# A Survey on Multicast Routing Approaches in Wireless Mesh Networks

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**Abstract**

Wireless mesh networks (WMNs) which mediates the broadband Internet access, have been recently received many attentions by the researchers. In order to increase capacity in these networks, nodes are equipped with multiple radios tuned on multiple channels emerging multi radio multi-channel WMNs (MRMC WMNs). Therefore, a vital challenge that poses in MRMC WMNs is how to properly assign channels to the radios. On the other hand, multicast routing lets the delivery of data possibly from one source to several destinations which makes it suitable for multimedia applications such as video conferencing and distant learning. In this paper, different methods of multicast routing in WMNs are investigated. Moreover, the existing methods are classified from the viewpoints of management style (centralized / decentralized) and achieving optimal solution (heuristic / meta-heuristic / operation research).

***Keywords:*** *Wireless Mesh Network, Multicasting, Multiple Radio, Multiple Channel.*

## 1. Introduction

The most important application of Wireless Mesh Networks (WMNs) is to access broadband Internet [1]. WMN is a metropolitan area network and can be used to access the networks in universities, mobile phone networks, and expansion of the coverage area of WLANs. In Multi Radio Multi Channel WMN (MRMC WMN) every node can be equipped with limited number of radios less than the number of available channels [1, 2]. Figure 1 shows the architecture of MRMC WMN. In upper level there are several gateways interconnects mesh network and the wired Internet. The intermediate level consists of several stationary mesh routers forming the infrastructure. There is no limitation of power consumption in the intermediate level. The lower level contains the stationary and mobile end-user devices with restricted capabilities. In these networks simultaneous transmissions will result in interference which decreases the capacity. One feature of IEEE 802.11 and IEEE 802.15 standards is providing more than one channel for data transmittal [3, 4] leading to the improvement of throughput. Figure 2 depicts the available channels in IEEE 802.11b.

One of the main issues in WMN deployment is multicast routing. Multicast routing presents a method of communication between multiple nodes transmitting data from a source node to a set of destination nodes in a scalable way. With regard to the limited bandwidth of wireless networks, the existing wired multicasting solutions are not applicable to WMN. In addition, the reported methods in WMN try to solve the sub-problems multicast links construction and channel assignment in sequence which cannot yield to a near-optimal solution. In this paper, a new method using intelligent water drops for multicast routing and channel assignment in WMN is presented to cope with aforementioned shortcomings.

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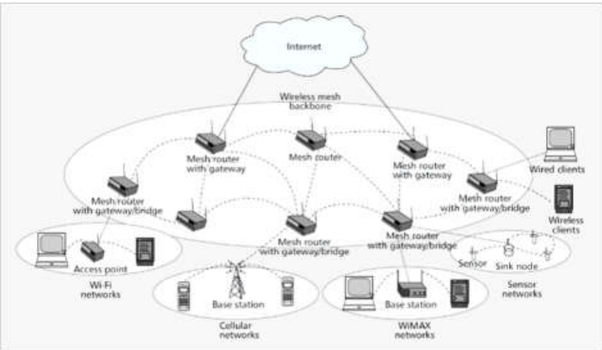



Fig. 1. Architecture of wireless mesh network [5]

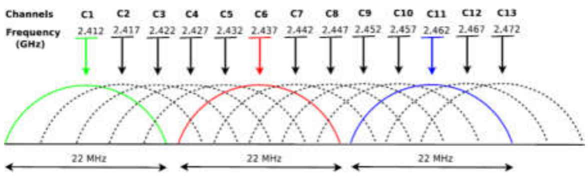



Fig. 2. The available channels in 802.11b standard [3]

The remaining parts of this paper is organized as follows: section 2 includes related works. Section 3 is a discussion on the matter. In section 4, the conclusion and some directions for future works are given.

## 2. Related Works

In this section we classify the reported methods based on some criteria.

### *2.1. Classification According to the Network Management Style*

Multicasting is performed in two ways of centralized and decentralized. In centralized approach, the information in collected from all other nodes and based on the provided information, the decision regarding routing and channel assignment is made. Next, these results are delivered to all other associated nodes. For example, in [6] a centralized interference-aware method has been proposed. Here, the priority is with nodes closer to gateway nodes [7].

Some algorithms were presented based on Tabu search. In this method, assumption is that the channel assignment is already conducted. Centralized approaches are divided into three groups: graph-based, flow-based, and network partitioning methods. Flow-based methods were designed to eliminate the graph-based methods which attempt to consider the traffic flow. In network partitioning methods the idea is that radios and links are divided into several orthogonal sets and each set only uses one channel. The only method in this group is the one in [8]. The input of this algorithm is the unit disk graph. Each node has several radios and the number of k channels is available. In this method in which the conflict graph is used for modelling interference. A scheduling algorithm of link should be used for networks partitioning to decrease interference in each sub-networks. The defect of this approach is that if there are not many channels available such that we encounter the problem of assigning a unique channel to each section, then we will have partial stability. In contrast, in decentralized methods, there is no central controller and each separate node performs channel assignment using local information. Since in these methods it is necessary that all the nodes collaborate with each other, the design of these methods is more complicated than the one in centralized methods. In decentralized methods, each node measures its local information and informs its neighbours to perform channel assignment. In other words, there is no node with global information about whole the network. Each node has local information about itself and its neighbours. In decentralized algorithm, the nodes usually communicate with each other using passing messages and collecting information and finally making a decision using this local information. In decentralized algorithm, the node of WMN decides how to link its interfaces to its neighbours and assigns the channel to these interfaces without global coordination. One of the advantages of using decentralized approach in this case is to effective use of the entire network bandwidth. These methods differ in their performance metrics. For example in [9], each radio selects the channels with minimal interference among the all radios available in its range.

In [10], the channel diversity is considered as the performance metric in which the channel diversity equals the maximum use of channels minus the minimum use of the channel. In some researches, the utilization rate of radios is considered as a performance metric that is equal to the ratio of available radios in all the active links to sum of the all network node radios. In this research, the traffic rate of each link is considered the same and the aim is to maximize active links or the utilization rate of radios. Also, it is possible that the methods consider the number of links which use the same channel and are in interference range of each other, furthermore, the traffic load on the channel and the signal to interference ratio (SIR) or a combination of which. These methods with regard to the traffic are divided into two groups: gateway-centered and peer-based methods. In gateway-centered methods it is assumed that the traffic from / to the gateway is heavy. Therefore, heuristic channel assignment methods are presented in which the idea is that the links close to the gateway should allocate more bandwidth to themselves. In peer-based methods, the assumption is that the traffic is sent between two nodes and there is no any traffic pattern. Some of methods try to optimize throughput and some to minimize the interference. In gateway-cantered methods, it is assumed that the gateway is the source or the destination of traffic.

In [11], it has been proved that the multicast routing problem is NP-complete. Finding the optimal set of links in routing graph resulting from WMN with centralized algorithm is not applicable enough in large scales. Considering researches in [12], the execution of channel assignment algorithms and centralized routing is not more suitable than decentralized ones. A centralized solution due to single-point-of-failure is not always the best approach and is not scalable. On the other hand, the centralized algorithm can provide more efficient functionality in such networks.

In [13], one design attempts to prove that clustering the nodes in WMN is not a superior approach, since the management of clusters in a decentralized system is a complicated issue.

### *2.2. Classification According to Achieving Optimal Solution*

The existing methods of multicast routing, in terms of achieved results, can be classified into three groups of heuristic, meta-heuristic, and operation research. In the following, the reported methods in each category will be discussed.

### *2.3. Multicast Routing with Heuristic Approaches*

Greedy algorithm is one of the most common heuristic methods. In this approach, the channels are assigned to the links greedily; a first free channel with the minimum load is assigned to the first link having no assigned channel. This process continues until all the channels are assigned to all links [14]. Wireless network have Wireless Broadcast Advantages (WBA) feature. It means that if a node performs one-hop broadcast, then all the nodes located in its communication range will receive the transmitted messages.

In [15], e heuristic algorithm considering WBA has been proposed which operates based on static channel assignment. Their heuristic algorithm includes three steps: first of all, given traffic information, a multicast tree is searched for each multicast request to solve the problem of routing. Next, an optimization of the capacity of the multicast tree links is approximated. Afterwards, according to the obtained results, the channels are assigned to the links.

In [16], considering multi radio multi-channel advantages two methods of Parallel Low-rate Transmission (PLT) and Alternative Rate Transmission (ART) have been presented. Also, to increase the coverage area and achieving high throughput an algorithm for constructing multicast tree named LC-MRMC (Link-Controlled Multi-Rate Multi-Channel Multicast) was proposed. It has been attempted to solve two problems of channel assignment and rate adjustment separately. In PLT, every node uses from two orthogonal channels in parallel for required transmission rate each one carrying half of data. PLT divides wireless mesh nodes into two groups of ordinary and PLT nodes. Ordinary nodes work on one channel with the predefined rate R. PLT nodes use rate R5 for packet transmission. LC-MRMC attempts to choose the minimal number of relay nodes to connect multicast sources to their associated receivers. Tree construction in LC-MRMC is initiated by registration of multicast receivers. Every multicast receiver sends a registration packet to the multicast source. The packet includes: Group ID identifying the multicast group, Hop count that counts the hop numbers between a mesh node and the multicast source and a Forwarder list that stores IP addresses of the registration senders.

Shittu et al. [17], does not discuss multicast tree construction and instead uses the Steiner tree algorithms to create a minimal cost multicast tree. In WMNs, the interference has to be considered in channel assignment. The interference in relay nodes effects sending packets. If a node has a specified interference with other nodes, it may encounter a considerable delay in sending packets due to several times of re-sending. In such a case, the multicast tree may not deliver packets to all destination nodes of one path with delay constraint. In this method, different priorities are considered for interference reduction among different trees. When a multicast session with delay constraint is requested, the multicast tree relating to the first session is created. The proposed algorithm divides the delay constraint of multicast tree path into several node-based delay constraints. This algorithm has a feature called priority-aware which permits multicast trees with high priority less interfere. In this research, a heuristic channel assignment algorithm named NOPA (Node-oriented Priority-aware) has been proposed to support the required delay which utilizes both orthogonal and partially overlapping channels. The proposed algorithm divides the network level delay constraints into several node level delay constraints.

Zeng et al. [18], proposes a Bottom-up decentralized approach to construct a multicast tree and to assign the radio channels. The following estimated algorithm has been proposed to produce the minimal set of relay nodes and construction of multicast tree: 1) the parents whose one child has the minimal parent are selected. 2) Among which, the parents with the maximum number of children, are candidate. 3) The selected parents and all of their children are eliminated from one-hope and two-hop node lists. The algorithm continues until the list of both one-hop and two-hop nodes become empty. Another algorithm is priority-aware and allows the multicast trees with higher priority less interfered [19]. The authors proposed a method named CAMF (Channel Assignment with Multiple Factor) for channel assignment and multicast routing with supporting nodes' mobility. This algorithm uses a concept named path weight for the purpose of increasing network throughput and considering nodes' priorities in channel assignment. In CAMF, it is assumed that the multicast tree is already constructed and some metrics such as transmission path weight, distance, window size and receiver nobilities are considered. Firstly, each node according to a pre-specified procedure determines the transmittal path weight and list of interfering nodes. Next, every node accomplishes the channel assignment phase for itself. To increase network throughput, channel assignment to nodes is done according to the order of their path weights. When a given node p intends to choose a channel, first it looks at the set of interfering nodes and identifies higher priority nodes for channel assignment process. Then, it checks whether those nodes have performed channel assignment or not. If not, that node should wait until the other nodes finish their task. Afterwards, every of 11 available channels are considered as a candidate channel for node p. To minimize the interference the node p should choose the channel with minimal interference. In the next step, the node p sends the information of chosen channel to all the interfering nodes. Each interfering node saves the incoming information sent by node p. Each node in the WMN may have one or more interfering nodes. In such a case, if a node of tree and one of its associated interfering nodes transmit packets simultaneously contention will occur.

In [20], an integrated algorithm of multicast routing, channel assignment and rate assignment namely JRCAR (Joint Routing, Channel Assignment and Rate Allocation Heuristic) in form of centralized has been presented. The problem is divided into three separate sub-problems of routing, channel assignment, and rate assignment. In the proposed algorithm the following states have been considered: 1) the path flows are calculated in order to load balancing. 2) load-aware channel assignment based on the routing resulting of the previous stage is calculated. 3) NLP (non-linear programming) concave problem is solved for the determined route flow rate and channel assignment. Whenever the network condition is changed, the channel assignment again will be done. Multi radio-multi channel multicast algorithms believe that the membership in group of multicast tree is not varied. But, the receiver belongs to the dynamic tree.

In [21], the nodes were permitted to join and leave the multicast tree without influencing the channel assignment. Therefore, in this reference, for reaching the goal, two algorithms are suggested for dynamic multicast tree: Node Joining the Multicast session algorithm (NJM) and Node Disjoining the Multicast session algorithm (NDM). These algorithms are given in order to increase in throughput and minimizing the number of nodes.

In Zeng et al. [22], two approaches have been proposed for construction of multicast tree and channel assignment. In the first method, the algorithm first applies a Breadth-first search (BFS) to the network nodes so that the nodes are placed in different levels. The relay nodes in multicast trees are determined using a bottom-up algorithm: if a receiver node, v, has several parents and one of those exists on multicast tree, the receiver is connected to the associated parent ($f_v$). Otherwise, one of the parent nodes is randomly chosen and one link is established to the parent ($f_v$). The algorithm is recursively continued for node ($f_v$). After the construction of multicast tree, using Level Channel Assignment (LCA) algorithm, channels are assigned to nodes considering the level of nodes in BFS. The channel i is assigned to the nodes located at level i of tree. The channel i+1 to level i+1 and this process will continue until the channels reach the end. Then again it starts from channel zero and is assigned to other levels respectively. The disadvantage of this method is that in case of several candidate nodes, a multicast receiver should randomly choose a parent that might not be the best choice. In addition, the nodes placed at the same level are subject to interference. On the other hand, if the number of channels gets more than number of levels, the existing resources are not sufficiently used.

Yang and Hong [23] introduces another method named MCM (Multi-channel Multicast), in which the nodes of tree are placed at different levels using BFS. In this method, the links among the same level nodes are removed. The minimum number of RNs constituting the multicast tree is determined using the following algorithm: 1. a parent, whose one child owns less parent, can be chosen as the RN. 2. Among candidate RNs, one node with the greater number of children is chosen. 3. The selected RN and its children are removed from tree and steps 1 and 2 repeat until all the nodes placed at level i+1 are removed. After the construction of multicast tree, two methods of channel assignment are presented in [22]. The first method called "Ascending Channel Assignment" (ACA) and the second one is "Heuristic Channel Assignment" (HCA). ACA algorithm is as follows: channels are assigned to the nodes placed at different levels and to the left and right sub-trees in order starting from zero. When all the channels are used, the algorithm re-assigns the channel zero to nodes of the next sub-tree and the process repeats. For partially diagonal trees, ACA suffers from the same defects as LCA. HCA method uses all the available channels for assigning. In this method, a channel is assigned to node (u) if the sum of the square of interference factors between node (u) and all of its neighbor nodes (v) is minimized. In [23], a multicast tree has been proposed with no interference and with restricted delay and the maximum mesh clients in MRMC WMNs.

Furthermore, an optimization problem in [24, 25, and 26] was presented which is about the cross-layer design scalability in MRMC WMNs and how to construct a multicast tree such that the number of mesh clients is maximized. The problem above is given as a problem of maximum-revenue and delay-constrained multicast, Cross-Layer and Load-Oriented (CLLO) that acts according to metrics such as user's demands throughout the tree formation process and channel assignment. All the available channels including partially overlapped and orthogonal channels are used. This algorithm considers users requests and channel assignment conjointly, throughout the construction of multicast tree. In this research, the delay is between the nodes has been considered. In this reference the goal is that by defining the upper limit of the delay$\Delta$, the multicast tree $\mathbf{T} = \{\bar{\mathbf{V}}, \bar{\mathbf{E}}\}$ is created starting from multicast origin route such that the channels were assigned to it. All the routes from the multicast source to every multicast receiver in T, have to satisfy to constraints below: (1) for each node $\mathbf{u} \in \mathbf{T}$ the route delay from multicast source to U, should not be greater than $\Delta$. (2) All the edges of T should have no interference and be capable of transmitting data simultaneously. Because the number of channels is limited, it is possible that the obtained multicast tree covers only a group of multicast receivers. Therefore, the mail goal is to find a multicast tree having no interference and to meet the need of delay constraint. The objective function can be implemented in the following way:

$$\text{Gain} = \sum_{u \in T \,\&\, u \in M} \text{demand}(u) \quad (1)$$

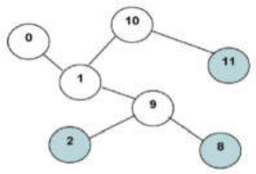
Where, the gain value implies the number of clients capable of receiving data, the demand (U) is the number of clients receiving data from node U. Considering that the proposed algorithm solves two problems conjointly, this can achieve better results. But, this algorithm may not cover all the users.

### *2.4. Multicast Routing with Meta- Heuristic Approaches*

The methods solving NP-hard problem using heuristics are not scalable. To solve this problem, soft-computing-based methods can achieve solutions near to optimal solutions in polynomial time. In the following, these categories of algorithms are investigated.

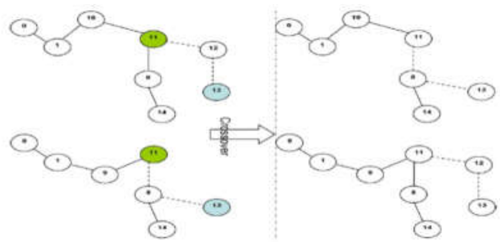
The neural network actually is used for predicting WMN traffic and reducing congestion. Neural network's model is able to have strong self-learning and self-adaption. In [28], a neural network model named Cerebellar Model Articulation Controller (CMAC) is used to predict unconditional probability of paths and to find the high reliable paths. Its main idea is based on associative memory including associated inputs and outputs. Here, the idea is to access a balanced-load network for higher quality of services in SRSC WMNs. The input space is divided into two separate sections and the memory is partitioned for each associated section, for storing the information of that section. Retrieving data from the associated memory section produces the output. The most obvious advantages of CMAC neural networks are rapid learning-speed and excellent convergence properties. Here, the idea is to achieve a network with balanced load for higher service quality in SRSC WMN. In [28], a Genetic Algorithm (GA) method has been presented for multicast routing. For initializing the population a set of chromosomes is randomly generated, each one indicating all the routes in multicast tree routing. Here, each multicast tree is displayed using a two-dimensional array (chromosomes). The number of chromosomes' row is corresponding to the number of multicast receivers. The row i, indicates one route of the multicast source s to the receiver $R_i$. The number of columns in chromosome equals the maximum path length from s to members of the multicast group members. The representation of chromosomes is according to the identifiers of relay nodes available in the path length from the transmitter s to the multicast group members. In this method, the chromosome is created according to Figure 3, which shows the tree representation in this algorithm.

After construction of multicast tree, the channels are assigned to the links from number zero respectively. After of link passage, the channel number will be increased. The fitness function in this reference is defined based on the sum of channel interference in all of available links in the multicast tree.

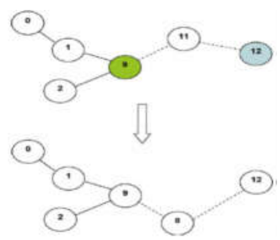



| | | | | | | |
|---|---|---|---|---|---|---|
| 0 | 1 | 9 | 2 | | | |
| 0 | 1 | 9 | 8 | | | |
| 0 | 1 | 10 | 11 | | | |

Fig. 3. Representation of a multicast tree using a two-dimensional chromosome [28]



a. Cross over operation [28]



b. Mutation operation [28]

Fig. 4. Mutation and cross over operation [28]

Figure 4 (a and b) shows two operators of cross-over and mutation. In general, the overhead resulting from the new chromosomes construction, along with the cross-over and mutation operators are considerable. Furthermore, if the number of channel is greater than the number of multicast tree levels, some channels will be used nowhere. The channel assignment to each row of the chromosome will result in hidden channel problem. The most important challenge in relation to the multicast is the different bandwidth of the receivers, which restricts the data rate to the receivers by the slowest one.

In [29], an algorithm named Multi-Gateway Multi-Rate (MGMR) multicast routing was presented to maximize all the data rates obtained by receivers properly. MGMR contains three phases: gateway selection, channel assignment and rate assignment. In the first phase, a receiver gateway is chosen using meta-heuristic method. The objective of this phase is to balance the load of WMN in order to save greater bandwidth for maximum throughput in the phase of rate assignment. Using multi-rate technique, data rate obtained by a receiver, is restricted by data rates of their parent's links. Since the objective is to achieve the maximum throughput of the network the links which transmit data to the greater number of receivers are more effective in the better performance of the network. In the second phase, an operation research-based method has been introduced for channel assignment. This algorithm estimates the observed interference considering multi-rate capability and assigns the channels with fewer loads to the links greater interference. By this method, the interference of different channels throughout the WMN will be balanced. Therefore, more space will be provided to increase the data rates with receivers. In the third phase, the data rates obtained by the receivers are determined in the phase of rate assignment. The resulting model determines the rates obtained by receivers. In multicast routing, the distribution of traffic among the nodes properly leads to the reduction of interference. To do so, in [29], a method named LMTR (Load-Balanced Multicast Tree Routing) is proposed in which a trade-off between load balancing and delay is considered. The part of the network in which the congestion happens should be free of traffic and hence, a load-aware routing mechanism should be employed.

In [30], an approach for channel assignment and routing is given in which the channel assignment problem has been divided into two phases; connecting neighbour to interface and interface to the channel. For connecting a neighbour to an interface, network interfaces are divided into two classes; UP-NIC for connecting a node to its parent and DOWN-NIC connects the node to its child. For linking interface to the channel, each node assigns the channels to its DOWN-NIC and forces each UP-NIC to follow the same DOWN-NIC channel as its parent. The reason for this kind of channel assignment is to avoid the ripple effect. In [31], it is pointed that centralized solutions are not more efficient than decentralized ones. Centralized solutions suffer from the single-point-of-failure and are not scalable properly. In greedy algorithm, the first minimum-load channel is assigned to the first unassigned-channel link [18].

In Ref [28], the approach of multi-objective optimization based on Non-dominated Sorting Genetic Algorithm (NSGA-II) has been used to solve the problems of channel assignment and multi-radio multi-channel multicast routing. Firstly, the multicast tree with the objectives of minimal cost, delay and interference is constructed and then the channel assignment is performed using a Tabu search algorithm. In the next phase, the quality of the multicast tree is quantified by PARETO ranking method. A congestion distance is allocated to each solution and based on the selection operators the cross-over and mutation of new answers are created and checked. Eventually, the multicast tree is created using the optimized channel assignment, according to the overall objectives of tree cost, the total channel interference and the average of end to end delay. In simulated annealing (SA) algorithm, to simulate annealing process, the concept of solid physics was used [28]. As mentioned in [31], SA researches via changing a response and obtaining its neighbour as the response. Thus, to construct the neighbour two methods are presented. In the first one, which is called fine-grain adjustment, the receiver $R_i$ is randomly selected and then on the route from the source to the selected receiver, a node Vi is randomly selected. Next, sub-route between $V_i$ to $R_i$ is replaced with a new route. In the second one, which is called coarse-grain adjustment at first, the trees based on LCA and the shortest length are generated and then the channel assignment is performed. Next, the interference is calculated and the tree with the minimal interference is selected as an initial response and then its neighbours should be constructed with regard to these two above methods [28].

In [32], a decentralized meta-heuristic algorithm for multicast routing named LAMR has been introduced in which channel assignment and multi radio multi-channel multicast routing are solved in the form of cross-layer. In this reference the Learning Automaton (LA) residing in the node interfaces, determines which radio using which channel is used to make a connection with the neighbour. The proposed design includes two steps; in the first step, the route has been constructed with the minimal end-to-end delay between multicast source and each multicast receiver. In the second step, the residing LA, improves the primary tree to reach a tree with the minimal interference. The first step operations are organized in several phases which are explained in the following: LA residing in the DOWN_NIC of multicast source nodes which are denoted by j are activated in parallel. The activated LA, $LA_{ij}$, selects an action according to its probabilities vector. The selected action determines a channel, by which the connection is made with the UP_NIC of its neighbour. Then, a RREQ packet is generated by the source node in which the selected channel by $LA_{ij}$ and the node ID appear in the channel list and ID list fields, respectively. The generated packet is next send to all neighbours. This process repeats by the nodes until reaches one of the receivers. The receiver changes the type of message to RREP and then sends it to the source using Dijkstra algorithm. As the feedback mechanism upon receiving the RREP message, the multicast source checks the DR Field of the received message. In this case RREP message is received from receiver nodes which their identifiers are written in the DR Field. Here, the first RREP will be considered. As the feedback, the round trip time between two successive RREP messages are checked. If the end-to-end delay reduces, multicast source sends a reward messages to all the nodes, which their identifiers are stored in the ID list of RREP message and is in the form of a new discovered route from source to receiver. Once the reward message is received by relay nodes, they update the routing table and the action probability vector according to the LRI learning rule. The multicast source then waits for T times, for receiving RREP message from other receivers on i-th UP_NIC. When multicast source receives RREP message from all the multicast receivers, the above process will be ended. In this case, the initial multicast tree has been created and the second phase will start. In this phase, the minimum end-to-end delay of the created multicast tree in the first phase, is improved with respect to the inter-channel interference. LAMR also considers hidden channel problem which usually occurs when the nodes in 2-hop away attempt to tune on the same channel. Despite the efficiency of the LA in various domains it has been criticized for the low convergence speed.

### *2.5. Multicast Routing with Operation Research Approach*

Unlike two previous approaches, this kind of optimization methods leads to the optimal solutions. In mathematical optimization, the metrics such as interference, the number of available radios, and available channels are considered for mathematical modelling. In [31], it has been mentioned that presenting a mathematical framework to obtain an optimal solution for multicast routing and considering the hidden channel problem are counted as necessities. In [32], a sequential solution for channel assignment and decentralized multicast routing problem with the objective of maximization of throughput was presented. Also, in this reference, a mathematical model for the joint problems of channel assignment and multi radio multi-channel multicast tree has been introduced. In this method, firstly the single radio multi-channel multicast problem is converted to a mathematical programming model and next an iterative primal-dual optimization method was designed. In [33], the multicasting problem has been modelled as a linear programming framework. In this model, the optimization function is defined for selecting path with the minimum traffic among other routes.

In [34], Minimum Delay Maximum Flow (MDMF) multicast algorithm was introduced to solve the intended problem. The evolution results show that the proposed algorithm has less transmission number, higher packet delivery ratio and less delay compared to other algorithms in this category. In this research, multi radio multi-channel multicast throughput optimization has been modelled in Integer Linear Programming (ILP). LP model is not scalable to large network sizes and hence, in what follows a heuristic approach will be presented to solve the problem. In the first design, initially, the channels are assigned to the radios using Breadth-First Search (BFS) greedily. Next, the obtained results are applied to LP model to calculate the throughput. In the second design, the dependent radio channels created by BFS, are corrected using LP model in each iteration. In this reference, the construction of multicast tree is not the main issue.

In [35], the authors presented Utility-Based Multicast Routing and Channel Assignment (UBMR-CA) design with two objectives of loop-free routing and minimizing the sum of utility function from multicast source to destination. They formulized the constraints of the problem in a LP model. The utility function is calculated for each link using Utility Weight Metric (UWM) only once which uses for sending multicast message from source to the destination. The channels are employed using UWM consisting of factors such as interference, load and the exclusive capacity of links. This algorithm contains three steps: in the first step, the utility based-multicast tree is constructed. In the second step, channel interference graph is constructed and in the third step, utility-based channel assignment is done.

In [7], Optimal Multicast Multi Sources Routing (OMMSR) algorithm based on LP and Constraint Based Routing (CBR) with the objectives of improving network efficiency, data rate, bandwidth and time consumption has been presented. Every Single Source Multicast Session (SSMS) sends data packets from a source node, $s_i$, to the groups of destination nodes denoted by $t_i$. Every SSMS needs to create a path for sending data to destination nodes that is possible using a routing algorithm. When the number of SSMS increases, the routing algorithm has to be separately executed N times. This leads to an increase in calculation time and bandwidth consumption. In this reference, a new approach is presented for integrating multicast sessions in order to create a Multi-Source Multicast Session (MSMS) which is done by executing routing algorithm once. OMMSR algorithm supports optimization routing, congestion control and traffic management.

In [36], binary integer programming (BIP) approach for solving the joint problem of channel assignment and multi radio multi-channel multicast routing was used. Two methods based on BIP with cross-layer and sequential approaches have been presented. In cross-layer approach, the interaction between multicasting in network layer and channel assignment in MAC layer have been considered. Therefore, in this method a model based on integer programming in which both problems of multicast tree construction and channel assignment are conjointly solved, is presented. In sequential approach the optimal solution to each sub-problem is presented. In the first step, the optimal multicast tree is constructed based on MCT and afterwards, the constructed tree obtained from the first step is used as an input of channel assignment step. Analytical results show that cross-layer method more requires the memory and also its time complexity is more that sequential approach.

In [37], due to the importance of multicast operation improvement, at first the channel assignment is independently performed and then bottom-up multicast routing for synchronous multicast flows is executed. The focus of this paper is on the design of load-aware multicast routing metric for MRMC WMN. Firstly, a mathematical model is extracted from multi radio multi-channel network and then is modelled to solve the problem of multicast throughput optimization in synchronous multicast flow. According to this insight that the sum of throughput and network load capacity for multicast flows can be improved trough finding multicast route with less congestion, two metrics of load-aware multicast routing namely Flow Load Multicast Metric (FLMM) and Flow Load Multicast Metric Reliable (FLMMR) have been proposed. FLMM assists to find better multicast route which decreases from the viewpoints of intra-flow and inter-flow interferences and uses the channel diversity for improving bandwidth and network throughput. By applying the above metrics to Multicast Ad hoc On-Demand distance Vector (MAODV) protocol, the MAODV-MR protocol is created. Eventually, the joint problems of routing and channel assignment for optimal multicast throughput in MRMC WMNs is modelled to a cross-layer binary linear programming.

In [38], the PaMeLA algorithm is used which possesses to phases: JCAR and post processing in order to decrease in packet loss rate and decrease in execution time. In the first phase of PeMeLA the general problem of JCAR (Joint problem of Channel Assignment and Routing) in divided into several sub-problems. Because each sub-problem only considers its constraints on the interference. Each sub-problem is formulated and solved as an optimized binary linear programming that can find the optimal solution using branch-and-cut in a reasonable time. In the second phase of PaMeLA for each solution, a post processing phase is executed which guarantees that no useless interface exists. The best solution among all the solutions is selected considering fairness metrics that is combined with the aim of load-aware interference. In [39], G-PaMeLA is also used. It is comprised of two phases: JCAR and post processing which are used to decrease packet loss rate, collision probability, the fairness between flow traffic. The phase nucleus of the JCAR is based upon two approaches of divide-and-conquer to break the problem into smaller sub-problems of manageable size which are sequentially solved.

The number of sub-problems is equal to the maximum number of hops to gateway. In two cases, each sub-problem is modelled as optimization problem of ILP. Using branch-and-cut technique it is possible to find an optimal solution for each sub-problem. The output of each sub-problem defines channel assignment and local routing for related nodes of this sub-problem. In the second phase for each solution obtained from the previous step, the post processing phase is executed once until the results of the related sub-problems are combined such that no useless interface exists. The final solution is obtained after this phase to improve network connections. Divide-and-conquer method considerably decreases the execution time and creates a practical solution to scalable WMNs. G-PaMeLA is not easily scalable.

In [40], the channel assignment algorithm and interference-aware time scheduling were presented. The optimal routing in WMN depends on the specified capacity on the link. Two increase throughput and network capacity, several channels and radio interfaces are used. Although, due to direct impact of interference on bandwidth, the use of links and channel assignment is restricted. In this reference the problem in conjunction with constraint are modelled as a linear programming problem and a new metric of Link Cost Metric (LCM). LCM metric is an improvement of Expected Transmission Count (ETX) metric in which the priority factor for considering fairness (including traffic flow) is added to ETX. Route selection procedure considers the interference impact on the next input connections using LCM. The proposed method includes Link Assignment Matrix (LAM) construction and links are grouped to each other. This method supports the kind of applications programs such as VOIP and video conferencing. In this research two types of traffic Constant Bit Rate (CBR) and Variable Bit Rate (VBR) were considered. The optimal distribution of traffic load on different routes can increase reliability and whole network capacity. In this method, firstly the links are sorted and placed in special groups, next the traffic is categorized into models and links are assigned to particular groups. In the first step it is assumed that no information of priority exists about the traffic pattern. In the second step, the Link Utilization Ratio (LUR) of each link based on the traffic class in calculated as VBR and CBR. In the third step, links are placed into a specified group. Next, those are assigned to a channel based on the availability and without contradicting the problem constrains. The mail goal of the channel assignment to the nodes is that the number of assigned channels to those does not exceed the number of their radios. A group including the types of links should assign to a special channel such that it reduces global network interference. The group of links possesses higher LCM compared to other groups are firstly considered for channel assignment. This causes these groups will not interfere with other groups.

## 3. Discussion

In this paper, the existing researches in the multicast routing in WMN were investigated. The general purpose of this study was to find a suitable solution to data transmission without interference and with the least delay. The methods based on mathematical approach, lead to optimal solutions but are not scalable enough. With regard to the fact that intended problem is known as NP, their functionality is not satisfactory in lard-size networks. On the other hand, soft-computing based approaches can provide near-optimal solution of the problem in polynomial time for the large network size. However, these methods still require improvement in convergence time and parallel search of the problem solution space. Furthermore, centralized methods normally lead to better solutions in small networks. However, their functionality in larger network reduces. On the other hand, decentralized methods provide suitable solutions in reasonable times. To better appreciate existing researches, channel assignment and multicast routing algorithm in WMN, are listed in Table 1.

## 4. Conclusion

In this paper, the multicast routing problem in WMN was discussed. Reported methods were investigated from several viewpoints. Considering the conducted study, the lack of distributed ad scalable methods based on meta-heuristic solutions is observed. Also, with regard to the conducted study, one of the issues of multicast routing and channel assignment in multi radio multi-channel WMN is the multi rating problem. On the other hand, in future studied it is necessary to further focus on the methods which solve two sub-problems of multicast tree construction and channel assignment conjointly.

Table. 1. Compare various methods multicast routing and channel assignment in wireless mesh networks

| | Special attribute | | Problem solving ordering | | | Optimization parameters | | | | | | | | | | Problem solving method | | | Management style | | Network structure | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Protocol name** | **Multi sessions( multi sources)** | **Multi rate** | **Conjointly** | **Channel assignment – routing** | **Routing – channel assignment** | **Transmission rate** | **Overhead** | **Bandwidth usage** | **Load balancing** | **Packet lost ratio** | **Channel conflict** | **Overall multicast tree cost** | **Packet delivery ratio** | **End to end delay** | **Throughput** | **Meta- heuristic** | **Heuristic** | **Operation research** | **Decentralized** | **Centralized** | **Multi radios multi channels** | **Single radios multi channels** | **Single radio single channel** |
| **LAMR** | - | - | ✓ | - | - | - | - | - | - | - | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | - | - | ✓ | - | ✓ | - | - |
| **NSGA2** | - | - | - | - | - | - | - | - | - | - | ✓ | ✓ | - | ✓ | - | ✓ | - | ✓ | - | ✓ | ✓ | - | - |
| **LCA,MCM** | - | - | - | - | ✓ | - | - | - | - | - | ✓ | - | - | ✓ | ✓ | - | ✓ | - | | ✓ | ✓ | - | - |
| **NJM,NDM** | - | - | - | - | ✓ | - | - | - | - | - | - | - | - | ✓ | ✓ | - | ✓ | - | - | ✓ | ✓ | - | - |
| **MDMF,PROD** | - | - | - | - | - | ✓ | - | - | - | - | - | - | ✓ | ✓ | ✓ | - | - | ✓ | - | ✓ | - | - | ✓ |
| **GSA,TS** | - | - | ✓ | - | - | - | - | - | - | - | ✓ | ✓ | - | ✓ | - | ✓ | - | - | - | ✓ | ✓ | - | - |
| **CLLO** | - | - | ✓ | - | - | - | - | - | - | - | ✓ | - | - | ✓ | ✓ | - | ✓ | - | - | - | ✓ | - | - |
| **LMTR** | - | - | - | - | - | ✓ | - | - | ✓ | - | - | - | - | ✓ | - | - | ✓ | - | - | - | ✓ | - | - |
| **NOPA** | - | ✓ | - | - | ✓ | - | - | - | - | - | ✓ | - | - | ✓ | ✓ | - | ✓ | - | - | ✓ | ✓ | - | - |
| **CAMF** | - | - | ✓ | - | - | - | - | - | - | - | ✓ | - | - | ✓ | ✓ | - | ✓ | - | ✓ | - | ✓ | - | - |
| **JRCAR** | ✓ | ✓ | - | ✓ | - | - | - | - | - | - | - | - | - | - | ✓ | - | ✓ | - | - | ✓ | ✓ | - | - |
| **MGMR** | - | - | - | - | - | - | - | - | ✓ | - | - | - | ✓ | - | ✓ | ✓ | - | ✓ | - | ✓ | ✓ | - | - |
| **UBMR-CA,UWM** | - | - | - | - | ✓ | - | - | - | - | - | - | - | - | ✓ | ✓ | - | - | ✓ | ✓ | - | ✓ | - | - |
| **MAODV-MR** | ✓ | - | - | ✓ | - | - | - | ✓ | ✓ | - | ✓ | - | - | - | ✓ | - | - | ✓ | ✓ | - | ✓ | - | - |
| **PAMELA** | - | - | ✓ | - | - | - | - | - | - | ✓ | ✓ | - | - | - | - | - | - | ✓ | - | ✓ | ✓ | - | - |
| **G-PAMELA** | - | - | ✓ | - | - | - | - | - | - | ✓ | - | - | - | - | - | - | - | ✓ | - | ✓ | ✓ | - | - |

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