ISSN 2278-3091
Volume 8, No.5, September - October 2019
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse25852019.pdf
https://doi.org/10.30534/ijatcse/2019/25852019

Fuzzy Logic based Channel Selection Algorithm for Wireless Mesh Networks

B. Muni Lavanya [1] C Shoba Bindu[2]
[1]Research Scholar, Department of Computer Science and Engineering, JNTUA, Anantapur, AndhraPradesh, India
munilavanya45@gmail.com
[2] Department of Computer Science and Engineering, JNTUA, Anantapur, AndhraPradesh, India
shobabindhucse@jntua.ac.in

ABSTRACT

IEEE 802.11 Wireless Mesh Networks are used widely in commercial and civilian applications. Most importantly, wireless mesh networks are used as last-mile broadband Internet access technology so that user can experience wireless broadband high-speed Internet connectivity. Usually, a router in wireless mesh network has at least two radio interfaces: access interface and routing interface. As the radio spectrum has limited number of orthogonal channels, the two radio interfaces must be assigned with channels having low interference and maximal non-overlapping frequency to improve the network performance. This paper proposes a new scheme of channel allocation based on fuzzy logic for wireless mesh networks. A mesh router uses four parameters: channel access delay, signal to interference ratio, link bandwidth and hop count from gateway node to rate the channels and the router selects a best channel in improving the user quality access. Through the simulation results, it is observed that the proposed scheme is scalable and has a significant performance.

Key words: WMN, MCMR, Channel Allocation, Fuzzy logic.

1. INTRODUCTION

Wireless Mesh Networks (WMNs)[1]–[3] are multi-hop wireless networks based on fixed infrastructure. User devices and routers are the two types of devices present in WMN and they are connected in a hierarchical structure as shown in Fig. 1. A router in WMN has to play triple role as the situation demands. The first role of router is that a router acts as an access point to the user device. When a user device wants to connect to the WMN to utilize the services provided by WMN, then user device has to associate with one of the access points in WMN. The second role of router is routing functionality i.e. the mesh router forwards the packets of users to other routers towards the destination point. Third role of router is gateway functionality. To provide the connectivity with the external networks such as Internet, a few routers in the WMN act as gateway nodes. A router can play one, two or three roles as designed and used in WMN. Usually, a mesh router device comes with at least two radio interfaces to which allocating channels such that no or least interference exists between them. Channel allocation to multiple interfaces of a single node such that co-channel interference would be minimized is an important research problem to which significant attention from the researchers is needed because it affects the network performance a lot[4]–[9].

The first generation of WMNs have routers with single radio interface to which only one channel is allocated. One radio-One channel allocation is not significant as only one communication takes place. Later, researchers suggested to use multiple radio interfaces on a router and allocate orthogonal channels to them so that all interfaces can be used simultaneously to transmit and receive data simultaneously to increase the capacity of WMN. As the number of orthogonal channels is small, it is a challenge for the researchers to allocate the channels to the interfaces of a router node in WMN.

According to IEEE 802.11b/g standard 3 orthogonal channels are present among 14 available channels in 2.4GHz radio spectrum. Similarly, IEEE 802.11a standard defines 23 non-overlapping channels in 5GHz band. Compared to number of radio interfaces present in WMN, available orthogonal channels are minimum and hence proper allocation of channels to minimize interference is important. It is also recommended by researchers that allocating partially overlapping channels in addition to orthogonal channels results in efficient utilization of radio spectrum in improving the network performance [10]–[17].

This paper proposes a novel algorithm of allocating all available channels both orthogonal and partially overlapping channels to the multiple interfaces of a mesh router such that overall interference is minimized and network performance is improved. The proposed algorithm is referred as FLCS (Fuzzy Logic based Channel Selection) algorithm. There exist many algorithms of channel selection in the literature but the novelty and uniqueness of FLCS algorithm lies in the approach it follows. Access Point (AP) applies fuzzy logic rules to select best available channel for the users such that users experience better service from the network. AP uses a few important parameters such as access link transmission delay, signal to interference ratio of access link, bandwidth of access link and capacity of backhaul link in terms of hop count from AP to nearest gateway node. The simulation results of FLCS show the remarkable performance of proposed FLCS algorithm.

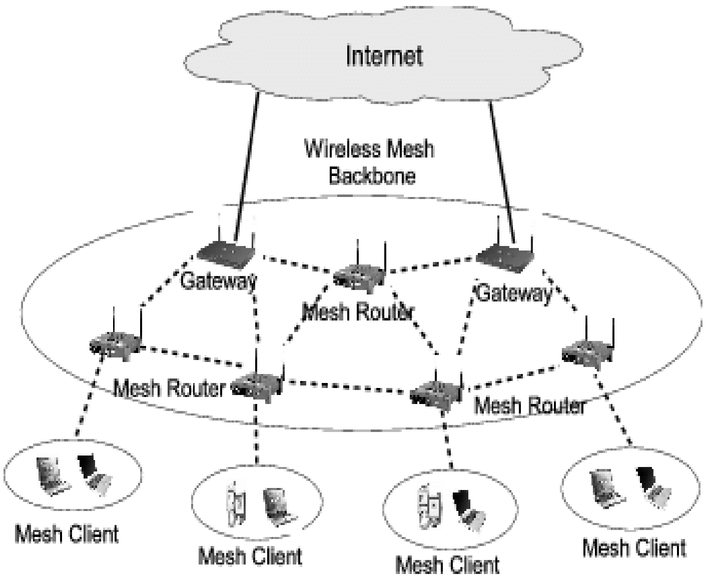

Figure 1: Wireless Mesh Network Architecture.

The rest of the paper is structured as follows: section 2 presents relevant background knowledge in brief and section 3 gives most recent and relevant literature on channel selection algorithms. Section 4 presents the system model of FLCS algorithm. Performance analysis of FLCS algorithm is given by section 5 and finally the paper concludes with the section 6.

2. BACKGROUND KNOWLEDGE

According to IEEE 802.11 b/g standard[18], a wireless network can be setup in license-free band of 2.4 GHz in which 3 non-overlapping channels exist among 14 channels as shown in Fig. 2.Similarly, IEEE 802.11a standard provides the radio spectrum of 5 GHz with 24 non-overlapping channels of 20 MHz and 12 non-overlapping channels of 40 MHz. The discussion in this paper is concentrated on wireless mesh networks that are set up using 2.4 GHz license-free spectrum band as most of the academic research and civilian applications make use of such networks.

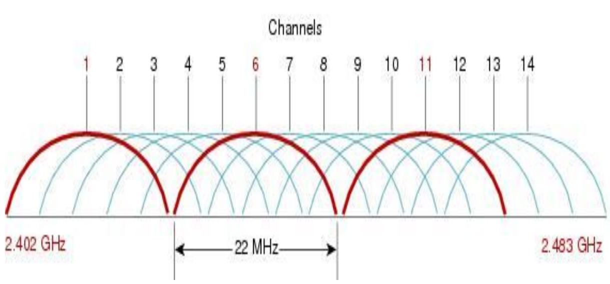

Figure 2 : IEEE 802.11 b/g channels.

It is known fact that a radio interface is half-duplex in its operation. A node with a radio interface can send or receive data at a time but not able to do both simultaneously. Moreover, the sender and receiver nodes must be tuned to the common channel before they communicate, otherwise communication is not possible. It is also known that a radio interface has a fixed transmission range so that when a pair of nodes are communicating together, all other nodes in their transmission range must be silent until the communication is over. The capacity of a wireless network is improved when a node is able to perform both transmission and reception operations simultaneously. When a node has at least two radio interfaces, it is possible for the node to communicate with other nodes in a full duplex fashion if and only if all radio interfaces are allocated orthogonal channels.

WMN has numerous nodes with multiple radio interfaces implies that the number of channels are less than number of radio interfaces in the network. It must be noted here that same channels are allocated to different interfaces. But challenging task is allocating channels to all interfaces in the network to minimize the overall interference and improving the network performance.

As specified in [19], [20], network connectivity and channel interference have a trade-off. Exclusively for a WMN, the mesh backhaul connectivity must be kept by tuning all the routers into a common channel. At the same time, a router interface must have minimum/no interference from the channels of neighbouring interfaces. The researchers have to compromise between network connectivity and channel interference for the efficient utilization of radio spectrum to improve the network performance.

3. RELEVANT LITERATURE

Assigning best suitable channels to the multiple interfaces of a mesh router is an important task in improving the performance of WMN. The previous solutions of channel assignment problem in WMN must be studied in a structured way by following the classification of channel selection algorithms in the literature. Our previous work[21] presents a detailed study on channel assignment algorithms in the literature.

As specified in [22] the channel assignment algorithms are classified as centralized and distributed algorithms. In centralized algorithms, the responsibility of assigning channels to the interfaces is taken care by a critical entity of network. On the other hand, in distributed algorithms each node takes care of itself in selecting proper channels for its interface. To mention, there exist a few centralized algorithms[23], [24] and distributed algorithms[25]–[28] of channel selection in the literature.

Another classification of channel assignment algorithms is specified by in which three different categories are static, dynamic and hybrid algorithms. In static algorithms [29]–[31], the channels are selected and assigned to interfaces during the network setup and the allocation is not changed during the life time of network. Once the channels are fixed to the interfaces, their allocation is not changed during the network operations.On the other hand, dynamic algorithms[32]–[34] suggest changing channel allocation according to the dynamic environment of wireless network. Hybrid algorithms[9], [35]–[38] combine the best features of both static and dynamic algorithms. In hybrid algorithms, a few interfaces have some fixed channels and remaining interfaces change other channels dynamically. Static algorithms have less overhead in channel allocation but dynamic algorithms have additional overhead of periodic allocation of channels to adopt the network changes from time to time.

Channel assignment algorithms are designed with specific objective of reducing interference [33], [39], [40], topology control [41], [42], congestion control [43].

This paper proposes an unique method of channel selection to the interfaces of a mesh router using fuzzy logic. The proposed algorithm FLCS is different from the previous work in applying a new approach to select a best suitable available channel to the given radio interface using fuzzy logic

4. FLCS DESIGN

While designing the channel selection algorithm FLCS, the assumptions made on WMN model are as follows:

The WMN has mesh nodes and user nodes connected together in a hierarchical structure as shown in Fig. 1. A mesh node can be configured as access point, router and gateway. Also, it is assumed that each mesh nodehas at least two radio interfaces based on IEEE 802.11 standard. All the mesh nodes are connected together in a multi-hop fashion to form a complete wireless mesh backbone to support user communications. Mesh nodes acting as access points provide users the network access and a user node has to associate with anyone of the access points in the WMN. Mesh nodes acting as routers forward the packets to other routers placed towards the destination side. All the mesh nodes are assumed to be placed in fixed locations and provided with electric power supply. The mesh nodes acting as gateway provide connectivity with external networks such as Internet. The user nodes are considered as laptops, smart phones, etc which can move from place to place. The mesh nodes have less/no mobility compared to user nodes.

It is assumed that each mesh node has at least two radio interfaces: access interface and routing interface. Mesh node uses access interface to provide network access to the users while routing interface is used to connect with other mesh router nodes. A mesh access point can provide network access to numerous users and a user node can associate with only one mesh access point. To keep the mesh backhaul connectivity, all the routing interfaces are assigned to a common channel. The mesh access point assigns a best suitable channel to the access interface using the proposed method FLCS.

The proposed method FLCS is a QoS constraint channel selection based on Fuzzy inference system. Transmission Delay, Signal to Interference Ratio, Band Width, Hop Countare taken as QoS metrics for the selection of channels which influences the throughput of the network. Unlike the previous work mentioned in the previous section, the proposed method FLCS assigns a best suitable channel to the access interface with the objective of improving end-to-end performance of the users.

Mesh access point selects a best suitable available channel to the access interface using fuzzy logic and all the routing interfaces in the network are assigned to a fixed common channel to keep network connectivity. As the user performance heavily depends on the channel being used, the mesh access point uses four important parameters in selecting a best channel for the users. The mesh access point periodically measures the transmission delay of packets received from all its associated users.The aggregated transmission delay indicates the current channel load. The channel would be considered busy if delay is more. The access link present between mesh access point and the user device is error prone. Signal to Interference ratio is an indicator of quality of access link. The mesh access point periodically measures the signal to interference ratio while receiving data packets from all its associated users through the access link. This ratio indicates the interference from the other nearby mesh access points. More the ratio is the more quality signal. Also, the access link bandwidth is also important for the user performance. Higher bandwidth links improve the user performance in transmitting or receiving data faster and in more volume. As an important application of WMN is providing high speed wireless broadband Internet access to the users, another important metric in deciding the user performance is the hop count from the mesh access point to which the user is associated with to one of the gateways. As specified in [44], [45], each hop decreases the bandwidth by 1/(hop count) amount for the first three hops and become worse for the remaining hops.It is assumed that the mesh router knows the hop count from itself to the nearest gateway using a mesh routing protocol with hop count as the routing metric. The mesh access point collects the values of these four parameters periodically and the channels are ranked using fuzzy logic. These metrics are considered as inputs to fuzzy inference system to calculate rating of the channels as shown in figure 3. Using fuzzification and de-fuzzification methods, rating is evaluated for the available channels which are used for selection of channels for data transmission.

4.1 Signals-to-Interference Ratio (SIR)

Signal to Interference Ratio (SINR) is the ratio of the signal strength of the wanted signal to that of the background signal from other links and noise. For packet to be successfully received on a particular link, its SINR value should be above some threshold. This threshold depends on the transmit rate. The delivery probability of a particular link increases with SINR. It has been well established that any wireless link has a particular error rate associated with it. The error rate a link experiences depends on its RSSI values and in particular the Signal to Interference plus Noise Ratio (SINR) values.

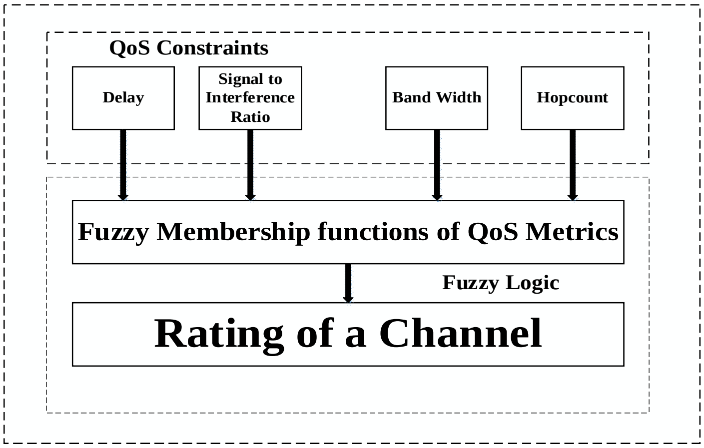

Figure 3: Fuzzy inference model for channel ranking.

In this work, we consider only the Signal to Interference Ratio (SIR) for interference estimation instead of SINR. This is because the interference we expect, is much higher than the background noise.

According to the FRACTEL measurement study [46], out-door wireless links generally have some inherent but quantifiable variability. That is, a link is associated with a band of RSSI values instead of a single RSSI. As, SIR is practically the difference between the sender and receiver RSSI in dBm, and the sender and receiver RSSI are not single values but form a distribution, the SIR also forms a distribution. The SIR distribution between two nodes with RSSI distribution Px and Py is given by

$$P_{SIR}(\alpha) = \sum_{k=-K}^{K} P_x(k) + P_y(k-\alpha) \quad (1)$$

Where k is the transmission power.

4.2 Access Link Bandwidth

In Time Division Multiple Access (TDMA) method [47], [48], the link bandwidth is calculated in terms of time slots. Here the link bandwidth between two nodes depends on the common free time slots of the nodes.

The mesh network topology can be modelled as a graph(N, L) , where N and L represent set of nodes and links respectively. NB_i is the set of neighbours of node n_i i.e. $NB_i = \{n_j \in N : (n_i, n_j) \in L\}$. At each node, the time slots are represented as $S = \{s_1, s_2, s_3, ..., s_m\}$. For every node, TS_i (transmission schedule) is represented as a set of time slots, where a node can transmit the data. The receiving schedule RS_i is defined as a set of time slots, where a node can receive the data.

For a node n_i, the time slot s_t can be used to transfer the data to its neighbour node n_j based on the following conditions.

1) St should not be assigned as transmitting/receiving slot at both the nodes n_i or n_j.

2) St should not be assigned as receiving slot at any neighbour node (n_k) of a node n_i .

From two conditions,

$$TS_i = \left\{ s_t \in s : s_t \notin TS_i, s_t \notin RS_i, s_t \notin U_{n_k \in NB_i} RS_k \right\}$$

The receiving slot s_t of n_i from its neighbour node n_j is defined as per the below two conditions

1) St should not be assigned as transmitting/receiving slot at the both nodes ni or nj.

2) St should not be assigned as transmitting slot at any neighbour node (nk) of a node ni.

From two conditions,

$$RS_i = \{ s_t \in s : s_t \notin TS_t, s_t \notin TS_{i,} s_t \notin U_{n_k \in NB_i} TS_k \} \quad (2)$$

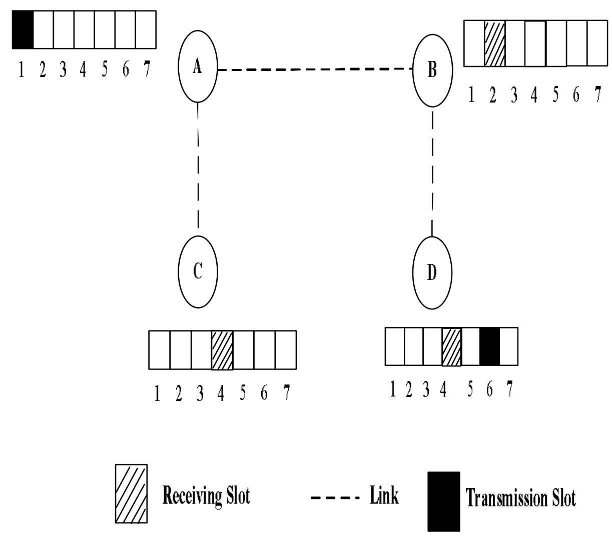

Figure 4: Bandwidth Calculation using TDMA.

In the Figure 4, each node has 7 time slots. Here the possible time slots for data transfer from node A to B are computed as per TDMA. Time slots 1, 2 are scheduled as a transmission and receiving slots of nodes A, B respectively. Slot 4 is assigned as receiving slot at node C. Slot -6 is scheduled as transmission slot at node-D. As the remaining common slots at nodes A, B are 3, 5, and 7, the link bandwidth between A, B is three time slots.

Throughput is defined as the number of data packets delivered at destination node in unit time, which depends on bandwidth.

4.3 Hop Count

Hop count is defined as "the number of hops or links between the source and destination nodes". Average hop count is considered for overall communicating nodes in the wireless mesh networks. Multi-hop connectivity matrix is used to compute average shortest path hop-count at each point in time [49].

Hop count h is

$$h = \frac{\sum_{i=1}^{T} hops_i}{\sum_{i=1}^{T} paths_i} \quad (3)$$

where T, number of multi-hop matrices, $hops_i$ is the total number of hops at time i, and $paths_I$ is the number of cells at time i that contain a non-zero entry.

4.4 Delay

The delay is defined as the time taken to transfer the data from the source node to a destination node in the network.

$$Delay = \frac{\sum_{i=1}^{n} [D_i - D]}{n} \quad (4)$$

Where
D D– The average packet delay
D_iDi– Delay of i^{th} packet.
n – Number of data packets.

Rating of a channel is evaluated using fuzzy Interference system which considers the Crisp Inputs Channel Access Delay, Signal to Interference Ratio, Band Width, and hop count as input parameters.

4.5 Procedure for calculating rating of a channel

i. Fuzzification

Fuzzification is a method, which compares input values with membership functions for obtaining the membership values from the past history and converts into linguistic labels. In the proposed methodology, we consider QoS metrics Crisp Inputs Transmission Delay, Signal to Interference Ratio, Band Width, and Hop Count and the rating of a channel as the fuzzy output variable as shown in Figure 5.

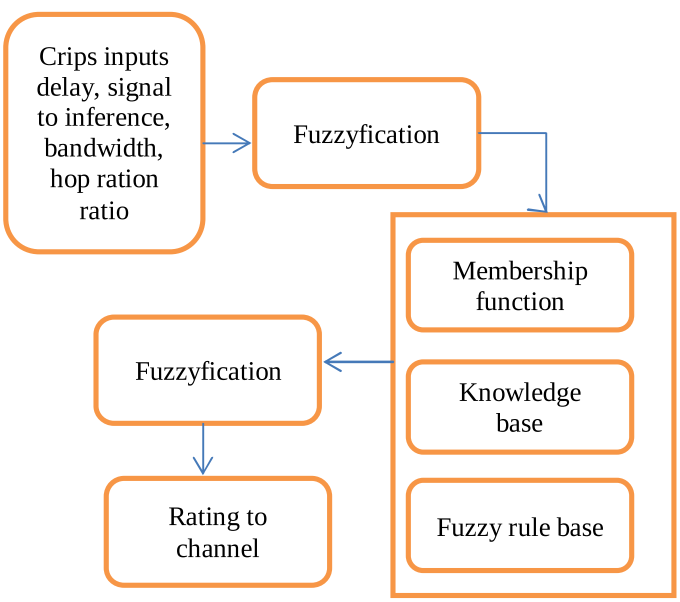

Figure 5: Fuzzy inference model to calculate rating of a channel.

ii. Fuzzy membership functions

As shown in Figure 6, the crisp fuzzy input variables, Signal to Interference Ratio,Delay, Band Width, and Hop Count are divided into four fuzzy sets as, very low, low, moderate and high. The output crisp values are generated by the same fuzzy functions. Here we considered triangular membership to calculate rating of the channel [50].

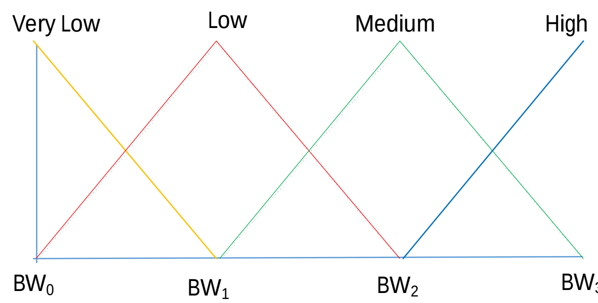

Figure 6a: Bandwidth.

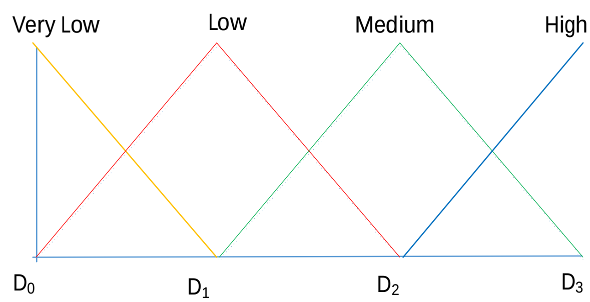

Figure 6b: Delay.

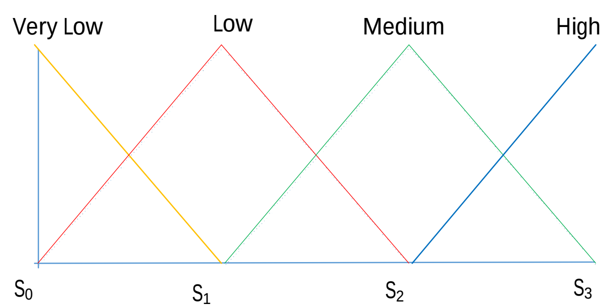

Figure 6c: Signal-to-Interference Ratio.

iii. Fuzzy Rule Base

Fuzzy rule base is a database of rules, which is formed by the combinations of fuzzy input sets. Each rule is represented by “IF-THEN”. Here the fuzzy input variables are 4 sets, so the fuzzy rule base contains maximum of 256 (4 X 4 X 4 X 4) rules. Only a few of the rules are presented in Table1.

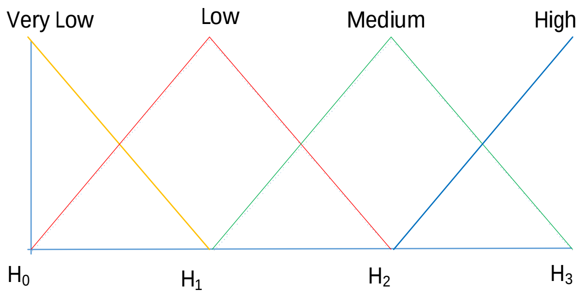

Figure 6d: Hop Count.

Table 1 : Fuzzy Rules

Signal to Interference Ratio	Hop Count	Band Width	Delay	Rating
Very Low	Very Low	High	Very Low	High
Very Low	Low	Moderate	Low	High
Low	Low	Low	Moderate	Moderate
Low	Moderate	Low	High	Moderate
High	High	Moderate	Low	Low
High	High	Low	Low	Low
High	High	High	High	Very Low
High	High	Low	High	Very Low

Table 2: Fuzzy sets of QoS parameters

QoS Parameters	Very Low	Low	Moderate	High
Signal to InterferenceRatio(dBm)	0 - -27	0 – -54	-27 – -80	-80 - -106
Hop Count	0 - 5	0 – 10	5 - 15	10 - 20
Band Width (Mbps)	0 – 1	0 – 2	1 – 3	2 – 3
Delay(ms)	20 - 37	20 – 54	37 – 70	54 - 87

iv. Fuzzy Inference System to evaluate rating of a channel

In the fuzzification process, the max-min rule is used to combine crisp input values (Signal to Interference Ratio, Delay, Band Width, and Hop Count)[51], [52]. In the Figure 7, we applied two fuzzy rules for fuzzification and the fuzzy set intervals are discussed in the Table2.

Fuzzy Rules

- Rule 1: If (Signal to Interference Ratio is Very Low, Hop-count is Very Low, Band Width High, and Delay is Low) then (Rating is High)
- Rule 2: If (Signal to Interference Ratio is Low, Hop-count is High, Band Width High, and Delay is Low) then (Rating is High)

Let the input crisp values of Signal to Interference Ratio, Hop Count, Band Width, and Delay, of acontext are like -6.67 dBm, 2.65, 2.48 Mbps and 26.5ms respectively as shown in figure 7(a). In each rule, find the degree of membership value of every input value (i.e. intersecting point of corresponding fuzzy set triangular wave). Identify the minimum degree of membership value of all input values and consider corresponding shaded portion in the output fuzzy set. Union all output fuzzy set's shaded portion and apply Centre of Gravity defuzzification method to evaluate crisp node and channel rating. Similarly rule 2 is represented as shown in figure 7(b).

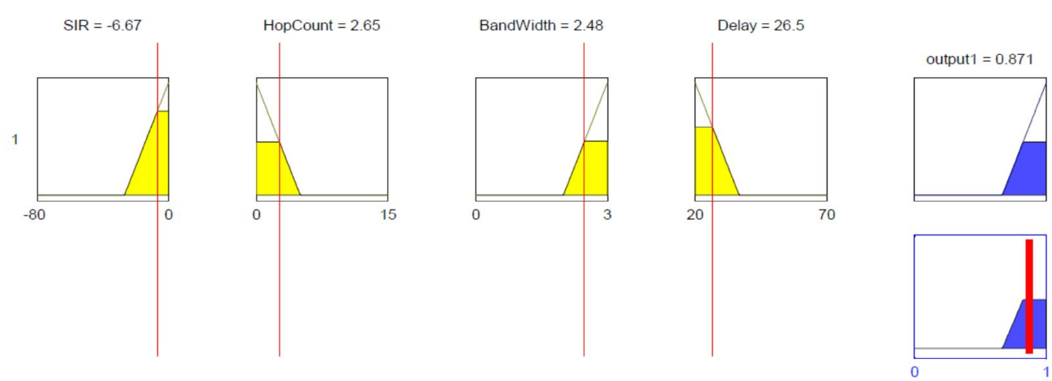

Figure 7a: Rule 1

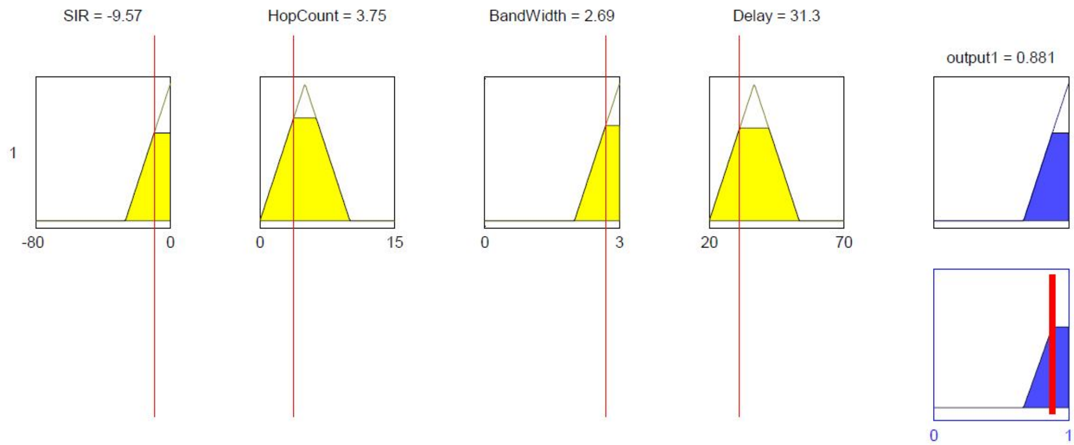

Figure 7b: Rule 2

Figure 7: Defuzzification evaluation of channel rating.

v. **Defuzzification**

The output fuzzy set value is converted into crisp output value in defuzzification process [53]. Centre of gravity is one of the popular defuzzification methods as shown in equation (7) and for the example shown in figure 6(a), the output crisp value of rating is 0.871.

$$COG = \frac{\int_0^1 \mu(t)tdt}{\int_0^1 \mu(t)dt} \qquad (5)$$

These QoS constraints are normalized by fuzzy logic and a set of values are established between node and access point. Among the list of channels max rated channel is selected to transfer the data.

5. FLCS PERFORMANCE ANALYSIS

The performance of proposed method FLCS of channel selection is analysed using NCTUns simulator[54]. Kernel re-entering methodology is unique feature of NCTUns simulator and it supports various models of different types of networking nodes, mobility models, transmission models, etc. The main advantage of NCTUns simulator is its rich featured graphical user interface through which it is very easy to simulate WMN.

The simulations used IEEE 802.11b WMN with 9 routers/mesh access points with two radio interfaces and 20 user devices that are randomly distributed over 1000m X 1000m terrain area. Also, one gateway node is used to connect WMN to Internet with high speed wired connection of 1Gbps as shown in Figure.8. Each mesh router is configured to run OSPF routing protocol with default routing metric of hop count. UDP saturated traffic flow with data packet size of 1000 bytes from Internet to users via gateway node is simulated.The simulations are conducted for 100 simulation seconds and the results obtained are analysed. As the IEEE 802.11b radio spectrum provides three orthogonal channels 1, 6 and 11, all the routing interfaces are assigned with a common fixed channel 1. The simulations are conducted with traditional method of allocating only orthogonal channels and the proposed method FLCS of allocating both orthogonal and partially overlapping channels.

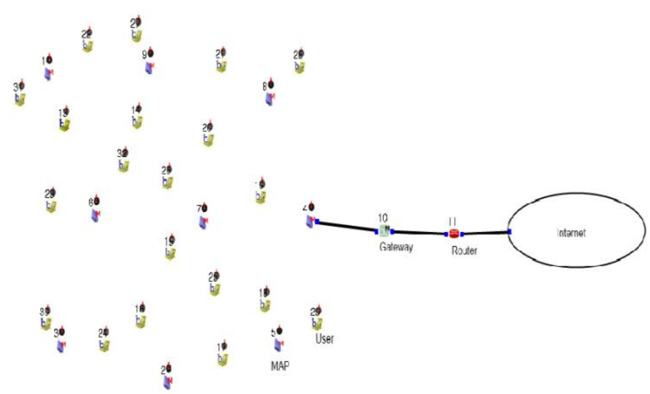

Figure 8: Simulated WMN scenario.

Network aggregate throughput is one of the important performance metric. So, from the simulation results, the system throughput is calculated by increasing number of users gradually and shown in Fig. 9. It is observed that using only two orthogonal channels 6 and 11 for access interfaces is not beneficial in improving the user performance. Partially overlapping channels also assigned properly, the network performance can be improved.

Similarly, the average end-to-end transmission delay is another important performance metric and the results of delay against the number of users are shown in Fig.10. Using only two orthogonal channels 6 and 11 for access interfaces results into co-channel interference from neighbouring interfaces. If partially overlapping channels also assigned properly, the overall interference can be minimized as shown by FLCS results.

In order to analyse the efficiency of proposed method FLCS, the channel load is increased gradually in terms of traffic load. As FLCS method assigns channels dynamically with respect to traffic load, as shown in Fig. 11 and Fig. 12, the results of FLCS are seems to be better than traditional method of using only two orthogonal channels 6 and 11 and not changing the allocation as per the traffic load.

Further analysis of FLCS includes the simulations with grid topology of mesh routers that are separated by 200m from each other as shown in Fig. 13. This topology is used for simulations with uniform and non-uniform distribution of users as shown in Fig. 13 and Fig. 14 respectively. In both the scenarios, under the same simulation settings, the results obtained for throughput and delay are shown in Fig. 15 and Fig. 16 in which the FLCS method shows better performance than using only two orthogonal channel assignments.

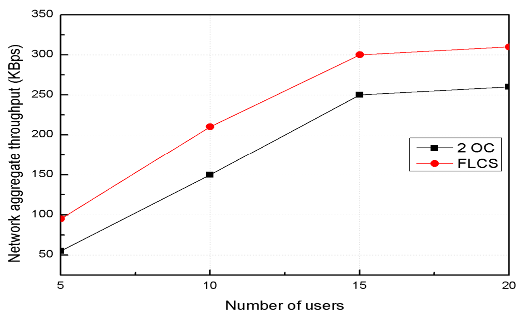

Figure 9: Network Throughput.

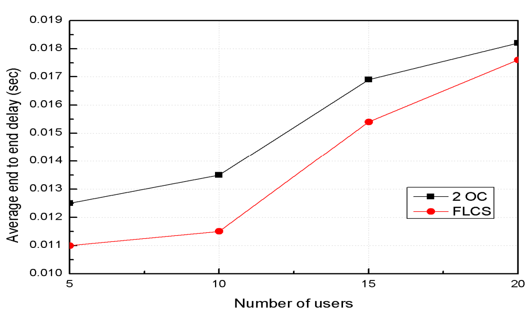

Figure 10: End to end delay of transmissions.

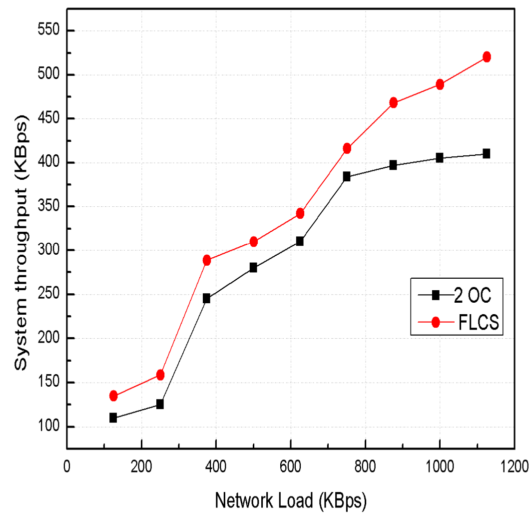

Figure 11: Impact of network load.

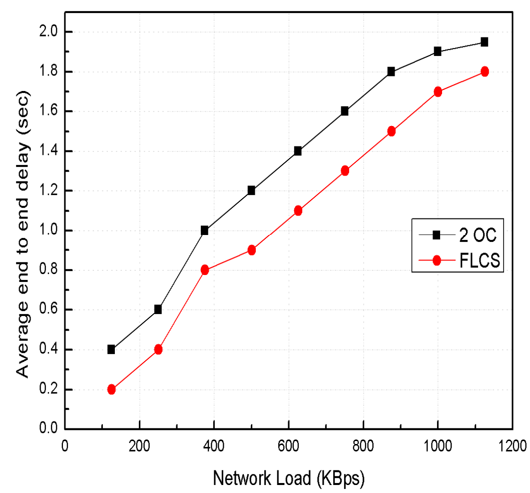

Figure 12: Network Load vs Delay.

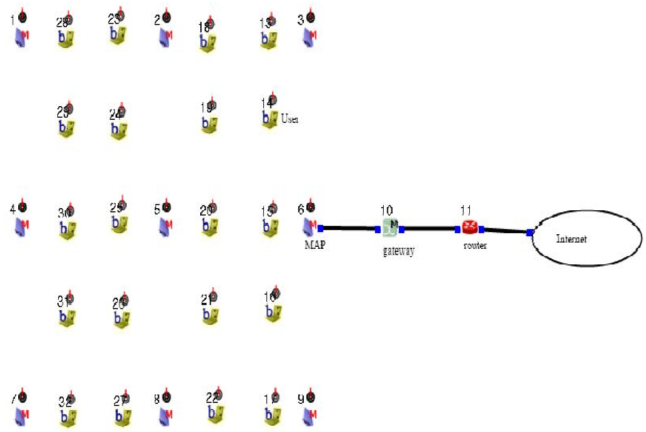

Figure 13: Uniform distribution of users and routers.

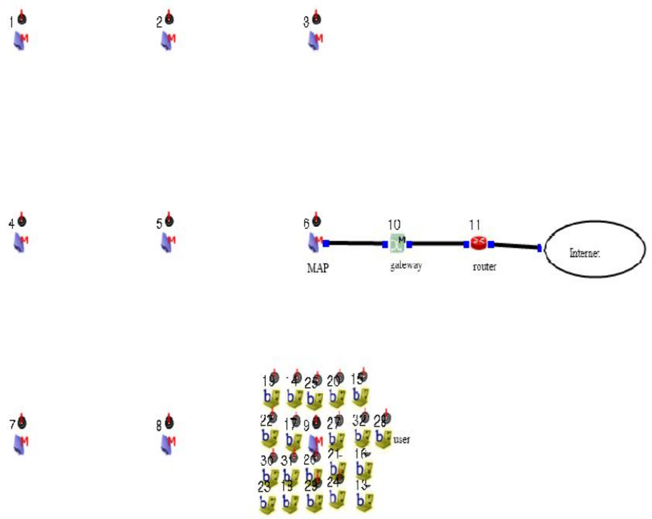

Figure 14 : Non-uniform distribution of users.

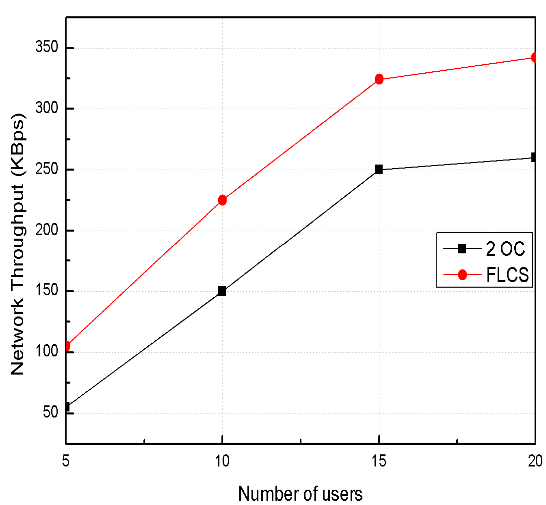

Figure 15: Network throughput in uniform distribution of users.

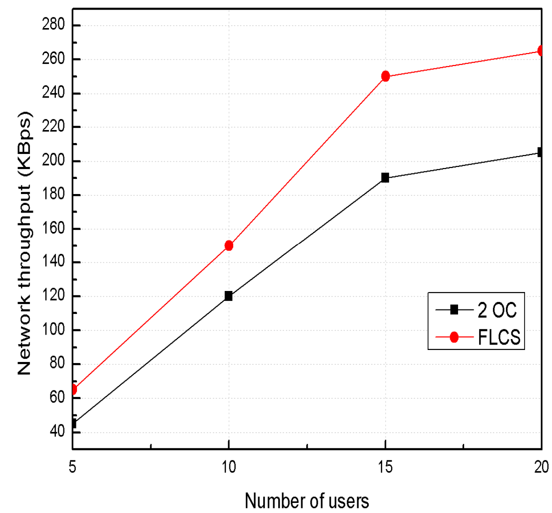

Figure 16: Network throughput in non-uniform distribution of users.

6. CONCLUSIONS

Wireless mesh networks with IEEE 802.11 nodes have the important application of providing wireless broadband Internet access to the mobile users. Usually, mesh nodes have multiple radio interfaces to which orthogonal channels are assigned to increase the capacity of WMNs. As the number of orthogonal channels is limited and smaller than the number of radio interfaces in the network, proper allocation of channels is must for the improvement of network performance. This paper proposes a novel method of channel assignment based on fuzzy logic inference system. According to FLCS method, the mesh access point selects a best channel among all available channels including orthogonal as well as partially overlapping channels with the objective of improving user end-to-end performance. FLCS method is efficient in utilizing the radio spectrum as it uses all channels for assigning to the radio interfaces. Also, it is scalable as the number of users and mesh nodes are increased, the performance is not degraded. Further enhancement of FLCS includes the consideration of more input parameters to fuzzy inference system than those considered by FLCS method in this paper.

REFERENCES

[1] H. Lee, “**Wireless mesh networks,”** in *Mobile Communications Handbook, Third Edition*, 2017. https://doi.org/10.1201/b12494-35

[2] K. C. Karthika, “**Wireless mesh network: A survey**,” in *Proceedings of the 2016 IEEE International Conference on Wireless Communications, Signal Processing and Networking*, *WiSPNET 2016*, 2016, pp. 1966–1970. https://doi.org/10.1109/WiSPNET.2016.7566486

[3] D. Benyamina, A. Hafid, and M. Gendreau, “**Wireless mesh networks design - A survey,”** *IEEE Communications Surveys and Tutorials*. 2012. https://doi.org/10.1109/SURV.2011.042711.00007

[4] A. B. M. Alim Al Islam, M. J. Islam, N. Nurain, and V. Raghunathan, "**Channel Assignment Techniques for Multi-Radio Wireless Mesh Networks: A Survey**," *IEEE Communications Surveys and Tutorials*, vol. 18, no. 2, pp. 988–1017, 2016. https://doi.org/10.1109/COMST.2015.2510164

[5] S. Chieochan and E. Hossain, "**Channel assignment for throughput optimization in multichannel multiradio wireless mesh networks using network coding**," *IEEE Transactions on Mobile Computing*, vol. 12, no. 1, pp. 118–135, 2013. https://doi.org/10.1109/TMC.2011.252

[6] I. W. H. Ho, P. P. Lam, P. H. J. Chong, and S. C. Liew, "**Harnessing the high bandwidth of multiradio multichannel 802.11n mesh networks,**" *IEEE Transactions on Mobile Computing*, 2014.

[7] D. Chakraborty and K. Debbarma, "**Q-CAR: an intelligent solution for joint QoS multicast routing and channel assignment in multichannel multiradio wireless mesh networks**," *Applied Intelligence*, 2017. https://doi.org/10.1007/s10489-016-0871-2

[8] H. Li, Y. Cheng, C. Zhou, and W. Zhuang, "**Routing metrics for minimizing end-to-end delay in multiradio multichannel wireless networks**," *IEEE Transactions on Parallel and Distributed Systems*, 2013 https://doi.org/10.1109/TPDS.2012.327.

[9] Y. Ding, K. Pongaliur, and L. Xiao, "**Channel allocation and routing in hybrid multichannel multiradio wireless mesh networks,**" *IEEE Transactions on Mobile Computing*, 2013.

[10] Y. Cui, W. Li, and X. Cheng, "**Partially overlapping channel assignment based on “node orthogonality” for 802.11 wireless networks**," in *2011 Proceedings IEEE INFOCOM*, 2011, pp. 361–365. https://doi.org/10.1109/INFCOM.2011.5935182

[11] and C. L. Liu, Yuting, Ramachandran Venkatesan, "**Channel assignment exploiting partially overlapping channels for wireless mesh networks,**" in *IEEE Global Telecommunications Conference*, 2009, pp. 1–5.

[12] Y. Ding, Y. Huang, G. Zeng, and L. Xiao, "**Using partially overlapping channels to improve throughput in wireless mesh networks**," *IEEE Transactions on Mobile Computing*, 2012. https://doi.org/10.1109/TMC.2011.215

[13] Y. Ding, Y. Huang, G. Zeng, and L. Xiao, "**Channel assignment with partially overlapping channels in wireless mesh networks,**" in *Proceedings of the 4th International ICST Conference on Wireless Internet*, 2008. https://doi.org/10.4108/ICST.WICON2008.4907

[14] F. Tang, B. Mao, Z. M. Fadlullah, and N. Kato, "**On a Novel Deep-Learning-Based Intelligent Partially Overlapping Channel Assignment in SDN-IoT,**" *IEEE Communications Magazine*, 2018. https://doi.org/10.1109/MCOM.2018.1701227

[15] F. Bokhari and G. Zrub, "**Partially Overlapping Channel Assignments in Wireless Mesh Networks,**" in *Wireless Mesh Networks - Efficient Link Scheduling, Channel Assignment and Network Planning Strategies*, 2012. https://doi.org/10.5772/48476

[16] V. Bukkapatanam, A. A. Franklin, and C. S. R. Murthy, "**Using partially overlapped channels for end-to-end flow allocation and channel assignment in wireless Mesh Networks,**" in *IEEE International Conference on Communications*, 2009. https://doi.org/10.1109/ICC.2009.5199559

[17] D. Wang, P. Lv, Y. Chen, and M. Xu, **"POCAM: Partially overlapped channel assignment in multi-radio multi-channel wireless mesh network,**" in *11th International Symposium on Communications and Information Technologies, ISCIT 2011*, 2011.

[18] IEEE 802.11 Working Group, "**Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications, Amendment 6: Wireless Access in Vehicular Environments**," *IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirements.* 2010.

[19] V. Sarasvathi, N. C. S. N. Iyengar, and S. Saha, "**An efficient interference aware partially overlapping channel assignment and routing in wireless mesh networks,**" *International Journal of Communication Networks and Information Security*, 2014.

[20] B. Jaumard, A. Voruganti, and M. Kaddour, "**Assigning and scheduling partially overlapping channels in wireless mesh networks,**" in *International Conference on Wireless and Mobile Computing, Networking and Communications*, 2013. https://doi.org/10.1109/WiMOB.2013.6673390

[21] B. M. Lavanya, C. S. Bindu, and G. V. Kumar, "**A study on channel assignment algorithms for multi-channel multi-radio wireless mesh networks,**" in *2017 International Conference on Intelligent Sustainable Systems (ICISS)*, 2017, pp. 568–575. https://doi.org/10.1109/ISS1.2017.8389234

[22] W. Si, S. Selvakennedy, and A. Y. Zomaya, **"An overview of Channel Assignment methods for multi-radio multi-channel wireless mesh networks**," *Journal of Parallel and Distributed Computing*, 2010.

[23] A. Raniwala, K. Gopalan, and T. Chiueh, "**Centralized channel assignment and routing algorithms for multi-channel wireless mesh networks,**" *ACM SIGMOBILE Mobile Computing and Communications Review*, 2004.

[24] M. Alicherry, R. Bhatia, and L. E. Li, "**Joint Channel Assignment and Routing for Throughput Optimization in Multiradio Wireless Mesh Networks,**" *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 11, pp. 1960–1971, Nov. 2006. https://doi.org/10.1109/JSAC.2006.881641

[25] B.-J. Ko, V. Misra, J. Padhye, and D. Rubenstein, "**Distributed Channel Assignment in Multi-Radio 802.11 Mesh Networks,**" in *2007 IEEE Wireless Communications and Networking Conference*, 2007, pp. 3978–3983.

[26] H. Wu, F. Yang, K. Tan, J. Chen, Q. Zhang, and Z. Zhang, **"Distributed Channel Assignment and Routing in Multiradio Multichannel Multihop Wireless Networks,"** *IEEE Journal on Selected Areas in Communications*, vol. 24, no. 11, pp. 1972–1983, Nov. 2006. https://doi.org/10.1109/JSAC.2006.881638

[27] M. Shin, S. Lee, and Y. Kim, "**Distributed Channel Assignment for Multi-radio Wireless Networks**," in *2006 IEEE International Conference on Mobile Ad Hoc and Sensor Sysetems*, 2006, pp. 417–426. https://doi.org/10.1109/MOBHOC.2006.278582

[28] A. Dhananjay, H. Zhang, J. Li, and L. Subramanian, "**Practical, distributed channel assignment and routing in dual-radio mesh networks,**" *ACM SIGCOMM Computer Communication Review*, vol. 39, no. 4, p. 99, Aug. 2009. https://doi.org/10.1145/1594977.1592581

[29] A. K. Das, R. Vijayakumar, and S. Roy, **"Static channel assignment in multi-radio multi-channel 802.11 wireless mesh networks: Issues, metrics and algorithms,**" in *GLOBECOM - IEEE Global Telecommunications Conference*, 2006.

[30] H. Cheng, G. Chen, N. Xiong, and X. Zhuang, **"Static channel assignment algorithm in multi-channel wireless mesh networks,"** in *CyberC 2009 - International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery*, 2009.

[31] W. Wang, J. Zhang, S. Huang, and J. Li, "**Optimization of static channel assignment in multi-radio multi-channel wireless mesh network,**" in *2008 11th IEEE Singapore International Conference on Communication Systems, ICCS 2008*, 2008. https://doi.org/10.1109/ICCS.2008.4737367

[32] A. Naveed, S. S. Kanhere, and S. K. Jha, "**Topology control and channel assignment in multi-radio multi-channel wireless mesh networks**," in *2007 IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems, MASS*, 2007.

[33] J. Tang, G. Xue, and W. Zhang, "**Interference-aware topology control and QoS routing in multi-channel wireless mesh networks**," in *Proceedings of the International Symposium on Mobile Ad Hoc Networking and Computing (MobiHoc)*, 2005.

[34] R. Akl and A. Arepally, "**Dynamic Channel Assignment in IEEE 802.11 Networks**," in *2007 IEEE International Conference on Portable Information Devices, PIDs 2007*, 2007. https://doi.org/10.1109/PORTABLE.2007.63

[35] X. Ma, F. Li, F. Hu, and X. Liu, "**A hybrid channel assignment strategy to QoS support of video-streaming over multi-channel ad hoc networks,**" in *Journal of Systems and Software*, 2012.

[36] A. A.-K. Jeng and R.-H. Jan, "**Role and channel assignments for wireless mesh networks using hybrid approach,**" *Computer Networks*, vol. 53, no. 12, pp. 2225–2240, Aug. 2009. https://doi.org/10.1016/j.comnet.2009.03.020

[37] M. Li and Y. Feng, "**Design and implementation of a hybrid channel-assignment protocol for a multi-interface wireless mesh network,**" *IEEE Transactions on Vehicular Technology*, 2010.

[38] J. Zheng, W. Xu, G. Sun, X. Tian, and X. Wang, "**Hybrid channel assignment in multi-hop multi-radio cognitive ad hoc network**," in *IEEE International Conference on Communications*, 2013.

[39] S. CHO and C. -k. KIM, "**Interference-Aware Multi-Channel Assignment in Multi-Radio Wireless Mesh Networks**," *IEICE Transactions on Communications*, vol. E91-B, no. 5, pp. 1436–1445, May 2008. https://doi.org/10.1093/ietcom/e91-b.5.1436

[40] A. P. Subramanian, H. Gupta, S. R. Das, and J. Cao, "**Minimum interference channel assignment in multiradio wireless mesh networks**," *IEEE Transactions on Mobile Computing*, vol. 7, no. 12, pp. 1459–1473, 2008.

[41] G. Zhang, J. Gu, Z. Bao, C. Xu, and S. Zhang, "**Joint routing and channel assignment algorithms in cognitive wireless mesh networks,**" *Transactions on Emerging Telecommunications Technologies*, vol. 25, no. 3, pp. 294–307, Mar. 2014. https://doi.org/10.1002/ett.2560

[42] M. K. Marina, S. R. Das, and A. P. Subramanian, "**A topology control approach for utilizing multiple channels in multi-radio wireless mesh network**s," *Computer Networks*, 2010. https://doi.org/10.1016/j.comnet.2009.05.015

[43] A. Giannoulis, T. Salonidis, and E. Knightly, "**Congestion control and channel assignment in multi-radio wireless mesh networks**," in *2008 5th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks, SECON*, 2008.

[44] P. Hofmann, C. An, L. Loyola, and I. Aad, "**Analysis of UDP, TCP and voice performance in IEEE 802.11 b multihop networks,**" in *13th European Wireless Conf*, 2007.

[45] J. Hoblos and H. Peyravi, **"End-to-end throughput capacity in multi-hop wireless networks,"** *International Journal of Wireless and Mobile Computing*, vol. 8, no. 3, p. 213, 2015. https://doi.org/10.1504/IJWMC.2015.069386

[46] D. Gokhale, S. Sen, K. Chebrolu, and B. Raman, "**On the Feasibility of the Link Abstraction in (Rural) Mesh Networks,**" in *2008 Proceedings IEEE INFOCOM - The 27th Conference on Computer Communications*, 2008, pp. 61–65.

[47] C. Zhu and M. S. Corson, "**DRUM: Bandwidth Calculation in a TDMA-based Ad Hoc Network**," pp. 1–22.

[48] Wen-Hwa Liao, Yu-Chee Tseng, and Kuei-Ping Shih, "**A TDMA-based bandwidth reservation protocol for QoS routing in a wireless mobile ad hoc network**," in *2002 IEEE International Conference on Communications. Conference Proceedings. ICC 2002 (Cat. No.02CH37333)*, 2001, vol. 5, pp. 3186–3190.

[49] S. Kurkowski, T. Camp, and W. Navidi, "**Two standards for rigorous MANET routing protocol evaluation,**" in *2006 IEEE International Conference on*

Mobile Ad Hoc and Sensor Systems, MASS, 2006, vol. 1, pp. 256–266.

[50] T.-P. Hong and C.-Y. Lee, "**Induction of fuzzy rules and membership functions from training examples,**" *Fuzzy Sets and Systems*, vol. 84, no. 1, pp. 33–47, Nov. 1996.

[51] N. Sirisala and C. S. Bindu, "**Uncertain Rule Based Fuzzy Logic QoS Trust Model in MANETs**," in *Proceedings - 2015 21st Annual International Conference on Advanced Computing and Communications, ADCOM 2015*, 2016, pp. 55–60. https://doi.org/10.1109/ADCOM.2015.17

[52] Veeresh, R. P. Sam, and C. S. Bindu, "**Fuzzy based optimal QoS constraint services composition in mobile ad hoc networks,**" *International Journal of Communication Networks and Information Security*, vol. 9, no. 3, pp. 491–499, 2017.

[53] N. Sirisala and C. Bindu, "**A Novel QoS Trust Computation in MANETs Using Fuzzy Petri Nets**," *International Journal of Intelligent Engineering and Systems*, vol. 10, no. 3, pp. 116–125, Apr. 2017. https://doi.org/10.22266/ijies2017.0430.13

[54] S.-Y. Wang and C.-C. Lin, "**NCTUns 6.0: A Simulator for Advanced Wireless Vehicular Network Research,"** *IEEE Vehicular Technology Conference*, 2010. https://doi.org/10.1109/VETECS.2010.5494212