Interference-Aware and Cluster Based Multicast Routing in Multi-Radio Multi-Channel Wireless Mesh Networks

Rasoul Behravesh [a], Mohsen Jahanshahi [b,*]

[a] Faculty of Computer and Information Technology Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran

[b] Department of Computer Engineering, Central Tehran Branch, Islamic Azad University, Tehran, Iran

Abstract

Multicast routing is one of the most important services in Multi Radio Multi Channel (MRMC) Wireless Mesh Networks (WMN). Multicast routing performance in WMNs could be improved by choosing the best routes and the routes that have minimum interference to reach multicast receivers. In this paper we want to address the multicast routing problem for a given channel assignment in WMNs. The channels that are assigned to the network graph are given to the algorithm as an input. To reduce the problem complexity and decrease the problem size, we partition the network to balanced clusters. Fuzzy logic is used as a tool for clustering in our method. After clustering and electing most suitable nodes as cluster head, we take a mathematical method to solve the multicast tree construction problem. We conducted several simulations to verify the performance of our method and the simulation results demonstrated that our proposed method outperforms CAMF algorithm in terms of throughput and end to end delay.

Keywords: Wireless Mesh Networks, Multicast, Multi Radio Multi Channel, Channel assignment.

1. Introduction

Wireless mesh networks (WMN) is a communication network which is mainly used to provide high bandwidth internet access for suburban areas. WMN includes a large set of wireless routers which are stationary and connect in multi-hop manner. In WMNs some routers have higher capability and act as gateway to connect WMN to other external networks such as internet. Mesh routers which are intermediate nodes and relay the traffic between mesh gateways and mesh clients. Mesh clients which are recipient of mesh topology. Since only the gateway nodes can connect to internet with wired lines, the mesh clients use multi-hop wireless communications to access internet through the gateways [1, 2].

Due to high available bandwidth in WMNs, multicast routing is an appealing service which has many attractive applications such as video conferencing, online games, web cast and distance learning. Due to the broadcast nature of the air medium, wireless communications are convenient for performing multicast routing [3]. Wireless interference is the main issue for conducting multicast services in WMNs, which decreases network achievable throughput. Using multiple radios and

---

* Corresponding author. Email: mohsenjahanshahi@gmail.com

multiple channels could decrease network interference to a large extent. In IEEE 802.11b/g, there are eleven available channels among which three channels are orthogonal. It is hard to achieve an interference-free network solely by using limited orthogonal channels (OCs). Channels that have less than five-channel separation are referred to as partially overlapped channels and could be very useful for interference reduction. Efficient utilization of partially overlapping channels allows significant enhancement in parallel transmissions and overall network throughput [4].

IEEE 802.11 standard minimizes the impact of collision and solves the hidden node problem by using Request-to-Send and Clear-To-Send (RTS/CTS) as long as all the nodes are one-hop away from each other. In this study, we assumed collisions were being minimized by 802.11 and we pay attention to the interference. To be more precise, if the source of interfered communication is within a maximum distance of a detectable signal (one hop away) or the distance threshold is, then its interference will be minimized most likely by RTS/CTS. However, if the distance is more than this limit/threshold, the electromagnetic wave reaches the destination as a noise (or in this case as interference) and will interfere with the actual communication. It actually affects the Signal to Interference and Noise Ratio (SINR) and the transmission successful rate [5].

In general, there are three categories for constructing channel-allocated multicast trees aiming at minimizing network interference for multi-radio multi-channel wireless mesh networks: (a) multicast tree is constructed at prior and then assign channels to the tree links. (b) Channel assignment method is determined first for a given network in which a multicast tree is built for a given multicast group. (c) Multicast routing and channel assignment problems takes into consideration jointly. Our approach falls into second category in which we have a channel assigned network topology and we want to find routes to the destinations in way that network interference is minimized and as a consequence the network capacity is maximized.

Designing optimized trees for multicast routing is an essential problem for which a method should be designed. A tree which minimizes the interference has a great impact on delivering data to multicast destinations. Compared to existing channel assignment approaches our contributions for multicast tree construction can be listed as follows:

•Designing a clustering method for wireless mesh networks.

•Designing a mathematical model which solves multicast routing problem.

The rest of the paper is organized as follows: Section 2 surveys the previous related works. The details of the proposed methods are described in Section 3. Section 4 evaluates the performance of our proposed algorithm. Section 5 illustrates the experimental results. Finally, Section 6 concludes the paper.

2.   Related Work

Zeng et al. in [6] proposed a method named Level Channel Assignment (LCA) for constructing multicast tree and channel assignment in wireless mesh networks. In this approach the problem of multicast tree construction and channel assignment are considered as two disjoint sub-problems and solved sequentially. In this algorithm level of each node should be specified at first. Birth First Search algorithm is used for this purpose. Then using bottom-up approach nodes will be joined to multicast tree. When the tree construction phase is completed the channels are assigned to the links using a method named Ascending Channel Assignment. This algorithm has several drawbacks such as: (a) Interference could not be eliminated among same level nodes; (b) The algorithm could not take partially overlapping channels into consideration; (c) In some situation nodes are selected randomly.

Zeng et al. in [6] proposed another method called multi-channel multicast (MCM) to construct a multicast tree and assign channels to the multicast

tree. This algorithm has better performance compared with LCA. This algorithm takes partially overlapping channels into consideration which results in interference reduction. Similar to LCA the nodes are partitioned into levels and the edge between same level nodes will be removed in tree construction phase. Then using a bottom-up manner nodes that have maximum childes will be selected as relay nodes and added to the tree. Authors proposed two approaches for assigning channels to the tree links. This two methods are ascending channel assignment and heuristic channel assignment. Ascending channel assignment, takes a top-down approach to assign channels to radio interfaces. In the second method, the channel that minimizes the sum square of the interference factor between a node and its neighboring relay nodes is assigned to the radio interface. This algorithm has some drawbacks such as: (a) suffers from hidden channel problem; (b) Randomly selection of channels may not reach best result.

As stated MCM suffers from hidden channel problem, authors in [7] proposed a new algorithm named Minimum interference Multi-channel Multi-radio Multicast (M4) that takes one-hop and two-hop neighbors information into consideration to assign more suitable channels to radio interfaces and eliminating hidden channel problem.

Cheng et al. in [8-10] use Genetic Algorithm, Simulated Annealing and Tabu Search to solve joint multicast routing and channel assignment problem for MRMC WMN. The objective function of this algorithm are similar and all of them try to minimize network interference. Binary interference model is used to estimate interference. These algorithms use iterative methods to alter the path from source to a multicast receiver and channels assigned to the links on the path, afterwards the corresponding fitness function is calculated. These algorithms may have some drawbacks as follows: (a) The hidden channel problem still exists in the network; (b) Interference among same level nodes could not be eliminated; (c) Cannot achieve optimal solution.

Proposed work in [11] by Jahanshahi et al. tries to gain optimal solution of the problem using a mathematical model. They consider the problem of the multicast routing and channel assignment as two disjoint problems and take a layered approach to solve them. Authors try to achieve the optimal solution of each sub-problems using binary integer programming. The objective function for tree construction and channel assignment are minimizing total links and total interference, respectively. To name some drawback of the Layered binary integer programming (BIP) we can say that: (a) Layered BIP cannot achieve optimal solution for the problem; (b) It does not exploit wireless broadcast advantage; (c) Layered BIP treats multicast communication in the same way as unicast communication; (d) This algorithm takes a long time to solve the problem for large scale networks.

The same authors [3] applied the same approach to jointly solve multicast routing and channel assignment in multi-radio multi-channel WMNs. in the second approach of BIP they take a cross-layer strategy in which the interaction between the sub-problems is taken into account. Therefore it conquers the limitations of current sequential multicast routing and channel assignment schemes. The objective is to minimize total number of links together with overall interference. (a) Cross-layer BIP does not exploit wireless broadcast advantage (WBA); (b) Furthermore, BIP is complex and the process to solve BIP is time-consuming, especially in large-scale networks.

Jahanshahi et al. in [12] suggested a Learning Automata based Multicast Routing protocol to solve the problem of joint multicast routing and channel assignment for multi-radio multi-channel WMNs. The operation of LAMR for each radios interface is composed of two steps: in the first step, a multicast tree with minimum end-to-end delay is constructed, which is carried out through sending out routing request and reply messages, channels are selected based on action probability vector. In the second step, the source node sends out routing request messages again along the paths constructed in the first step.

Then, channels are changed and the overall tree contention of the newly constructed tree is computed. If its value is smaller, the newly constructed multicast tree is formed. A stable multicast tree is derived after a few runs.

Authors in [13] considered multiple factors such as path forwarding weight, distance, contention window size, and receiver mobility to design an algorithm for multi-radio multi-channel wireless mesh networks. This algorithm is distributed and they called it Channel Assignment with Multiple Factor (CAMF). Authors assume that multicast tree is specified at prior and just take the channel assignment into consideration. This algorithm uses a parameter named forwarding weight to prioritize nodes in channel assignment phase. After channel assignment, the introduced interference among tree nodes could be further decreased by adjusting contention window size. Also this algorithm could support node mobility. CAMF performs channel assignment with determined multicast tree, so its performance depends on the given multicast tree structure. Therefore, only suboptimal solution can be achieved.

3. Proposed Approach

In this section, we will present our method for cluster based interference-aware multicast routing in wireless mesh networks. At First, we use fuzzy inference system to clustering the network and decreasing network size. Then using a mathematical model and keeping in mind that assigned channels to the network graph are known at prior, we solve the multicast routing problem. What follows is a description of the proposed approach in detail.

3.1. Clustering Using Fuzzy Inference System (FIS)

In this paper, we use three fuzzy inference system variables to cluster head election in wireless mesh networks: available bandwidth, number of one-hop neighbors, and distance to the gateway. It is assumed that gateway or multicast source has a complete knowledge about the network topology. Also we assume that nodes are fixed and their position will not change. In the proposed method, network nodes are partitioned into balanced clusters then using fuzzy inference system a cluster head will be chosen for two adjacent clusters and clusters are overlap.

3.2. Expert Knowledge Representation

Expert knowledge is represented based on the following three descriptors:

• Available Bandwidth: the maximum achievable bandwidth for a node.

• Number of one-hop neighbors: set of nodes that have a direct link to.

• Distance to Gateway: Euclidian distance to the network gateway or multicast source.

Table. 1. Fuzzy Rule Base

NO	Bandwidth	Neighbors	Distance-to-GW	CH-Chance
1	Low	Low	Close	Low
2	Low	Low	Medium	Very-Small
3	Low	Low	Far	Very-Small
4	Low	Medium	Close	Medium
5	Low	Medium	Medium	Small
6	Low	Medium	Far	Very-Small
7	Low	High	Close	Medium
8	Low	High	Medium	Medium
9	Low	High	Far	Small
10	Medium	Low	Close	Medium
11	Medium	Low	Medium	Medium
12	Medium	Low	Far	Small
13	Medium	Medium	Close	Large
14	Medium	Medium	Medium	Large
15	Medium	Medium	Far	Small
16	Medium	High	Close	Large
17	Medium	High	Medium	Medium
18	Medium	High	Far	Medium
19	High	Low	Close	Large
20	High	Low	Medium	Medium
21	High	Low	Far	Small
22	High	Medium	Close	Very-Large
23	High	Medium	Medium	Large
24	High	Medium	Far	Medium
25	High	High	Close	Very-Large
26	High	High	Medium	Medium
27	High	High	Far	Small

The linguistic variables used to represent the available bandwidth and the number of one-hop neighbors is divided into three levels: low, medium, and high, respectively. There are three levels to represent the distance to gateway variable: close, medium and far, respectively. The outcome to represent the node cluster head election chance was divided into 5 levels: very-small, small, medium, large, and very-large. We used triangle membership functions to represent the fuzzy sets. The membership functions developed and their corresponding linguistic states are represented in Table 1 and Figures 1 through 4. All the nodes are compared on the basis of chances and the node with the maximum chance is then elected as the cluster-head.

Fig. 1. Available bandwidth membership function
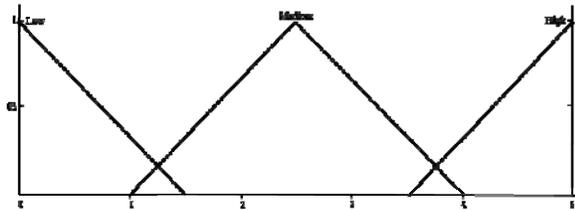
Fig. 2. Number of one-hop neighbor membership function
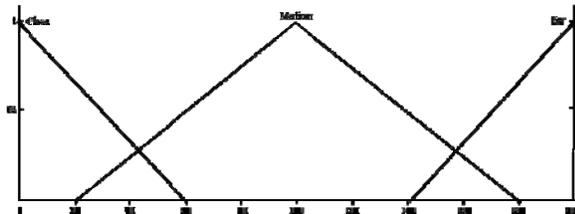
Fig. 3. Distance to the gateway membership function
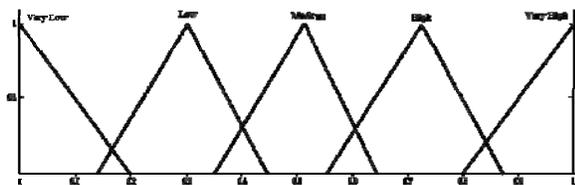
Fig. 4. Cluster head election chance membership function

3.3. Notations and Model Assumptions

In this method we assume that all mesh routers are distributed randomly on a specific area. Each router is equipped with multiple radio interfaces all of which use Omni-directional antennas, and have identical transmission and interference range. The method uses IEEE 802.11b standard with eleven available channels among which three channels are orthogonal.

3.4. Problem Formulation

In this subsection, the predefined sets, parameters, variables and constraints needed for our mathematical formulation will be presented. The required set definition and parameters are listed in table 2.

Table. 2. Sets and parameters

$G = (V, E)$	Network graph
R_T	Transmission range
$N = \{N_1, N_2, \ldots, N_n\}$	Nodes in the network
$MS = \{MS_i\} \; MS_i \in N$	Multicast source
$Radio = \{R1, R2, R3\}$	Set of radio interfaces for each node
$MR = \{MR_1, MR_2, \ldots, MR_p\}$ $MR_i \in N$	Multicast receivers set
$C = \{C_1, C_2, \ldots, C_c\}$	Set of clusters in the network
$CH = \{CH_{12}, CH_{13}, \ldots, CH_{qr}\}$ $CH_{jk} \in N, j \neq k$	Set of cluster heads
$R(Src)$	Radio interface of node Src
$Ph - Dist_{(C_i, Src, Des)}$ $Src, Des \in N$	Euclidian distance between to nodes.
$Ch(L(C_i, Src, SR, Des, DR))$	The channel that has been used by link L(Src, SR, Des, DR)
$C(N_i) \quad N_i \in N$	Cluster of node N_i
$CH(C_i) \quad C_i \in C$	Cluster head of C_i
$MR(C_i) \quad C_i \in C$	Multicast receivers of C_i
$EB(C_i, Src, Des)$	Effective bandwidth between two nodes.

Table. 3. Interference factor [6]

CS Rates	I_0	I_1	I_2	I_3	I_4	$I_{\geq 5}$
2M	2R	1.125R	0.75R	0.375R	0.125R	0
5.5M	2R	R	0.625R	0.375R	0.125R	0
11M	2R	R	0.5R	0.375R	0.125R	0

What follows describes the variables and constraints of the problem in detail.

3.4.1. Variables

First of all we need a variable to determine whether there is a link between two nodes or not. For this purpose we define $L(C_i, Src, SR, Des, DR)$ variable. The value of $L(C_i, Src, SR, Des, DR)$ is equal to 1 if there is a link between Src and Des, otherwise it is equal to zero. We define two non-zero variables to count the number of incoming and outgoing links from a node.

$$In - L_{(C_i,Src)} = \sum_{SR}\sum_{TR}\sum_{T} L_{(C_i,T,TR,Src,SR)}$$

$$C_i \in C \;;\; Src, T \in N \;;\; SR, TR \in Radios \tag{1}$$

$$Out - L_{(C_i,Src)} = \sum_{SR}\sum_{TR}\sum_{T} L_{(C_i,Src,SR,T,TR)}$$

$$C_i \in C \;;\; Src, T \in N \;;\; SR, TR \in Radios \tag{2}$$

Experimental results in [14] shows that when a link does not have any competing links and can send data at all times, its maximum throughput is smaller than its maximum bit rate. For example, a link with 11Mbps transmission rate achieves at most about 7 Mbps of throughput. Maximum achievable capacity of a link could be computed using equation (3).

$$C_{ij} = \frac{1}{\sum_{(u,v)\in CS_{ij}} 1/b_{uv}} \tag{3}$$

C_{ij} in the above equation is the maximum achievable throughput of the link between (u, v). Also CS_{ij} includes all links that are in interference range of (i, j) and compete with the link (i, j) to acquire a channel. b_{uv} is the effective bandwidth of the link (u, v) when there is no interfering links and transmits alone.

Considering the above definitions, $LC(C_i, Src, SR, Des, DR)$ is the another variable which computes the link capacity.

$$(C_i, Src, SR, Des, DR)$$
$$= \frac{1}{\left(\begin{array}{c} \sum_{T2}\sum_{TR2}\sum_{T1}\sum_{TR1} [PIN_{(Src,Des,T1,T2)} \times L(C_i,Src,SR,Des,DR) \\ \times isGreater(IF(Ch(L(C_i,Src,SR,Des,DR)), Ch(L(C_i,T1,TR1,T2,TR2)) \\ , Link\_Dist_{(Src,Des,T1,T2)})] \\ / EB(C_i,T1,T2) \\ + \frac{1}{EB(C_i,Src,Des)} \end{array}\right)} \tag{4}$$

$$C_i \in C \;;\; Src, Des, T1, T2 \in N \;;\; SR, DR, TR1, TR2 \in Radio$$

In the above equation, Link-Dist $_{(Src, Des, T1, T2)}$ is a variable to compute the distance between two links. Link distance equals to minimum distance between the nodes of two links.

$$Link - Dist_{(Src,Des,T1,T2)} =$$
$$min(Ph - Dis_{(Src,T1)}, Ph - Dis_{(Src,T2)}, Ph - Dis_{(Des,T1)}, Ph - Dis_{(Des,T2)}) \tag{5}$$
$$Src, Des, T1, T2 \in N$$

$Ph - Dis_{(Src,T1)}$ is a parameter which computes the physical distance between two nodes. In this equation we want to compute the minimum distance between the nodes of two links.

$$IF(Ch(LC(C_i, Src, SR, Des, DR)), Ch(LC(C_i, T1, TR1, T2, TR2))$$

Is another variable based on channel separation of two links, computes the interference factor from table 3. The R parameter in the table is stand for transmission range which is 250 meter in our model.

Finally, we need a variable to compute maximum achievable capacity for each cluster. We use a variable called $ClusterCapacity(C_i)$ which computes capacity for all links of a given cluster.

$$ClusterCapacity(C_i) = \sum_{Des}\sum_{DR}\sum_{Src}\sum_{SR} L(C_i, Src, SR, Des, DR) \tag{6}$$
$$C_i$$

3.4.2. Constraints

Here we define constraints that our proposed model should satisfy. First we define objective function of the problem that is maximizing network capacity.

$$Objective\ Function = Maximize(ClusterCapacity(C_i)) \tag{7}$$

Based on the tree definition, number of incoming links to an ordinary node should be equal or smaller than one. The following equation implies that number of input links to an ordinary node should be zero or one.

$$In - L_{(C_i,Src)} \leq 1$$
$$\forall Src \in N\backslash(MS, MR, CH) \;;\; \forall C_i \in C \tag{8}$$

As shown in the following equation, number of outgoing links from multicast source and cluster heads should be equal or greater than one. This

constraint implies that multicast source should have output links and a cluster head should have output link when it has an incoming link.

$$OL_{(C_i, Src)} \geq 1$$

$$\forall Src \in (MS \cup CH) \, ; \, \forall C_i \in C \tag{9}$$

Following equation illustrates that in each cluster, number of outgoing links from multicast source or cluster head should be at most equal to number of multicast receivers and cluster heads of that cluster. To prevent from extra routes within a cluster, number of outgoing links from multicast source or cluster head should not exceeds number of receivers.

$$OL_{(C_i, Src)} \leq |CH(C_i)| + |MR(C_i)|$$

$$\forall Src \in (MS \cup CH) \, ; \, \forall C_i \in C \tag{10}$$

It is clear that if a node has an incoming link, number of its outgoing links are smaller than number of radio interfaces.

$$OL_{(C_i, Src)} \leq |R(Src)|$$

$$\forall Src \in N \backslash MS \, ; \, \forall C_i \in C \tag{11}$$

Based on the tree definition, the root node has no incoming link. As a result, number of incoming links to multicast source is zero. Also the other equation implies that number of incoming links to a multicast receiver and cluster head should be equal to one. Using the stated constraints it could be proven that all multicast receivers are covered.

$$IL_{(C_i, Src)} = 0$$

$$\forall Src \in MS \, ; \, \forall C_i \in C \tag{12}$$

$$IL_{(C_i, Src)} = 1$$

$$\forall Src \in (MR \cup CH) \, ; \, \forall C_i \in C \tag{13}$$

In MRMC WMNs, each radio interface should be used at most once whether for transmitting or receiving.

$$\sum_{Des}\sum_{DR} L\,(C_i, Src, SR, Des, DR) + \sum_{Des}\sum_{DR} L\,(C_i, Des, DR, Src, Src) \leq 1$$

$$\forall C_i \in C \, ; \, \forall Src, Des \in N \, ; \, \forall SR, DR \tag{14}$$

To have a link between two nodes they should be within transmission range of each other.

$$L\,(C_i, T1, TR1, T2, TR2) \times Ph\_Dist_{(Src, Des)}$$
$$\leq L\,(C_i, T1, TR1, T2, TR2) \times R_T \tag{15}$$

$$\forall C_i \in C \, ; \, \forall Src, Des \in N \, ; \, \forall SR, DR$$

Finally, to have a link between two nodes, they should belong to the same cluster.

$$L\,(C_i, T1, TR1, T2, TR2) \times C(Src) = L\,(C_i, T1, TR1, T2, TR2) \times C(Des)$$

$$\forall C_i \in C \, ; \, \forall Src, Des \in N \, ; \, \forall SR, DR \tag{16}$$

As you saw, all variables and constraints for multicast routing in MRMC WMN are presented. The main problem of the proposed method is the time complexity.

4. Performance Evaluation

In this section, aiming at evaluating performance of the proposed work, the simulation results will be presented. We use GAMS optimization software to solve our mathematical model and then we use OPNET Modeller [15] to simulate our network. We have conducted several simulations for proving effectiveness of our proposed algorithm. We use the following metrics to measure the performance of our proposed work.

4.1. Average end-to-end Delay

End-to-end delay is defined as the average time elapsed between sending the packets by the multicast source and receiving at all the multicast receivers.

4.2. Average Throughput

Throughput is defined as the number of packets received by the receiver over the required time to deliver this number of packets averaged on all multicast receivers.

4.3. Average Packet Delivery Ratio

The packet delivery ratio (PDR) of a receiver is the number of data packets actually delivered to the receiver versus the number of data packets supposed to be received. The average PDR of a multicast group

is the average of the PDRs of all the receivers in the group.

Our simulations are based on IEEE 802.11b CSMA/CA medium access control because this is a widely accepted radio technique for WMNs. each mesh router has two radios. There are 11 available channels and transmission power is 20dB and it is fixed for all nodes. Transmission and interference range are 250 and 500 meters, respectively.

5. Experimental Results

At first, we want to evaluate our proposed approach in terms of end-to-end delay for a network with varying nodes. It is expected that our proposed method has a better performance against the CAMF algorithm, because it tries to choose the links with minimum interference. So if the interference is minimized then end-to-end delay will be minimized as so. Also our method computes the interference caused by partially overlapping channels. Figures 5, 6, and 7 show the obtained results for end-to-end delay.

Now we want to compare our proposed algorithm to others in term of throughput. In this series of experiments, we want to evaluate the performance of our proposed algorithm in terms of throughput. The number of nodes varies from 10 to 30 nodes. Figures 8, 9, and 10 shows that our proposed method can reduce network interference and increase throughput due to choosing least interfered nodes in the mesh topology.
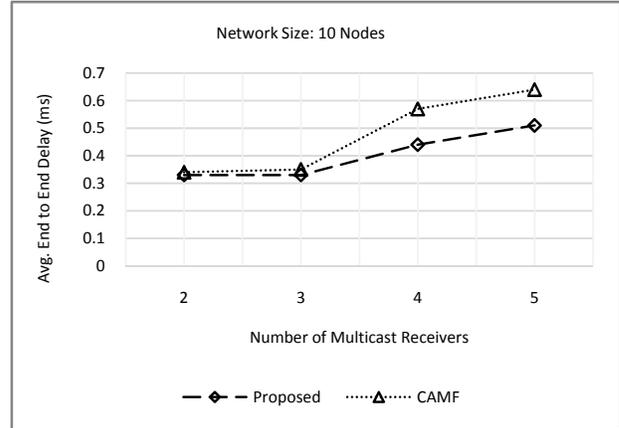

Fig. 5. Average end to end delay for a network with 10 nodes and different number of multicast receivers
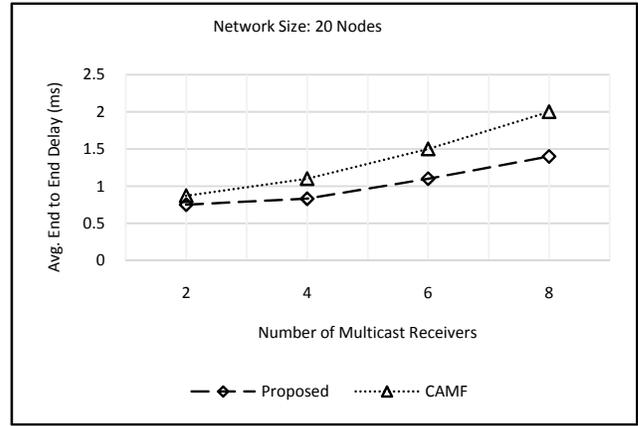
Fig. 6. Average end to end delay for a network with 20 nodes and different number of multicast receivers
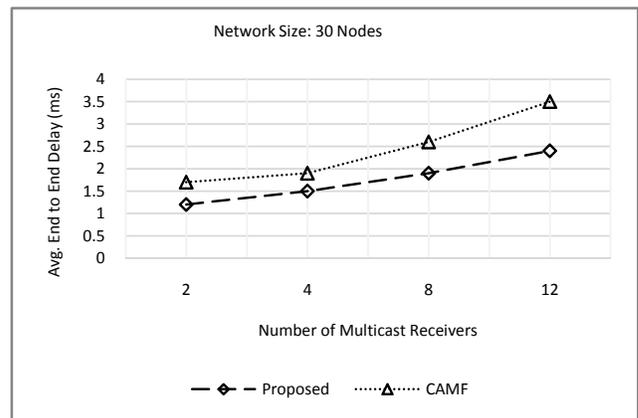

Fig. 7. Average end to end delay for a network with 30 nodes and different number of multicast receivers
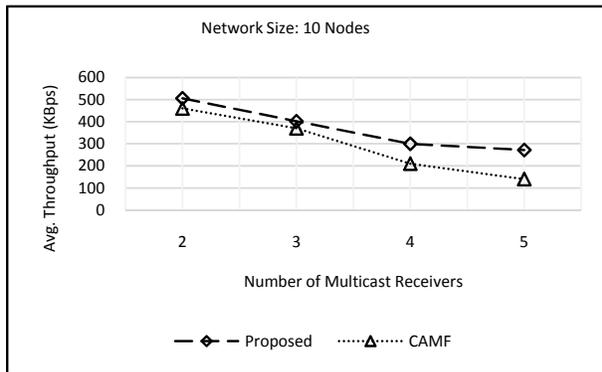
Fig. 8. Average throughput for a network with 10 nodes and different number of multicast receivers
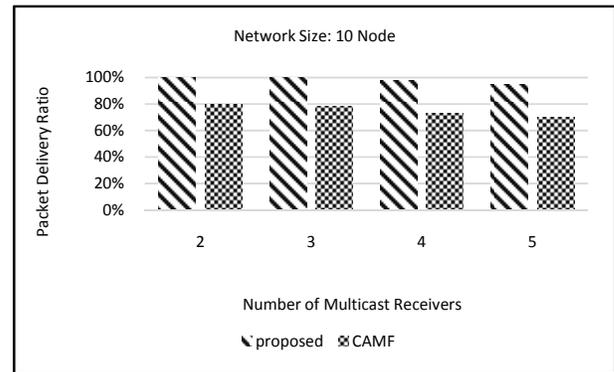

Fig. 11. Packet delivery ratio for a network with 10 nodes and different number of multicast receivers
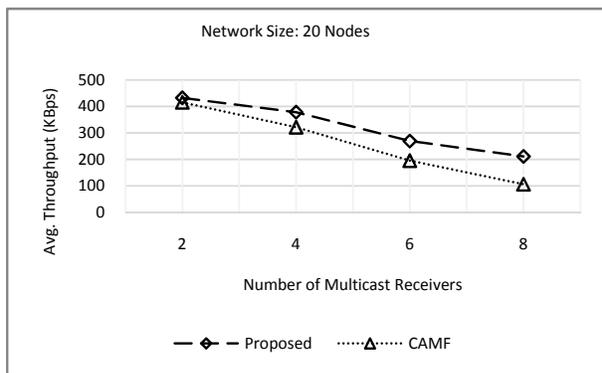
Fig. 9. Average throughput for a network with 20 nodes and different number of multicast receivers
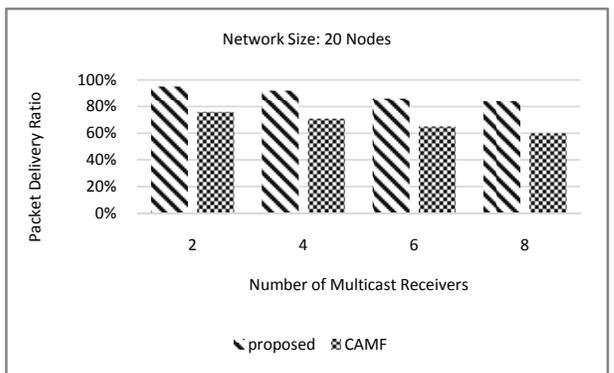
Fig. 12. Packet delivery ratio for a network with 20 nodes and different number of multicast receivers
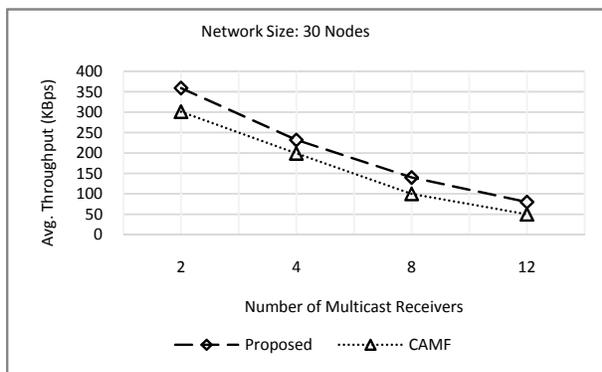
Fig. 10. Average throughput for a network with 30 nodes and different number of multicast receivers
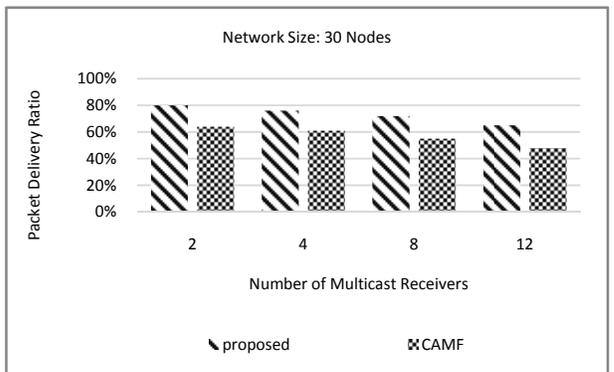
Fig. 13. Packet delivery ratio for a network with 30 nodes and different number of multicast receivers

At the end, we want to evaluate our proposed method against CAMF algorithm in term of packet delivery ratio. Like other experiment, the number of multicast nodes varies from 10 to 30 nodes. Figures 11, 12, and 13 present the results of evaluating our proposed method against CAMF algorithm. The results show the superiority of our proposed algorithm.

6.   Conclusion

Interference-aware multicast routing is a problem in which based on already determined channels, a multicast tree should be create that interference among links of the tree is minimized. In this paper, we addressed the problem of cluster based interference-aware multicast routing in MRMC WMNs. Also the impact of using partially overlapping channels to choose the routes with smaller interference is taken into consideration. Simulation results show that the proposed algorithm could achieve better performance compared with CAMF algorithm in terms of average end to end delay and average throughput.

References

[1]   Si, W.; Selvakennedy, S.; Zomaya, A. Y., "An overview of channel assignment methods for multi-radio multi-channel wireless mesh networks," Journal of Parallel and Distributed Computing, vol. 70, pp: 505-524, (2010).

[2]   Akyildiz, I. F.; Wang, X.; Wang, W., "Wireless mesh networks: a survey," Computer networks, vol. 47, pp: 445-487, (2005).

[3]   Jahanshahi, M.; Dehghan, M.; Meybodi, M. R., "A mathematical formulation for joint channel assignment and multicast routing in multi-channel multi-radio wireless mesh networks," Journal of Network and Computer Applications, vol. 34, pp: 1869-1882, (2011).

[4]   Feng, Z.; Yang, Y., "How much improvement can we get from partially overlapped channels?," in Wireless Communications and Networking Conference, 2008. WCNC 2008. IEEE, pp: 2957-2962 (2008).

[5]   Yang, W. L.; Hong, W. T., "A cross-layer optimization for maximum-revenue-based multicast in multichannel multiradio wireless mesh networks," International Journal of Communication Systems, vol. 27, pp: 3204-3222, (2014).

[6]   Zeng, G.; Wang, B.; Ding, Y.; Xiao, L.; Mutka, M., "Multicast algorithms for multi-channel wireless mesh networks," in Network Protocols, 2007. ICNP 2007. IEEE International Conference on, pp: 1-10 (2007).

[7]   Hoang Lan, N.; Uyen Trang, N., "Channel assignment for multicast in multi-channel multi-radio wireless mesh networks," Wireless Communications and Mobile Computing, vol. 9, pp: 557-571, (2009).

[8]   Cheng, H.; Yang, S., "A genetic-inspired joint multicast routing and channel assignment algorithm in wireless mesh networks," (2008).

[9]   Cheng, H.; Yang, S., "Joint multicast routing and channel assignment in multiradio multichannel wireless mesh networks using simulated annealing," in Simulated evolution and learning, ed Berlin Heidelberg: Springer, pp: 370-380 (2008).

[10] Cheng, H.; Yang, S., "Joint multicast routing and channel assignment in multiradio multichannel wireless mesh networks using tabu search," in Natural Computation, 2009. ICNC'09. Fifth International Conference on, pp: 325-330 (2009).

[11] Jahanshahi, M.; Dehghan, M.; Meybodi, M. R., "On channel assignment and multicast routing in multi-channel multi-radio wireless mesh networks," International Journal of Ad Hoc and Ubiquitous Comuputing, vol. 12, pp: 225-244, (2011).

[12] Jahanshahi, M.; Dehghan, M.; Meybodi, M. R., "LAMR: learning automata based multicast routing protocol for multi-channel multi-radio wireless mesh networks," Applied intelligence, vol. 38, pp: 58-77, (2013).

[13] Lin, J.W.; Lin, S.M., "A weight-aware channel assignment algorithm for mobile multicast in wireless mesh networks," Journal of Systems and Software, vol. 94, pp: 98-107, (2014).

[14] Lin, K. C.J.; Chou, C.f., "Exploiting multiple rates to maximize the throughput of wireless mesh networks," Wireless Communications, IEEE Transactions on, vol. 8, pp: 6038-6049, (2009).

[15] Modeler, O., "OPNET Technologies Inc," ed, (2009).