A Novel method of routing in multi-channel multi-radio wireless mesh networks

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Research Article

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A Novel method of routing in multi-channel multi-radio wireless mesh networks

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Abstract: In mesh networks, wireless mesh nodes include routers and mesh clients. In a wireless mesh network, the use of single-radio nodes operating on a single channel will reduce the capacity of the mesh network, and equipping the nodes with multiple radios, this operation on a non-overlapping channel will greatly increase the capacity and available bandwidth of the network. If the number of radios used increases the number of channels that can be used for the nodes, it will cause the links to use the same channels and lead to interference between the links. In this paper, two algorithms are proposed for multi- channel mesh network for routing selection. The first proposed algorithm is to allocate channels in multi-radio and multi-channel wireless mesh networks with tree structure, colonial competition and clustering algorithms, using the available bandwidth criteria, distance to destination. The load density of each node tries to form high-rate multi-channel paths. In the second algorithm, each router determines its priority in selecting the channel by considering the amount of potential interference in its interference range. The performance of the proposed protocols was compared with CAMF protocol and FB_MR routing protocol. Network productivity rate, end-to-end latency, number of lost packets are among the criteria used to compare the performance of the proposed method. The simulation was performed on OPNET pseudo-emulator version 10.5. The simulation results show better performance of the proposed ICA_MR colonial competition protocol than the RLFB_MR reinforcement learning method and the CAMF protocol and the FB_MR routing protocol.

Keywords: Fuzzy Logic; Mesh Network; Multi Radio; Multi Channel

1 Introduction

The ability to self-organize and self-configure wireless mesh networks, these network can be evolutionary implemented, and a node can be added to the network at any time. As more nodes are added to the network, the reliability and connectivity of users will increase. Implementing a wireless mesh network is not difficult, because all the required components are already available. Although these component is available in the form of routing protocols on case networks IEEE 802.11 protocol, WEP security protocols is main issue of routing in wireless mesh networks and has still of great importance. Designing routing protocols for wireless mesh networks is still a challenging research topic. An optimal routing protocol for wireless mesh networks should have features such as scalability, and robustness. In this research, it is assumed that the path with the least amount of interference is selected for routing using reinforcement learning and fuzzy logic. Firstly, the reward of network nodes is determined by fuzzy logic based on three criteria: interference rate, available bandwidth and available access and number of steps. The total reward of these three parameters determines the reward assigned to the node.

The method is distributed, and each node calculates the values of the mentioned parameters separately. When routing, it first finds the nodes with the highest rewards and sends the data from that path. The second algorithm using the colonial algorithm and tree clustering with the least amount of redistribution nodes and intermediate so that we can have fewer transmissions in the network. We also have channels with the least amount of interference to the links in the network. Channel allocation can greatly reduce network interference and improve network performance. The efficiency of the proposed methods will be compared with the weighting routing protocols CAMF [1] and FBMR [2] that network efficiency rate, end-to-end latency, packet loss rate, including the criteria used to compare the efficiency of the proposed method. The proposed method uses OPNET emulator version 10.5.

2 Related Work

In [1], the authors have proposed an exploratory algorithm called CAMF for channel allocation and multi-cast routing capable of supporting node mobility. This algorithm uses a concept called transmission path weight to increase network throughput and prioritize nodes for channel allocation. In this algorithm, it is assumed that there is already a multi-cast tree. They are also given a weight based on the number of receptors in each node. This algorithm assumes that 11 channels is used. The proposed channel allocation algorithm is an innovative algorithm. The proposed algorithm for optimal channel al- location considers criteria such as transmission path weight, distance, competition window size, and receiver movement. At the beginning of each node, based on a specific procedure, it determines the weight of the sending path and the list of its overlapping nodes. After calculating the weight of the transmission path and the overlapping nodes, each node in the multi-cast tree can allocate the channel to itself. To increase network permeability, channel allocation to nodes is based on their order. The authors in [2] performed fuzzy logic based on the criteria of number of steps, available bandwidth, and interference rate of routing in a multi-channel multi-radio wireless mesh network. The proposed method was named FB_MR. For each input criterion, two-value membership functions are defined in low and high intervals, and a five-state output membership function in low, very low, medium, high and very high intervals is considered. In the proposed method, based on fuzzy logic, routes with low interference rate, high bandwidth and low number of steps are selected. The efficiency of the proposed method is compared with the reference [1] and the proposed method in terms of end-to-end latency, and network efficiency. The data packet delivery rate could have worked better, but since the implementation of the fuzzy algorithm requires a lot of computing but has a high processing overhead. In reference [3] the author stated a combined approach to routing and scheduling that has two main factors that affect end-to-end latency: super frame length and transmission cut- off sequence. Shortening the super frame length in terms of slices is also expected to minimize active time between links, sorting transmission sections, on the other hand, increases the probability of continuous active links within a path.

The authors have proposed two algorithms in this paper. The JRS-Multi-DEC algorithm uses a new metric to minimize the load on each link. The JRS-BIP algorithm uses the binary linear programming method to solve this problem. Both proposed algorithms attempt to reduce the final delay by rearranging the transfer sections on the resulting schedule. The authors in [4] try to investigate the issue of routing load balance in multi- channel multi-radio wireless mesh networks. Their analysis focuses on the all-broadcast and multi-broadcast communication method, in which each communication specifies its own bandwidth requirements. It has been shown that using different channels and rates, network performance can be significantly improved. To achieve this goal, the authors have proposed two algorithms called IRMT and IRBT. The proposed algorithms solve the problems of creating a routing tree, channel selection, transmission rate selection, and communication acceptance control. As an advantage of the mentioned methods, IRMT and IRBT algorithms consider both types of in-streams and out- of-stream interference. These methods not only improve the efficiency of network resources, but also balance the traffic within the network. The authors in [5] have examined the problem of routing and scheduling in time division multiple access in wireless mesh networks in which real-time traffic flows. The authors of this article have proposed a framework that always calculates the optimal solution. The proposed framework does this by solving a hybrid nonlinear integer programming. The authors also propose an innovative method based on Lagrange decomposition to obtain a near-optimal solution in larger wireless mesh networks. They have shown that innovative solutions are near-optimal and are used to gain insight into scheduling in wireless mesh networks. The authors in [6] have proposed an optimization model for rate allocation, multi-cast routing, and channel allocation in multi-gateway wireless mesh networks. Rate allocation restrictions have also been added to the model for transmitting information to receivers. Also, radio and channel restrictions are provided for the model. The proposed algorithm includes three operational phases of gate selection, channel allocation and rate allocation. In the gate selection phase, the goal is to select the appropriate gate for each node. The proposed algorithm uses the genetic algorithm to select the gate. In the channel allocation phase, to achieve the maximum value of the link submission rate, the multi-rate property of the multi-cast algorithm is considered. The proposed algorithm tries to assign channels that have less load on them to overlapping links. In this way, the amount of link interference for different channels is balanced. The authors of [7] in wireless mesh networks have proposed a method called ALRS that can meet the requirements of service quality and recover link breakdowns. The proposed algorithm also considers the historical information about the network to avoid the need for antennas in mesh nodes and increase throughput, prevent interference and self-configuration. When implementing the ALRS algorithm for wireless mesh networks in an urban area, an initial algorithm must be implemented first. The gateway node should get complete information about the whole network and get its priority list for each link. In addition, all links leading to the gateway must be assigned channels with the highest throughput, which is done by the proposed algorithm. The authors in [8] proposed a channel allocation method with a source routing protocol that considers the quality of services, the algorithm is called MR-LQSR. Physical interference model is proposed in the algorithm. Computed transmission time (CTT) is introduced as a channel allocation criterion that can better reflect the actual network conditions and channel interference. There is also another measure called EWCETT for routing that maintains the balance of load and network bandwidth. The authors in [9] have proposed a routing algorithm with power control and channel allocation called JPCR, which seeks to find an optimal method for routing, power control and channel allocation for each stream that can also moderate and improve efficiency. Initially, considering the available channels and power level, a routing criterion called minimum flow rate is proposed, which is based on the physical interference model and Shannon channel models. The proposed algorithm is based on genetic algorithm and simulation to maximize the minimum flow rate.

3 The proposed Method

The two different algorithms are considered for the proposed protocol. In the first algorithm, the mesh nodes are trained using the reinforcement learning algorithm with fuzzy logic and with encouragement or punishment, their network nodes are trained according to the stated criteria. Number of steps, available bandwidth, and interference rate estimate the stability rate of the routes. It should be noted that fuzzy logic has been used to determine the score assigned to the nodes. In the second algorithm, using the colonial competition algorithm, it allocates channels, and routing in the multi-channel multi- radio mesh network. Routing mesh networks using reinforcement learning algorithm.

The proposed algorithm criteria for the reinforcement learning method in the mesh network routing problem is describe by three features nodes, action, and reward. Node: Mesh nodes are in the network. Action: Choose the best route with high stability for sending information Reward: The sum of the reflected quality of the route (here is the sum of the stability parameters of each route). The three criteria of interference rate, number of steps and available bandwidth are selected to select the best path using the reinforcement learning algorithm for selecting multi cast receivers in the broadcast tree. The proposed method, use fuzzy logic to score criteria. The basic idea in fuzzy systems is that real values (in fuzzy logic) or membership values are represented by values between 0-1, with 0 denoting absolute uncertainty and 1 denoting absolute truth. Contrary to the concept of the classical set, where each element belongs entire set or is completely out of the set, elements in a fuzzy set X can take values between 0 and

1. The fuzzy logic mechanism proposed in this scenario for mesh network routing is a controller based on fuzzy logic. This control mechanism is considered as an adaptive fuzzy control and based on it, we apply the fuzzy control rules along with the knowledge base to estimate the score belonging to the evaluation criteria (number of steps, available bandwidth, interference rate). The block diagram of this control system is shown in fig 1.

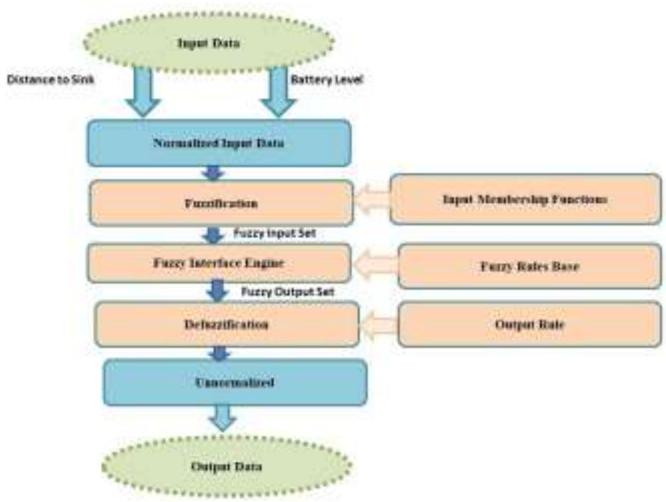


Fig. 1: Structure of a fuzzy system

A fuzzy system has three parts fuzzificaion, fuzzy inference engine, and defuzzification which are described below:

A. Fuzzification

The fuzzification determines how the real input is converted to fuzzy input to be used by the inference motor, the conversion apply to the fuzzy inference engine is called fuzzification. In fact, a fuzzy map maker is a real value to a fuzzy set. In the proposed method of fuzzy system input, three parameters are considered, which include the number of steps, the available bandwidth and the interference rate. For each of the input variables, we define two fuzzy sets with trapezoidal attachment functions. (From H for the upper limit and L for the lower limit) shown in Figures 2, 3 and 4. The reason for using trapezoidal attachment functions is its accuracy. For the output i.e., the link reward, five fuzzy sets with triangular belonging functions (H for the upper limit, H for the very high, M for the middle limit, L for the lower limit, and VL for the very low limit) are used, as shown in Figure 5.

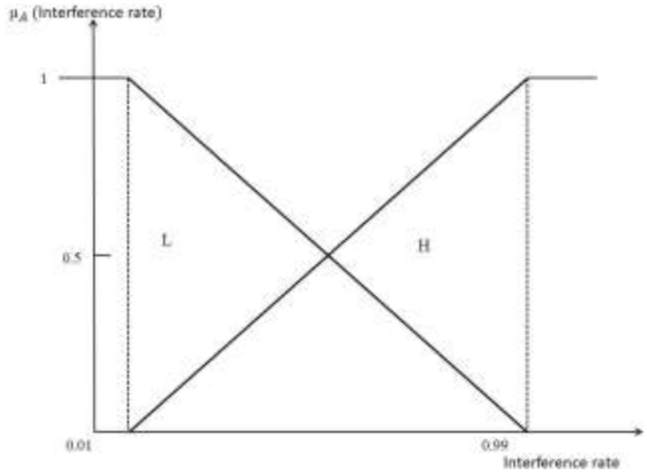


Fig. 2. Membership functions for interference rate input variables

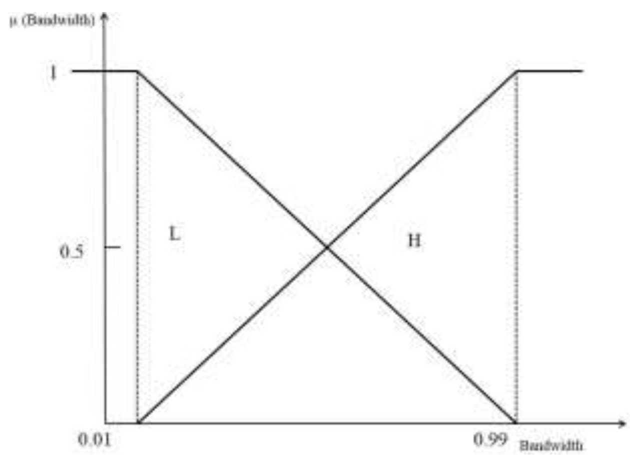


Fig. 3. Membership functions for bandwidth input variables

Initially, the source node "S" generates the path request packet (RREQ) and sets the field value of the number of steps and rewards to zero, then adds its available channel number and bandwidth to the RREQ packet and the path request packet. It broadcasts in its communication suffering. Neighbor nodes that have received this packet compare the channel number in the packet with the channel number, they use to transmit data and calculate the difference between the two channels. If the channel difference is higher than the threshold value (threshold value is 5), this indicates that the interference is low. After calculating the interference rate, the interference rate along with other criteria such as the number of steps and the available bandwidth is given to the fuzzy system as input to calculate the points assigned to the criteria and add to the total reward field. If it is positive, i.e. the node is encouraged and the appropriate link is recognized, and the node routing table will be updated.

Fuzzy inference engine: Fuzzy rules are placed in the knowledge base in the form of conditional statements. Fuzzy inference engine is one of the main components of the system to implement the rules properly. The inference engine deter- mines how the rules in the knowledge base are processed using the fuzzy inputs obtained from the fuzzy step. The inference engine uses fuzzy rules to calculate link rewards. For example, an introductory part if the "available bandwidth" is low, the interference is "low", the number of steps is high, and a result part then the reward is "low" link and then the result variable is "link stability is "low". The fuzzy inference engine used in this research is due to the simplicity of the Mamdani interference engine [8]. For each of the three input parameters, we have defined two fuzzy sets (Low and High) that produce eight fuzzy rules. These eight rules are defined as follows:

Rule (1). If (BW is Low and HC is Low and IN is Low) Then Node Chance is High
Rule (2). If (BW is Low and HC is Low and IN is High) Then Node Chance is Low
Rule (3). If (BW is Low and HC is High and IN is Low) Then Node Chance is Low
Rule (4). If (BW is Low and HC is High and IN is High) Then Node Chance is Very Low
Rule (5). If (BW is High and HC is Low and IN is Low) Then Node Chance is Very High
Rule (6). If (BW is High and HC is Low and IN is High) Then Node Chance is Medium
Rule (7). If (BW is High and HC is High and IN is Low) Then Node Chance is Medium
Rule (8). If (BW is High and HC is High and IN is High) Then Node Chance is Low

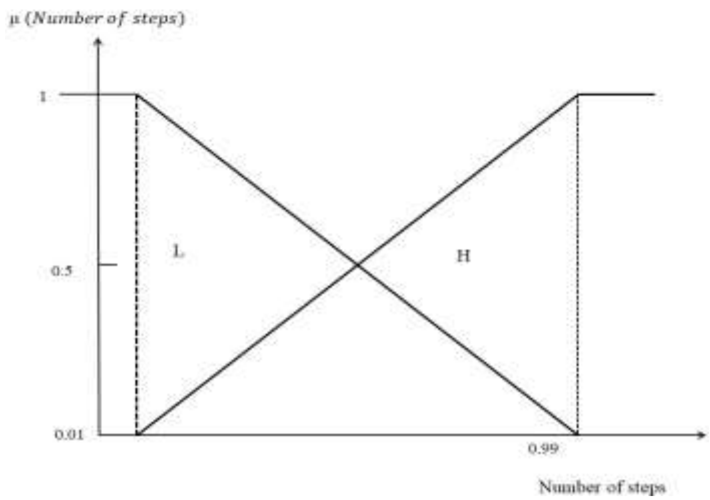


Fig. 4. Membership functions for input variables number of steps

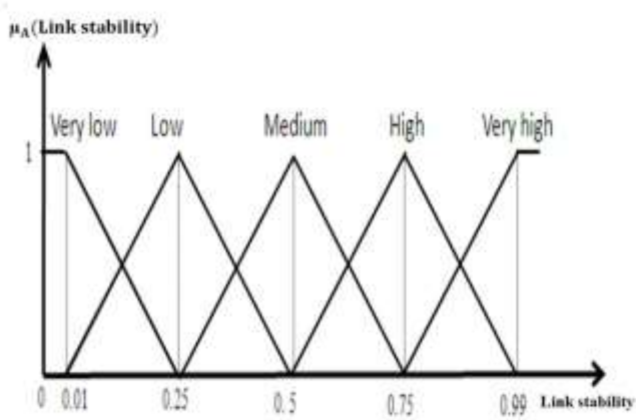


Fig. 5. Membership functions for link reward output variables

B. Defuzzification

Defuzzification is used to translate the fuzzy output into a numerical value. The input of any defuzzification process is a fuzzy set (the sum of the output fuzzy sets) and its output is a number. Although fuzzification helps with mid-stage valuation, the final desired output for each variable is only one. However, the community of fuzzy sets contains a series of output values and must therefore be defuzzification to be converted from a fuzzy set to an output number. In the proposed method, a non-fuzzy average of the centers is used, which is calculated using Equation 1.

$$\text{link Reward} = \frac{\sum_{l=1}^{m} y^{-l} \prod_{i=1}^{n} \mu A_i^l (X_i)}{\sum_{l=1}^{m} \prod_{i=1}^{n} \mu A_i^l (X_i)} \quad (1)$$

The parameters of this formula are: i: path index, m: number of fuzzy rules, n: number of membership functions of input variables ,µAl(Xi)The fuzzy value is the functions of the membership as well as the output centers. In the proposed method, we intend to use a system based on reinforcement learning to determine the appropriate route to send information to the destination and the node is given highest score. The path stagnation is extracted and save in the memory, thereby increasing the stability of the routes. The following is an example of how the proposed protocol works. A mesh network can be described by a graph of nodes (nodes are mesh routers). To describe how the proposed protocol works, consider the graph in Figure 6, in which a process in source node A wants to send a packet to destination node.

In the proposed method, each node has a table whose key in this table is the destination address, and each of the records in this table contains information about the destination and to which packet, the packet must be delivered to that destination. Source node A checks its routing table to find the route to the destination, if it finds a route, it sends data from that route. Suppose A searches its routing table and does not find any objects corresponding to I in it, now it must find a path to I. The same feature that routes are only detected when necessary has given the protocol a demand-based feature.

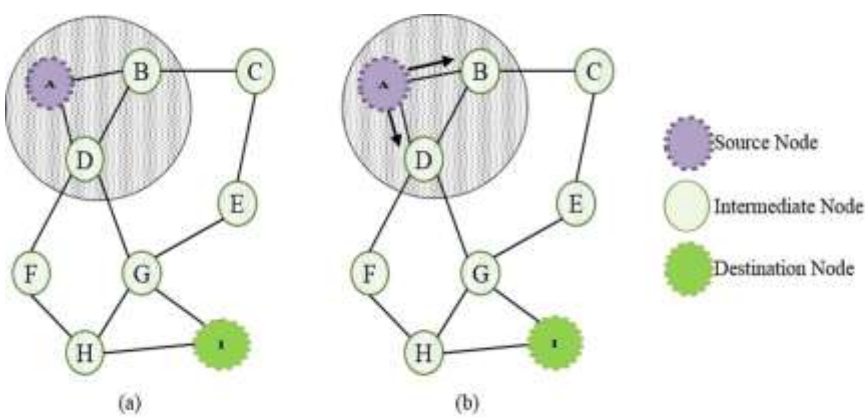


Fig. 6. (a) Coverage of broadcast coverage A and (b) Coverage A to nodesB, D

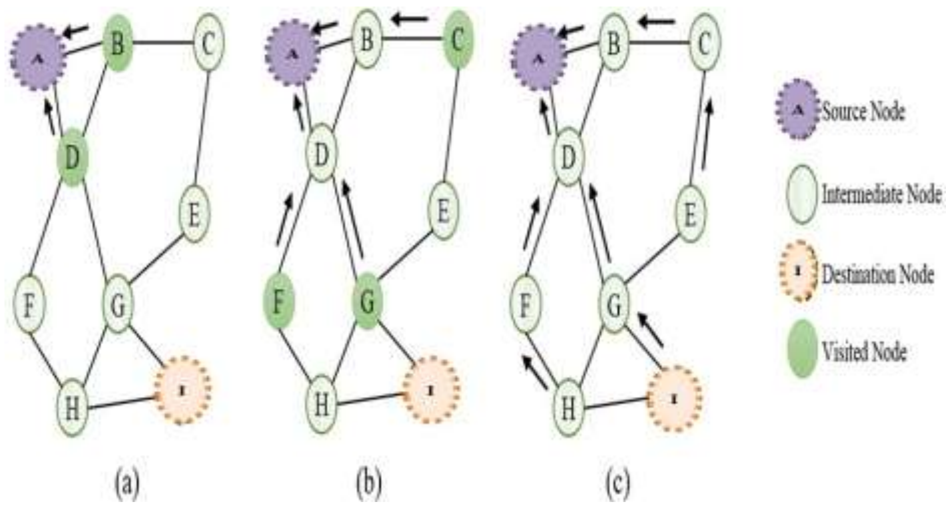


Fig. 7. (C) After B, D received the public broadcast of A. (D) After C, F, and G received the A-wide broadcast. (X) After E, H, and I have received the A scatterplot, the green nodes are the new receivers of each step; the arrows indicate the reverse path (return path).

The unit is added to it. The seventh field specifies the available bandwidth of the link for the nodes. Field 8 specifies the channel number. The last field specifies the sum of the rewards received, and the initial value of this field is also zero. When the route request packet reaches an intermediate node (B and D in this example), it is processed according to the
following steps:

1) : Firstly, the attribute pair (source address, request ID) is searched in a local table (which keeps records of such packets) to determine if the packet has already been received and processed. If it is duplicate, the packet is deleted, and the processing ends here. If it is not duplicate, this pair enters the packet attribute in the record table so, that similar packages with this packet will not be processed in the future. By doing this it prevents the formation of loops in the routing and the processing process continues.

2) : In the middle node B and D calculates the interference rate of the path request packet A. The calculated interference rate subtracted from transmitted channel number inside packet, if the number obtained is more than 5 There is no interference. The closer the difference is to zero, the higher the interference rate. Next, intermediate nodes B and D from the calculated data and other data inside the packet determine the route request. Is the link through which the packet received appropriate or not? That is, in fact, inside each intermediate node, it is checked whether all the stability parameters mentioned in the path request package, i.e., the interference rate and available bandwidth and the number of steps, are satisfied or not? For example, it checks whether the amount of bandwidth in this node is enough to send or not. If it has enough bandwidth, i.e., in the high range, a positive score is assigned by fuzzy logic to encourage the node, otherwise a negative score is assigned. It does the same for other parameters such as interference rate and number of steps, and then calculates the total points to determine the node reward and multiplies by $\gamma = 0.9$ and adds to the total reward field in the path request packet. Meanwhile, in the middle node, if the appropriate link is found, i.e., the sum of the reward calculated is a positive number, then the neighbor connection table in the middle node is updated. For example, suppose that in a node the available bandwidth is in the high range and the number of steps in the low range and the interference rate in the high range, so the score assigned to the available bandwidth criteria and the number of steps is +0.4 and 0.2 for the rate measure, if interference will be 0.3, the total reward assigned to this node is +0.3, which is a positive number, so the neighbor connection table in this node will be updated. If the total reward assigned to a numeric node is negative, the neighbor connection table in that node will not be updated. The node multiplies its total reward by a factor of gamma and adds the value of the total reward field in the path request packet field and replaces the new value with the total reward field in the path request packet. The receiver then searches the destination address in its routing table. If a new route is found to this destination, a route response packet is returned to the origin so that the origin is also aware of how to reach the desired destination. The presence of a route means that the field sequence number of the destination stored in the routing table must be greater than or equal to the same field in the route request packet. The origin is at the disposal of the destination, in which case the third step is performed.

: In this step, the receiver does not recognize any new path to that destination, it adds a unit to the value of the step counter field and redistributes the path request packet around it by entering its stability parameters, of course, the data inside extracts the packet and stores it as a new drive in the table (inverted paths). This information is useful because it is possible to create inverse paths and through it, in the future to return the answer to this demand to the source, the arrows seen in Figure 6 shows how to make inverse paths. As soon as a new reverse path is created, a timer is set for it. If the timer expires and there is no response to the path request package, the created path will be deleted.

None of the nodes B and D know where I is, so these two nodes also play the reverse path to return the response to A, changing the counter field to step 1, and entering their stability parameters to replay it. The replay of the package by B also reaches C and D. C also creates an object in its inverse table and adds the points earned to the request packet and redistributes the route request packet. In contrast, D deletes, it as a duplicate packet (because it has already received it through A). In the same way, the packet distributed by D and B is recognized as duplicate and deleted. However, as seen in Figure 6, the package published by D is accepted and stored in F and G. After that E, H, and I also receive the broadcast package, the route request message. finally reaches the destination (ie, it reaches I itself or the node that knows the exact location of I).At the destination, like the intermediate nodes, it extracts the stability parameters from the path request packet and saves the link if it is appropriate, and multiplies the total reward by fuzzy logic after calculation in the coefficient gamma (Figure 7).

Then, based on the total reward field, the decision is made to choose the best path (high reward path) which will be a sustainable path.

Node I generates a path response packet and sends the response packet only to the node through which the route request packet was received (in this example, node G). This packet sends its inverse path to D and finally to A goes on. In each node, a unit is added to the value of the step counter field so that each node that sees it understands how far it is from the destination node. Each intermediate node checks this packet on its way back. If one of the following three conditions is met, information about the path to I will be stored in the routing table of each intermediate node: 1) If there is no known path to I. 2) If the sequence number, I (i.e., the number I put in the destination sequence number field) is greater than the number listed in the routing table. 3) If the sequence number is the same but the new path is shorter (shortness is specified from the step counter field). In this method, all nodes on the reverse path are informed of the path to I (one of the side benefits of path discovery by A is the knowledge of the middle nodes). Nodes that receive the path request packet in the path received They do, but they are not in the opposite direction (in this example, H, F, E, C, B). After the timer expires, they delete the reverse path to A.

c. Routing mesh networks using colonial competition algorithm

The second proposed algorithm consists of three operational phases: cluster selection, channel allocation, and rate allocation. The details of each of the three phases is discuss in the following section.

In the cluster selection phase, the goal is to select the appropriate cluster for each cluster. The proposed algorithm uses the colonial competition algorithm to select the eclipse. The following describes the colonial competition. The algorithm of Colonial Competition is one of the evolutionary algorithms, which was inspired by the idea of human socio-political evolution by Gregory and Carlox in 2007[10]. It is one-way methods, the answer space is searched extensively, so there is less possibility for convergence to a local optimal point. In general, the colonial competition algorithm can be applied to any kind of optimization problem without any restrictions. This has led to the use of colonial competition algorithms in solving many problems in the field of electrical engineering, mechanics, industry, management, civil engineering, artificial intelligence, etc.

1) The clustering phase: In this phase, clustering is done by colonial competition. A simple method is used to display countries by using Ip mesh nodes to encrypt countries. Finally, the values within the countries are numbers between 1 and M (M is the total number of clusters). The length of the countries is considered as the number of incoming tasks. Figure (8) shows an example of how countries are represented, in which 5 ids are assigned to the algorithm to run 5 randomly selected mesh nodes for eclipse. As shown in the figure, for example, 25 is executed, which means that a node with the identifier 25 as the header for cluster four is randomly selected.

CH_1	CH_2	CH_3	CH_4	CH_5
20	1	10	25	45

Fig. 8. How to display the country in the ICA algorithm[11]

a) Fit function: The most important goal of this function is to maximize the fitness function for selecting a threaded node. In the proposed method to solve the clustering problem using the colonial competition algorithm, a country is more appropriate that in addition to the minimum cost, which means the cost of the distance between a threaded node to the destination node, also the maximum available bandwidth and the load density carried by the node is minimal to reduce interference. Equation (2) shows how the fitting function is calculated for each country. In the following, we will explain how to calculate the amount of available bandwidth and the density of the load and the cost function of the distance per solution is calculated.

Fitness = Fit(B(counteryi)) + Fit(P(counteryi)) + zit(C(counteryi))

Where B is the bandwidth available in country i (node i), C is the cost or distance of a selected node to destination in country i and p is the load density in country i. The higher the value of the fit function, the better the choice for the clustering problem. The coefficients applied in Formula (2) make it possible to determine the effect of each parameter on the degree of suitability of the solution. In the proposed method, we calculate the suitability of the criteria using the inferred mechanism based on fuzzy logic. The fuzzy logic mechanism that we have proposed for clustering is a controller based on fuzzy logic. This control mechanism is considered as an adaptive control. The principle to design a fuzzy controller need explicit and explicit relations. Discover the system using intelligent agents and apply the fuzzy control rules along with the knowledge base to estimate the score of the evaluation criteria. The block diagram of this control system is shown in Figure 9. As shown in Figure 8,

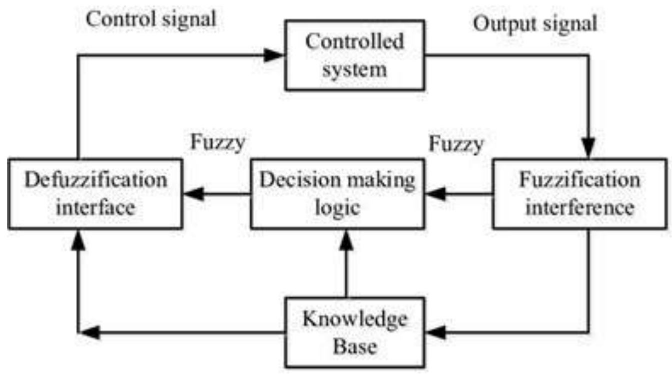
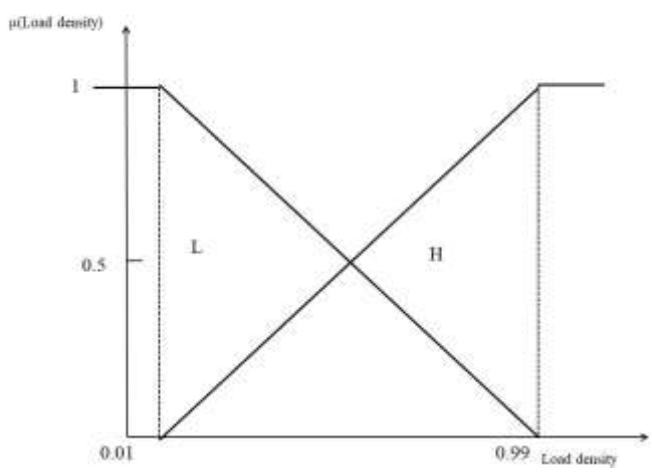


Fig. 9. Block diagram of fuzzy monitoring system

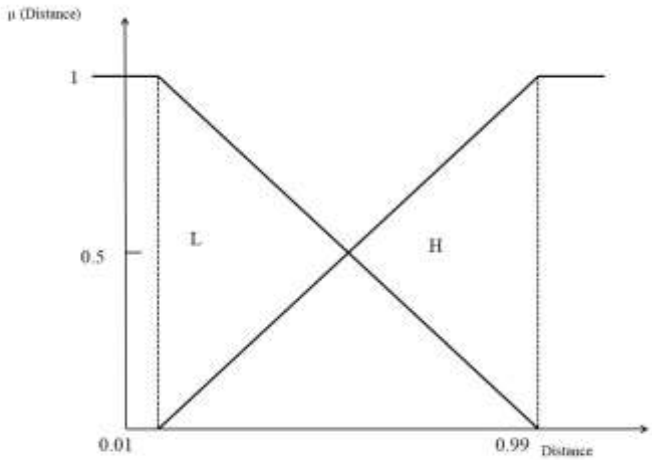
there are three main steps for applying fuzzy control to the above system, which are described below:

1. Fuzzification: In this step, fuzzy sets are defined for fuzzy input and output variables. Converting real inputs into fuzzy sets suitable for application to inference motors is called fuzzification. In other words, the fuzzy maker is the interface between the real inputs and the inference engine. In the proposed method of fuzzy system input, three parameters are considered, which include load density, cost or distance function and available bandwidth. For each of the input variables, we define two fuzzy sets with trapezoidal attachment functions (from H for the upper limit and L for the lower limit), which are shown in Figures 9-a, 9-b, and 9-c. Has been. The reason for using trapezoidal attachment functions is its accuracy. For the output, the stability rate of the fuzzy quadratic link with triangular attachment functions (H for the upper limit, VH very high, M for the middle limit, L for the lower limit and VL for the very low limit), which is shown in Figure 10.

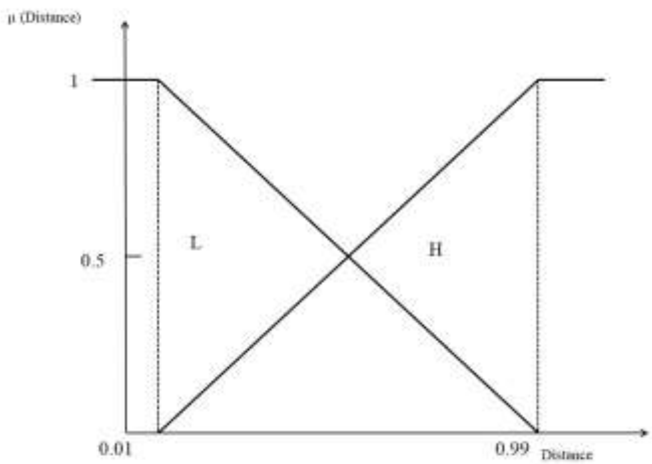
Fuzzy inference engine In the inference step, using fuzzy rules, we calculate the probability of eclipse for a node according to the value of the considered parameters, ie load density, cost function or distance and available bandwidth. Each fuzzy rule consists of two parts, one part of the introduction as "if the available bandwidth is low and the distance and load density are low" and one part of the result as "then the probability of eclipse is very low".



(a)



(b)



(c)

Fig. 10. Membership functions(a)Load density (b)Distance (c) available bandwidth input variables

In the proposed method, we have considered the fuzzy inference engine to be the minimum Mamdani. For each of the three input parameters, we have defined two fuzzy sets that produce eight fuzzy rules. These eight rules are defined in Table 1:

Table 1: Fuzzy Probability output

No	Input			Output
i	Distance	Load density	Bandwidth	Probability of clustering
1	Low	Low	Low	Medium
2	Low	Low	High	Very high
3	Low	High	Low	Low
4	Low	High	High	High
5	High	Low	Low	Low
6	High	Low	High	High
7	High	High	Low	Very Low
8	High	High	High	Medium

3. Defuzzifier Stage: Defuzzifier step used to translate fuzzy output numerically from a non-fuzzy generator. In the proposed method, the non-fuzzy generator of the mean of the centers according to Formula 1 is used. The parameters of this formula are: i: path index, m: number of fuzzy rules (here is 8), n: number of membership functions of input variables (here is equal to 3), $\mu Al(Xi)$: The fuzzy value is the functions of the membership as well as the output centers.

b) Absorption and revolution operators in the proposed ICA-Canell Assignment method: The agent of absorption is the policy of absorption has been built with the aim of changing the cultural and social structures of the colony towards the colonizer. In the proposed algorithm, first 40% of the colonial array cells are randomly selected. For example, in Figure 11, houses 1 and 4 are selected from the colonizer and other houses from the colony.

	T_1	T_2	T_3	T_4	T_5
Imperialist	3	3	2	1	2
Colony	1	2	3	3	2
New Colony	3	2	3	1	2

Fig. 11. The absorption operator

Revolutionary Operator: In this operation, two houses from a colony are randomly selected. Then their values are moved together, then both operations are repeated based on a percent- age of the total number of tasks available. If the new colony is better than the previous one, then the new colony replaces the previous one.

	T_1	T_2	T_3	T_4	T_5
Colony	1	2	3	2	2
New Colony	2	2	3	1	1

Fig. 12. The Revolutionary operator

D. The channel allocation phase

The principle of inter-cluster channel allocation is that adjacent clusters are assigned to fixed and different channels. In the first step, each head of the cluster performs an interference prevention algorithm to find the fixed channel of that cluster. The interference algorithm is the main part of the middle-cluster channel allocation design. This can be considered as a K-color graph coloring problem. Each cluster is a vertex in the graph. Two clusters are neighbors if an edge in the vertex graph connects them. Then we have to color the vertices of the graph in such a way that the two adjacent vertices are of different colors, and the number of interferences is minimized. To solve this problem, a mean distributed algorithm is proposed, which is as follows: In the next step, select a free channel that is not in the list of neighboring channels or the channel that creates the least amount of interference as a fixed channel. Notifies all clusters with lower IDs of the selected fixed channel. This algorithm does not try to color the graph with the least possible number of colors but find a solution that leads to the least amount of interference using a mean algorithm. In the next step, the nodes at the head of the cluster send fixed channels to the members of the cluster, and the normal nodes set their default radio to the fixed channel. The gateway nodes then set one of their radios to a fixed channel. After all the steps are completed, a connection is made between the clusters and the clusters are connected by gates. Therefore, the network connection is maintained.

E. The rate allocation phase

In a multi-rate wireless network, a node can change its transmission rate by changing the modulation method. In the IEEE 802.11b standard, the transmission rate change is intended for single-broadcast communications only. In this study, it is assumed that a node in a wireless mesh network can dynamically change its multicast transmission rate. Cables is used for multi-rate transmission flexibility to make optimal use of transmission, latency, and throughput under conditions where multiple channels are available. It is shown that in a multi-rate wireless mesh network, if a node has to have a multi-broadcast transmission to cover a number of receivers, then its transmission rate is the lowest transmission rate between the sending node and the receiving node. Is limited. In this phase, to solve the problem of rate allocation, an innovative algorithm is presented. And support the addition or deletion of multicast nodes. In the rate allocation phase, 11mbps, 5.5mbps and 2mbps transmission rates have been used. Each node in the network can send at multiple rates.

Therefore, since if the distance between the channels in- creases, the interference range decreases. Channel allocation should maximize channel separation for two links that have a short physical distance. The goal here is to reduce the interference range of all transmissions. The term IR (uv) is used to denote the interference of the sender u from one link to the sender v from another. According to the experiments performed, under the condition that all nodes have the same transmission range R, equation (3) is established : $IR(u_v) = R\sigma_{|i_u - i_v|}$

Nodes u and v use the iu and iv channels for their SI radios, respectively, which is also a measure of interference. Table (3) shows the standard values of interference versus channel distance for different data rates.

Table 2: IEEE 802.11b Interference Criterion [11]

	I0	I 1	I2	I3	I4	I 5
5M	2R	R	0.625R	0.375R	0.125R	0
11M	2R	R	0.5R	0.375R	0.125R	0

Therefore, if the Euclidean distance between nodes is be- tween 200 and 250 meters, the transmission rate is 2mbps, and for nodes whose Euclidean distance is less than 100 meters, the transmission rate is 11mbps, and for nodes whose Euclidean distance is between 100 meters and 200 meters, the transmission rate is 5.5. If we use mbps, the interference will be reduced.

4 Simulation of the proposed Method

In this paper, Opnet Modeler simulation software version 10.5 has been used to simulate the proposed method and compare it with the CAMF routing protocol in the article [1]. Table (4) shows some of the models implemented by this simulator in different layers. The simulation parameters are also shown in

Table (5). In the proposed method, we have considered the mesh network correlation of 10, 20, 30 and 50 mesh nodes (Figure 13). Three scenarios, the first scenario of the nodes based on the proposed algorithm and the second scenario based on the article [1] and in the third scenario based on the article [2] perform routing in a multi-channel multi-radio mesh network. In the following, we will discuss the simulation results of the proposed protocol based on the scenarios. Figure 14 shows the node editor model for the proposed simulated method.

Table 3: Implemented models for each layer

Layer	Model
Physical	free space
Data link	802.11
Network	AODV
Transport	TCP
Application	FTP,HTTP

Table 4: Simulation parameters in the proposed protocol

Simulation environment	Value
Number of mobile node	10,20,30,and 50
Simulation time	$600 Sec$
Simulation space	$100 * 100 m^2$
Transmission radius of each node	$250 m$
Number of sending data number	20 conversion
Data packets generated	1024byte
Size of data packets	25packet/sec
Packet sending frequency	2mbps
Motion model	Random walk
Traffic model	CBR
Dissemination model	Space TELCON 11
Interface access protocol	IEEE 802.11

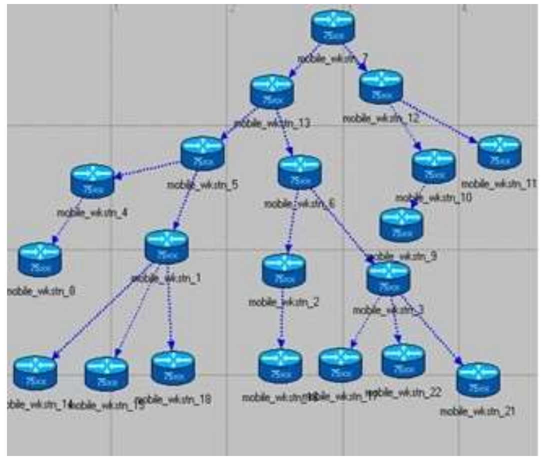
A. Performance criteria in the proposed method

To evaluate the efficiency of the proposed method, the following criteria are used.

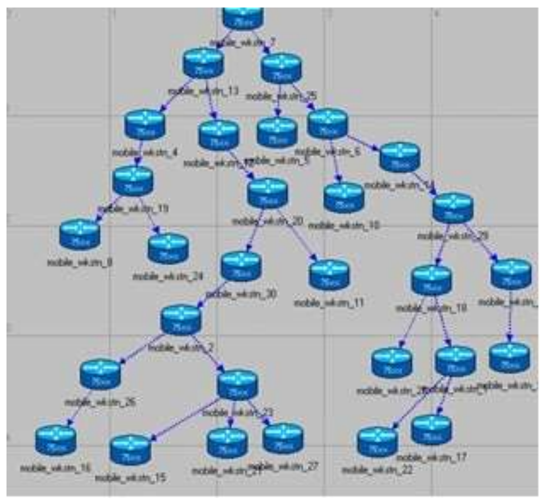
1. End-to-End delay: The average packet delivery time from origin to destination is defined as the average end-to-end delay. First, for each source-destination pair, the average delay is calculated, and then the average total delay is calculated from these source-destination pair delays. These include end-to-end latency, transmission buffer latency, transmission queue delay (interface queue), bandwidth competition latency in the MAC layer, and propagation latency.

2. Frequency: Defined as the total packets received by the receivers divided by the time between the receipt of the first packet and the last packet. In fact, it is equal to dividing the file size at that time, in megabits per second.

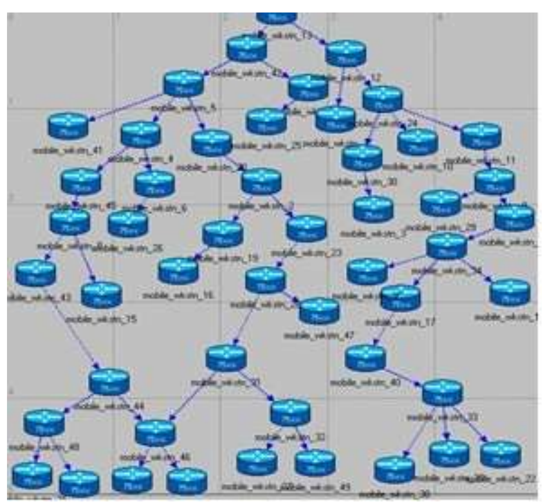
3. Data packet delivery rate: The ratio of the number of packets received to the number of packets produced is defined as the data packet delivery rate. "Number of packets received" is the total number of packets received at destinations and "Number of packets generated" is the total number of data packets generated by sources. This criterion can measure the reliability of package delivery as the efficiency of the protocol.



(a)



(b)



(c)

Fig. 13. View of Network Editor (a) 20 nodes(b) 30 nodes(c) 50 nodes

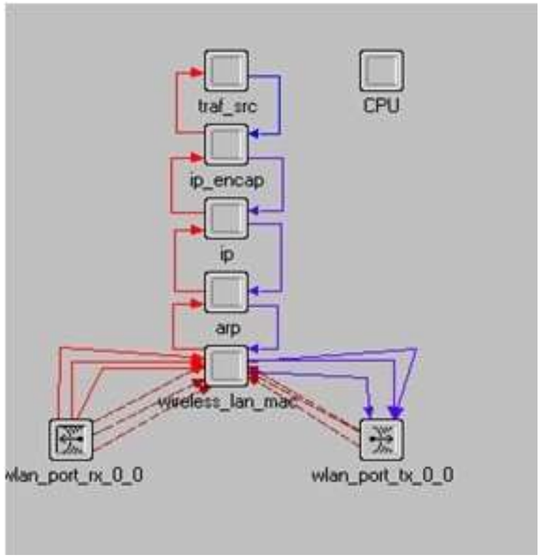
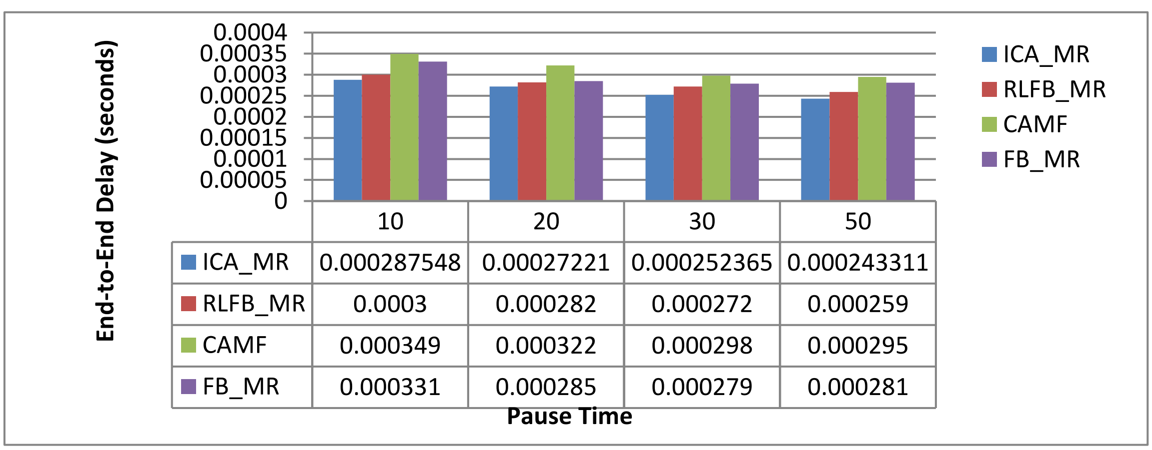


Fig. 14. View of the simulated model node editor model

5 Simulation Results

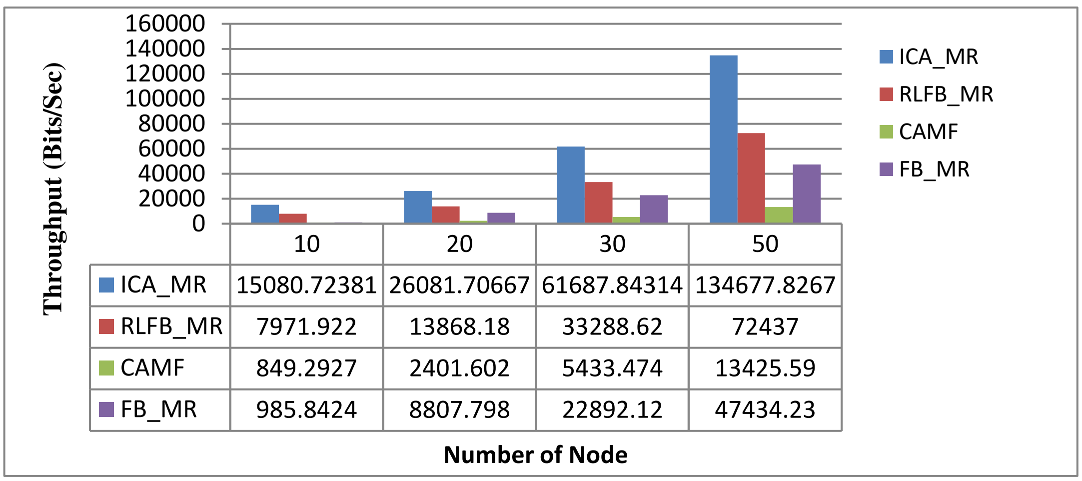
Figure 14 compares the end-to-end latencies for the pro- posed algorithm scenarios and the FB_MR and CAMF routing protocol scenarios. The vertical axis is the end-to-end delay, and the horizontal axis is the number of mesh nodes. As can be seen in the FB_MR and CAMF scenarios, the latency increases because some network nodes may send part of the data and to complete the transmission due to instability of the link due to interference nodes cannot complete the data transfer operation, but in the RLFB_MR protocol because it is able to determine the appropriate links for data transfer after learning by considering the stability of parameters. In other words, routes are created that most likely deliver the package to its destination, and there is no need to rediscover the route. Therefore, the latency of the whole network is significantly reduced. The proposed ICA_MR method can determine the appropriate path for data transmission after learning with colonial competition and clustering, considering the parameters of bandwidth and load density and distance with the least interference. Therefore, the latency of the whole network is significantly reduced.



	10	20	30	50
ICA_MR	0.000287548	0.00027221	0.000252365	0.000243311
RLFB_MR	0.0003	0.000282	0.000272	0.000259
CAMF	0.000349	0.000322	0.000298	0.000295
FB_MR	0.000331	0.000285	0.000279	0.000281

Fig. 14. End-to-end delay

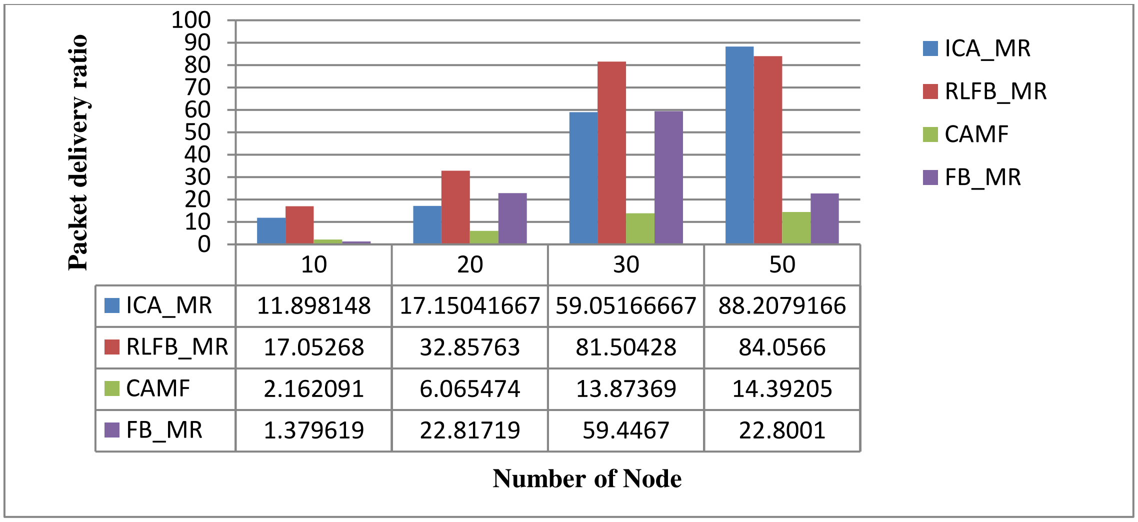
Figure 15 shows the throughput. The horizontal axis shows the number of nodes in the mesh network and the vertical axis shows the throughput rate. According to Figure 15, the FB_MR and CAMF routing protocols compared to the proposed methods, the number of data bits successfully de- livered to the destination node is less than the total packets transmitted by the network nodes, while in the proposed method RLFB_MR using Fuzzy and reinforcement learning to determines the appropriate links with high stability rate, if the link is appropriate it send data from that link. Therefore, the throughput rate for this scenario is higher than the FB_MR and CAMF routing protocols. The stable path does not change until the end of the data transfer phase. The proposed ICA_MR method of rate allocation and channel allocation was performed according to the criteria of load density, distance and bandwidth and was performed according to the colonial competition algorithm, so it could perform better than other methods.



	10	20	30	50
ICA_MR	15080.72381	26081.70667	61687.84314	134677.8267
RLFB_MR	7971.922	13868.18	33288.62	72437
CAMF	849.2927	2401.602	5433.474	13425.59
FB_MR	985.8424	8807.798	22892.12	47434.23

Fig. 15. Throughput rate

Figure 16 shows the packet delivery rate. FB_MR and CAMF routing are compared. The proposed RLFB_MR method, due to the finding of a new path before failure due to high interference rate or lack of required bandwidth, will have less packet loss than the proposed basic article protocol. The proposed method can determine the appropriate links with low congestion for data transmission. In other words, routes are created that most likely deliver the package to its destination. The proposed ICA_MR method also tries to reduce the number of data losses and the average latency by choosing paths with low interference.



	10	20	30	50
ICA_MR	11.898148	17.15041667	59.05166667	88.2079166
RLFB_MR	17.05268	32.85763	81.50428	84.0566
CAMF	2.162091	6.065474	13.87369	14.39205
FB_MR	1.379619	22.81719	59.4467	22.8001

Fig. 16. Delivery rate of data packets at the destination

5 Citations

Most of the research published is on multi-radio, multi- channel mesh networks but limited number of research has been done on the issue of routing in multicast applications. The problems in multicast routing and channel allocation to radio communications of multicast router member routers is examined in this article and the reinforcement learning algorithm and fuzzy logic as well as research using the colonial algorithm is used to solve the problem. The tree clustering with the least amount of redistribution nodes and intermediate to have fewer transmissions in the network. By allocating channels with the least amount of interference to the links in the network, we have greatly limited network interference and improved network performance. By choosing a path with high stability, network interference is greatly reduced, and network performance was improved. The simulation results were performed on ten, twenty, thirty, and fifty nodes of the network in opnet simulator and the results were compared with CAMF and FB_MR methods. The results of the simulation show better performance of the colonial algorithm method than other methods in terms of end-to-end latency and packet delivery rate and throughput rate.

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Conflicts of interest

All of the authors declare that they have no conflict of interest.

Availability of data and material

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Code availability

All code for data analysis associated with the current submission is available from the corresponding author upon reasonable request.

Ethical approval

This article does not contain any studies with human par- ticipants or animals performed by any of the authors.

Consent to participate

This article does not contain any studies with human par- ticipants or animals performed by any of the authors.

Consent for publication

This article does not contain any studies with human par- ticipants or animals performed by any of the authors.

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