If a node has a single radio channel, it is not necessary to switch channels. For multi-radio nodes, it is necessary to switch channels if necessary.

Among multiple channels between two nodes (Fig. 3), a minimum cost channel should be taken. This approach has been used for all pairs of nodes repeatedly, and the final graph has been formed (Fig. 4). The overall procedure of the channel assignment technique has been represented through the following flowchart (Fig. 5).

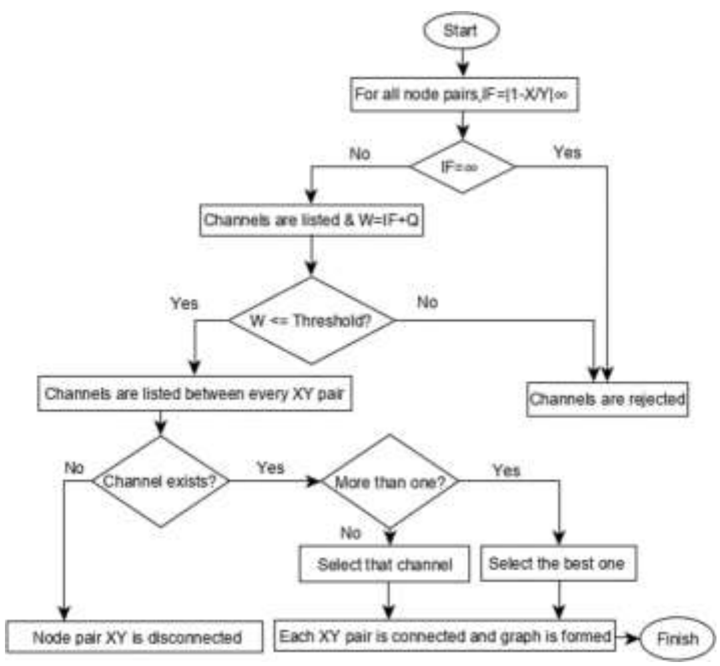

Figure 5: Flowchart of channel assignment algorithm.

In Fig. 6, a flowchart of the RBFS algorithm has been presented.

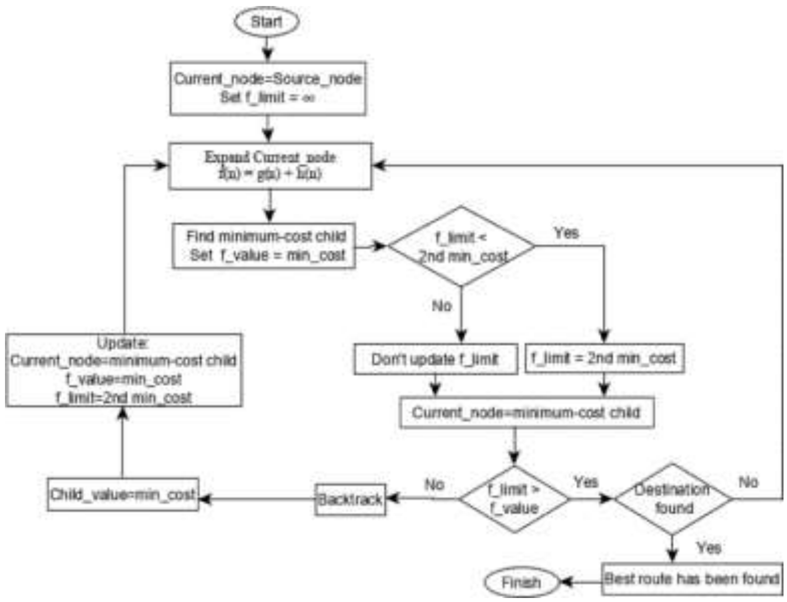

Figure 6: Flowchart of RBFS algorithm.

3.2 Global Database Server Concept

The global database serves two important issues. One is that it helps to assign channels. Channel weight is calculated by considering distance and other factors. The second issue is to provide node positions and straight-line distances when the RBFS algorithm is being used.

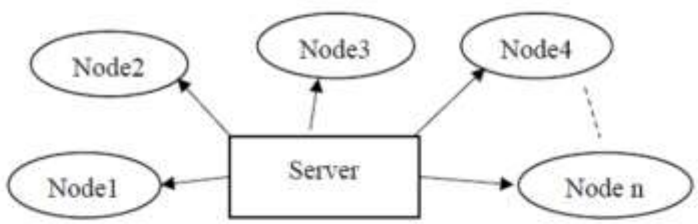

Figure 7: Global database server for providing straight-line distance.

There remains a time period for updating the database. Because nodes always change their positions randomly. So, their straight-line distances are also changing. Within a certain time period, the global database also updates all distances.

The list of selected channels contained within the best route is also stored in a global database so that data can be followed by these channels. Fig. 7 shows the global database server scenario.

3.3 Proposed Algorithm

Steps required to discover routes:

- Generate multi-hop graph using channel assignment algorithm.
- Update the global database to store the straight-line distances among dynamic nodes.
- Find the best (cost-efficient) route using the RBFS algorithm.

The overall methodology has been shown through a flowchart in Fig. 8. A global database server always monitors the locations of all nodes within the network. It updates the stored information within a certain time period to obtain the most recent locations of all the dynamic nodes.

Weights of all available channels have been calculated using the Gaussian normal probability distribution formula, and the information on straight-line distances is stored in the database according to the channel assignment algorithm. As a result, a new dynamic topology has been formed (Fig.4).

Then, the RBFS algorithm has been used to obtain the best route for transmitting data within the network.

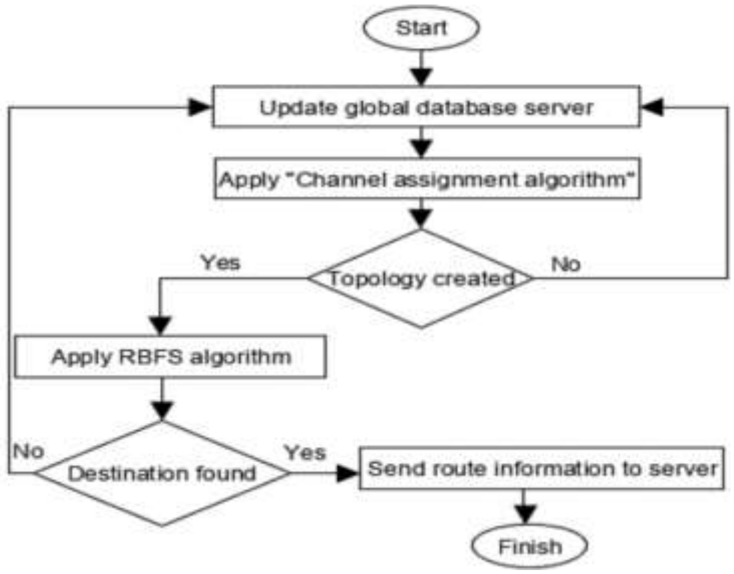

Figure 8: Flowchart of proposed methodology

Applying the above procedure in Fig. 4, destination node M has been reached. The optimal path is **A→E→I→L→M.** The number of visited nodes is 5, and the cost is 268 (Fig. 9).

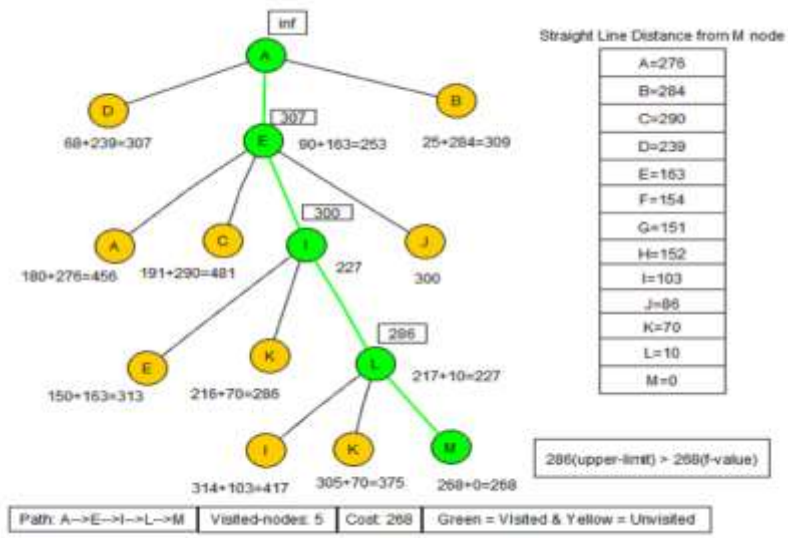

Figure 9: Finding the optimal route.

4. Results and Discussion

s Dijkstra and MST based routing protocols are better than traditional DSDV, AODV, DSR based protocols. But, the number of explored nodes needed to find the optimal path is higher. Thus, node processing cost increases. If there are more nodes to be explored to find the optimal path, the required time will be higher. The proposed RBFS based routing protocol works on the basis of a heuristic search approach. From the above experiment, we can see that it needs to explore less-number of nodes to find the route.

Fig. 10 represents the comparison of required explored nodes of both traditional and proposed protocols. It shows that the number of explored nodes increases with the increasing number of total nodes, where the proposed protocol needs fewer nodes to explore than the traditional Djkstra based protocol.

We have run the code 100 times and explored the routes. Every time we run the code, new topology and routes are found, and the average value is taken.

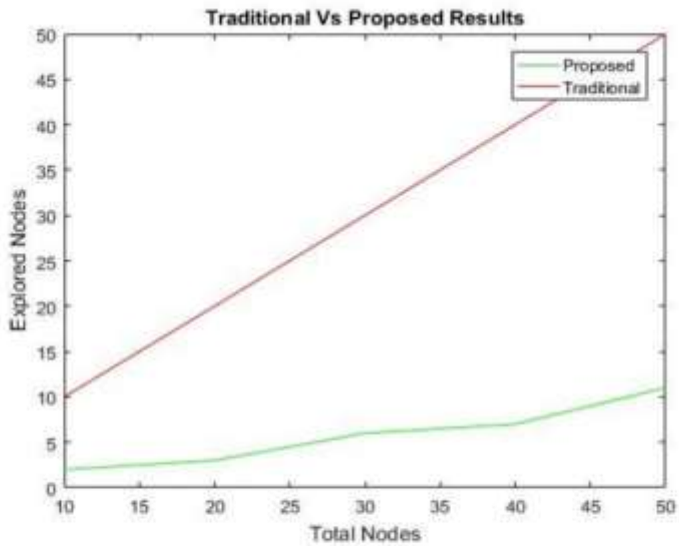

Figure 10: Comparison of required nodes between traditional and proposed protocol.

5. Conclusion

In this paper, an advanced routing protocol for multi-channel, multi-edge wireless cognitive mesh networks (WCMN) is discussed. Multi-edge graph model has been used to represent the system architecture. Previous routing protocols (DSDV, AODV, DSR, MST, Dijkstra based) were proposed for only static environments where nodes don't change their positions randomly. But, advanced RBFS based routing protocol can work for both static and dynamic structures where nodes can change their positions randomly. As RBFS is a heuristic-search algorithm, it expands less nodes to find the best route. So, the processing cost and time are less than the previous routing protocols. The flooding problem of routing protocols is solved using this proposed protocol.

Funding: This research received no external funding. This is a self-funded study.
Conflicts of Interest: The authors declare no conflict of interest.
ORCID ID: 0000-0001-7159-0990

References

[1] Ahmed E, Shiraz M., and Gani A., (2013) Spectrum-aware distributed channel assignment for cognitive radio wireless mesh networks, *Malaysian Journal of Computer Science*, 232- 250, March, 2013.
[2] Akyildiz IF, Lee W-Y, Vuran C M, Mohanty S, (2018) A survey on spectrum management in cognitive radio networks *IEEE Commun. Mag*. 46(4), 40–48, 2008.
[3] Asaduzzaman and Hyung Y K, (2011) Ergodic and outage capacity of interference temperature-limited cognitive radio multi-input multi-output channel, *IET communications*, 5, 5. 652-659, 2011.
[4] Alabady, S. and Salleh, M. (2013). Overview of Wireless Mesh Networks. *Journal of Communications*, 8(9),.586-599.
[5] Akyildiz IF, Lee W-Y, Vuran C M, Mohanty S, (2008) A survey on spectrum management in cognitive radio networks *IEEE Commun. Mag*. 46(4), 40–48, 2008.
[6] Ahmed E., Shiraz M. and Gani A. (2013) Spectrum-aware distributed channel assignment for cognitive radio wireless mesh networks, *Malaysian Journal of Computer Science*, pp: 232-250, March, 2013.
[7] Cordeiro C., Challapali K., Birru D., and Shankar S. N, (2006) IEEE 802.22: An introduction to the First wireless standard based on cognitive radios, *Journal of Communications*,1, 1, Apr. 2006.
[8] Cong L and Jie W (2009) Virtual-force-based geometric routing protocol in Manets', *IEEE Transactions on Parallel and Distributed Systems*, 20(4). 433–445. doi:10.1109/tpds.2008.103.

[9] Hernandez C., Salgado C., López H., and Rodriguez-Colina E. (2015) Multivariable algorithm for dynamic channel selection in cognitive radio networks, *SpringerLink*, 19-Sep-2015.
[10] Johnson V, Hu Y., and Maltz D., (2007) The dynamic source routing protocol (DSR) for mobile ad hoc networks for IPv4, *RFC Editor-4728*, Feb. 2007.
[11] Kapse V. and Shrawankar U., (2013) Interference-aware channel assignment for maximizing throughput in WMN," *International Journal on Ad-hoc Networking Systems*, 1, 1-12, 2013.
[12] Kiani, F. (2016) Ar-RBFS: Aware-routing protocol based on recursive best-first search algorithm for wireless sensor networks, *Journal of Sensors*, 2016, pp. 1–10. doi:10.1155/2016/8743927.
[13] Kojic, N. *et al.* (2010) Packet routing in wireless mesh networks', *10th Symposium on Neural Network Applications in Electrical Engineering* [Preprint]. doi:10.1109/neurel.2010.5644081.
[14] Kapse V. and Shrawankar U. (2013) Interference-aware channel assignment for maximizing throughput in WMN, *International Journal on Ad-hoc Networking Systems*, 1, 1-12, 2013.
[15] Kondareddy Y. R. and Agrawal P., (2008) A Graph Based Routing Algorithm for Multi-hop Cognitive Radio Networks," *Proceedings of the 4th International ICST Conference on Wireless Internet*, 2008.
[16] Kyasanur P. and. Vaidya N. H, (2005) Capacity of multi-channel wireless networks: impact of number of channels and interfaces, *in ACM International Conference on Mobile Computing and Networking*, 43,57, 2005.
[17] Musznicki, B., Tomczak, M. and Zwierzykowski, P. (2012) Geographic dijkstra-based multicast algorithm for Wireless Sensor Networks, *ipc*, 17(1–2), 33–46. doi:10.2478/v10248-012-0013-3.
[18] Ngo T., Nishiyama H., Kato N., Kotabe S., Tohjo H., (2016) GHAR: Graph-based hybrid adaptive routing for cognitive radio based disaster response networks, *In Communications (ICC)*, pp. 1-6, May 2016.
[19] Nguyen, H. L. (2012) High-performance Multicast in Multi-Channel Mlti-Radio Wireless Mesh Networks." *PhD thesis, York University*, 2012.
[20] Perkins C., Belding-Royer E. and Das S. (2003) Ad hoc on-demand distance vector (AODV) routing, *IETF Mobile Ad Hoc Networks Working Group*, IETF RFC 3561, July 2003.
[21] Perkins C. E. and Bhagwat V (1994) Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers, *Proceedings of the conference on Communications architectures, protocols and applications - SIGCOMM '94*, 24, 4, 234–244, Sep. 1994.
[22] Subramanian A. P., Gupta H., Das S. R., and Cao J., (2008) Minimum interference channel assignment in multi-radio wireless mesh networks, *IEEE Transactions on Mobile Computing*, vol. 7, no. 12, pp. 1459-1473, 2008.
[23] Singh A. and Singh K. (2014) Load balancing based channel assignment in multicast wireless mesh network," *in IEEE International Conference on Computing for Sustainable Global Development*, pp. 865-869, 2014.
[24] Tang F., Guo M., Guo S., and Xu C., (2016) Mobility prediction based joint stable routing and channel assignment for mobile ad hoc cognitive networks, *IEEE Transactions on Parallel and Distributed Systems*, 27, 3, 789–802, Mar. 2016.
[25] Wireless lan Medium Access Control (MAC) and Physical Layer (PHY) specifications, (1997) *IEEE Computer Society LAN MAN Standards Committee and others*, 1997.
[26] Wong V. W. et al., (2006) Joint optimal channel assignment and congestion control for multi-channel wireless mesh networks," *in IEEE International Conference on Communications*, 5, 1984-1989, 2006.
[27] Wang J., Shi W., and Jin F., (2015) On channel assignment for multicast in multi-radio multi-channel wireless mesh networks: A survey," *China Communications*, 12, 1, 122–135, 2015.
[28] Yuan Y., Bahl P., Chandra R., Moscibroda T., and Wu Y., (2013) Allocating dynamic time-spectrum blocks in cognitive radio networks, *Proceedings of the 8th ACM international symposium on Mobile ad hoc networking and computing - MobiHoc* '07, 2007.
[29] Zhao Q and Swami A., (2007) A Survey of Dynamic Spectrum Access: Signal Processing and Networking Perspectives, *IEEE International Conference on Acoustics, Speech and Signal Processing - ICASSP* 07, 2007.
[30] Zhao M., Yin C., and Wang X., (2013) A novel dynamic spectrum access algorithm for cognitive radio networks, *Journal of Communications and Networks*, 15, 1, 38–44, Feb. 2013.