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A New Method based on Intelligent Water Drops for Multicast Routing in Wireless Mesh Networks

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Abstract. In recent years a new type of wireless networks named wireless mesh networks has drawn the attention of researchers. In order to increase the capacity of mesh network, nodes are equipped with multiple radios tuned on multiple channels emerging multi radio multi channel wireless mesh networks. Therefore, the main challenge of these networks is how to properly assign the channels to the radios. On the other hand, multicast routing makes the delivery of the same content possible from one source to several destinations. For example, video conferencing and distant learning are some applications of multicast routing. The problem of multicast routing coupled with channel assignment is known as an NP hard problem, and hence operation research based methods are not scalable. Most of existing heuristic methods for this problem solve two aforementioned sub-problems in sequence. In this paper, the aim is to propose a new method based on intelligent water drops that solve sub-problem channel assignment in conjunction with multicast routing. Simulation results demonstrate the improvement of throughput, end to end delay, and packet delivery ratio compared to CLLO, CAMF, and LC-MRMC.

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Keywords: Wireless mesh networks; Multicast routing; Channel assignment; multi radio multi channel; Intelligent water drops.

1. Introduction

The most important application of wireless mesh networks (WMN) is to access broadband Internet [1]. WMN is a metropolitan area network and can be used to access the networks in universities and 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 [7, 8] leading to the improvement of throughput.

One of the main issues in WMN deployment is multicast routing. Multicast routing propose a method of communication between multiple nodes transmitting data from a

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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 solution is 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. 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.

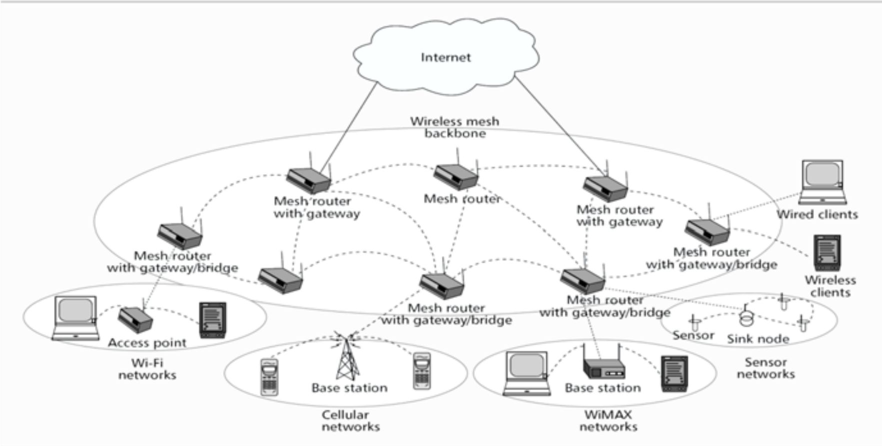


Figure 1. Multi radio Multi channel WMN architecture [19].

The rest of this paper is organized as follows: section 2 includes related works. Section 3 introduces the intelligent water drops technique. The proposed method based on intelligent water drops is elaborated in section 4. Section 5 discusses the evaluation of the proposed method efficiency compared to CLLO, CAMF, and LC-MRMC. Section 6 concludes the paper.

2. Related works

In [3], an approach for channel assignment and routing is given in which the channel assignment problem has been divided into two phases; connecting neighbor to interface and interface to the channel. For connecting a neighbor 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 greedy algorithm, the first minimum-load channel is assigned to the first unassigned-channel link [9]. In [18], considering multi radio multi channel advantages two methods of PLT and ART have been presented. Also, to increase the coverage area and achieving high throughput an algorithm for constructing multicast tree named LC-MRMC 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 R^5 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. Ref. [14] does not discuss multicast tree construction and instead uses the Steiner tree algorithms to create a minimal cost multicast tree. In this reference a heuristic channel assignment algorithm named NOPA 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. The algorithm is priority-aware and allows the multicast trees with higher priority less interfered [5]. The authors proposed a method named CAMF 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 mobilities 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. Ref. [9], proposes a down-top de-centralized approach to construct a multicast tree and to assign the radio channel. 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. Ref. [9] introduces another method named MCM, in which the nodes of tree are placed at different levels using BFS. The minimum number of RNs constituting the multicast tree is determined using a heuristic algorithm. After the construction of multicast tree, two methods of channel assignment are presented in [4, 9]. The first method called "Ascending Channel Assignment" (ACA) and the second one is "Heuristic Channel Assignment" (HCA). Furthermore, an optimization problem in [10, 11, and 12] was presented in which the problem is 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. In [15], 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. Here, the idea is to access a balanced-load network for higher quality of services in SRSC WMNs. In [16], an algorithm named multi-gateway multi-rate (MGMR) multicast routing is presented to maximize all the data rates obtained by receivers properly. In Ref [17], the approach of multi-objective optimization based on NSGA-II has been used to solve the problems of channel assignment and multi-radio multi-channel multicast routing.

3. Introducing the intelligent water drop algorithm

The intelligent Water Drop algorithm (IWD) uses a graph G (N, E). This graph models the behaviour of the intelligent water drops. The drops are transmitted over the graph links. Each drop moves on the nodes and gradually builds its proposed solution which is named T_{IWD}. Each T_{IWD} is represented by constructive links of the IWD traversed route. When all the drops build their own solutions, an iteration of the algorithm is finished. After the completion of each iteration the best solution of each iteration (T^{IB}) is determined according to a quality function over all the solutions obtained from all drops in current iteration. T^{IB} is employed to update the total best solution (T^{TB}). This solution is the best one from the beginning of algorithm up to current time. Also, at the end of iteration the amount of soil in the hops forming T^{IB}, decreases according to equation (1).

$$soil(i,j) = (1 + P_{IWD})soil(i.j) - p_{IWD} \frac{1}{(N_{IB}-1)} soil^{IWD} \quad \forall (i,j) \in T^{IB} \tag{1}$$

The parameter $soil_{IB}^{IWD}$ represents the amount of the soil building the T^{IB} corresponding solution. In addition, N^{IB} represents the number of available nodes in the best path. At the end of current iteration, another iteration using new drops and the same amount of soil is initiated over the graph paths and the algorithm is repeated again. The algorithm stops either the iteration reaches its maximum value, $Iter_{max}$, or T^{TB} obtains the expected quality extent.

In each iteration, drops move from the current location i to another location j. The velocity of drops in time t is updated to the amount of soil by equation (2),

$$\Delta \mathrm{Velocity}^{\mathrm{IWD}}\ (\mathrm{t}) = \frac{a_v}{b_v + c_v.\,\mathrm{soil}^{2\alpha}(i,j)} \tag{2}$$

where a_v, b_v, c_v and α are positive values have to be chosen by the designer. By varying the soil amount between two locations i and j by water drops, this soil is added to the soil which is available in the drop. This increase is inversely proportional to the time needed for moving drop between two locations i and j as indicated in equation (3).

$$\Delta \mathrm{soil(IWD)} = \Delta \mathrm{soil}(i,j) \propto \frac{1}{\mathrm{time}(i,j{:}\,\mathrm{IWD})} \tag{3}$$

where Ẋsoil(i,j) is obtained using equation (4).

$$\Delta \mathrm{soil}(i,j) = \frac{a_s}{b_s + c_s.\,\mathrm{time}^{2\theta}(i,j{:}\,\mathrm{IWD})} \tag{4}$$

On the other hand, the time interval needed for drop movement between two locations i and j, follows the physics movement rule and is proportional to the velocity of drop between i and j as in the equation (5).

$$time(i,j;IWD) \propto \frac{HUD(i,j)}{velocity^{(IWD)}} \tag{5}$$

The HUD parameter in equation (5) represents undesirability of the drop to the movement between i and j. The updated soil of this hop is denoted by soil(i,j) that is related to the soil removed by the drops traversed the path using equation (6).

$$soil(i,j) = (1-\rho_n)soil(i,j) - \rho_n\ \Delta soil(i,j) \tag{6}$$

The soil amount of a drop is denoted by $soil^{IWD}$ and depends on ∆soil(i,j) through the equation(7).

$$soil^{IWD} = soil^{IWD} + \Delta soil(i,j) \tag{7}$$

In order to choose a hop by an intelligent drop, a uniform random distribution function has been used. The probability of the drop movement from i to j is given by equation (8).

$$P(i,j;iwd) = \frac{f(soil(i,j))}{\sum_{k \notin vc(IWD)} \frac{1}{\varepsilon_s + g(soil(i,j))}} \tag{8}$$

The g function is also calculated according to the equation (9).

$$g\big(soil(i,j)\big) = \begin{cases} soil(i,j) & if \quad \min(soil(i,.)) \geq 0 \\ soil(i,j) - \min(soil(i,.)) & else \end{cases} \tag{9}$$

4. Network model and representing proposed method

In this research the WMN is mapped to a graph G(V,E) in which V is the set of wireless mesh routers among which E represents the set of communications. If two nodes i and j are located in the transmission range of each other and each one is equipped with a radio tuned on a common radio, a link may be established between those. In this case nodes i and j are considered one-hop neighbor nodes. Due to broadcast nature of wireless media, the transmission over a communication link between a pair of wireless nodes may interfere with the transmissions of other communications in neighborhood. The interference model determines the amount of interference of communications created in the network. The binary interference model is not capable of showing the actual interference. That is why a more real model is used to obtain the amount of interference. For example, when two transmissions are using the same channel (i.e. their channel separation is zero) they will interfere as long as their physical distance does not exceed the interference range (2R). Also, when two transmissions are using orthogonal channels that is, their inter-channel distance is greater than 5, without considering the physical distance; they can send and receive simultaneously without interference. The distance between two links is defined as the minimum distance between their nodes. For instance, the distance between two links (i,j) and (u,v) is defined as follows:

$$\text{distance}\big((i,j),(u,v)\big) = \min\{d(i,u), d(i,v), d(j,u), d(j,v)\} \tag{10}$$

In this study, the IEEE 802.11b standard has been used in which, 11 channels are available. Among which, three channels are orthogonal. The channels spaced by 5 or more are considered orthogonal. It means without consideration of physical distance no interference exists. In addition, in this standard assuming the constant transmitting power, each radio can transmit over rates {11Mbps, 5.5Mbps, 2Mbps, 1Mbps} by modifying modulation method. If two links are in the interference range of each other and their inter-channel distance is less than 5, they will interfere. The researches indicate the interference between two links also depends on the transmission rate between those. For instance, having the transmission rate and inter-channel distance of two links, their interference range can be calculated. In this research the results of investigations conducted in [9] listed in Table (1) will be used.

Table 1. The relation among the inter-channel distance, transmission rate and communication distance in IEEE 802.11b [9].

Interference / Bit rate	CS_0	CS_1	CS_2	CS_3	CS_4	$CS_{\geq 5}$
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**

Here, the assumption is that one node in the WMN is able to dynamically adjust its multicast transmission rate. Channel assignment in multi-rate WMNs plays vital role in decreasing interference followed by reducing delay and increasing throughput. In the proposed model based upon the intelligent water drop algorithm, each drop is considered equivalent to a packet. In this algorithm the velocity of drop per hop is varied with respect to the soil amount that is considered equal to bit rate in the proposed algorithm. Here, for each router two sets of network cards named UP-NIC and Down-NIC are considered. Each card can be tuned on one of the eleven channels based on IEEE 802.11 b standard. In the proposed method a customized packet according to the figure 2 is defined. As shown, this packet contains a field named Packet type identifying packet type (Control/ Data). In addition, in this packet two lists are defined namely ID_List and Channel_ List. The expected packet is defined for every drop.

Packet Type	Source ID	Destination ID	ID_List					Channel_List				

Figure 2. Customized Packet defined in the proposed method

In each iteration of the algorithm, c drops of each Down-NIC of the multicast source node are transmitted. In order to transmission from node i to j, each drop uses HUD (i, j) function for selecting the channel.

$$\mathrm{HUD(i,j)} = \underset{c^*}{arg\ max} \sum channel\_sepration(l_c(m,n), l_{c^*}(i,j)) \quad (11)$$

In equation (11), the nodes m and n are placed at two-hop neighborhood of nodes i and j. The channel assigned to theses nodes is called C. Each packet sent from parent's Down-NIC in a specific channel is received by corresponding UP-NIC in the one-hop child node and in the specified channel by parent node. That is each node receiving a drop in its UP-NIC has to transmit the received drop with the corresponding DOWN-NIC. In this way, the packets are transmitted over the network to reach a receiver. By receiving each drop by the receiver r, MulticastRicevere_UPNIC routine is called. In this routine the receiver r, sets the value of its flag at received and then calls Iteration_termination function in the multicast source node. It is noteworthy that each receiver r, notices only the first drop and discards the next received drops since the first drop reaches the receiver r, possesses the minimum delay and interference. The Iteration_termination function will call Tree_Quality function if it receives the message from all the receivers. In this function, the tree resulting from the existing iteration (T^{IB}) is compared to the best tree (T^{TB}) throughout the execution of the algorithm up to present. If the tree resulting from the existing iteration is better than the best existing tree, this will be considered as the best tree. For the evaluation of the resulting tree, two metrics named channel difference and delay exists in the formed communications are used according to equations (12) and (13). It is noticeable that the variables

Channel_speration and delay can be calculated using ID_List and Channel List of the customized packet.

$$\mathrm{cs}=\sum_{l(i,j)\in GeneratedMulticastTree} channel\_sepration \;\; l(i,j) \quad (12)$$

$$d=\sum_{l(i,j)\in GeneratedMulticastTree} delay \quad l(i,j) \tag{13}$$

This algorithm repeats until after t iteration, no considerable change in the quality of resulting tree is observed. In what follows, the psudocode for each of these algorithms is given:

```
MulticastRicevere_UPNIC(source,r,*IWD)                                    //
IWD is packet
  {
     if (MulticastRicevere[r].falg== received)
          {
           discard(IWD);
           exit();
          }
    else
       {
            MulticastReceiver[r].flag=received;
            Iteration_termination (source, *IWD);
       }
}
```

Algorithm1. The function handling the receive of packet in multicast receiver

```
Iteration_termination (source, *IWD)
{
For (r=0; i≤MulticastRecieverNumber; i++)
       if (MulticastReceiver[r].flag!=received)
            exit ();
       else
         {
        construct overall MulticastTree MT using IWDs' ID_List
        and Channel_List
       if Tree_Quality (MT) ≥ Tree_Quality (PMT);
          {
           PMT= MT;   // PMT (previous multicast tree)   is
           initiated randomly
          Update capacities of the links forming MT;
          }
         }
}
```

Algorithm2. The function handling the receive of packet in multicast source

Tree_Quality (MT)
{
cs=
$\sum_{l(i,j)\in GeneratedMulticastTree} channel\_sepration \quad l(i,j)$
//Compute cs using IWD.Channel_List and IWD.ID_List
d=$\sum_{l(i,j)\in GeneratedMulticastTree} delay \quad l(i,j)$ // Compute d using IWD. Channel_List and IWD. ID_List
Return ($\frac{cs}{d}$);
}

Algorithm3. The function handling the evaluation of the resulting tree

HUD(i,j)
{
Return
($\underset{c^*}{arg\ max}$ $\sum channel\_sepration(l_c(m,n), l_{c^*}(i,j))$
// *m* and *n* are two-hop neighbors if nodes *i* and *j*, and *c* denotes their already assigned channels
}

Algorithm4. The heuristic function of channel selection per hop by a drop

5. Experiment results

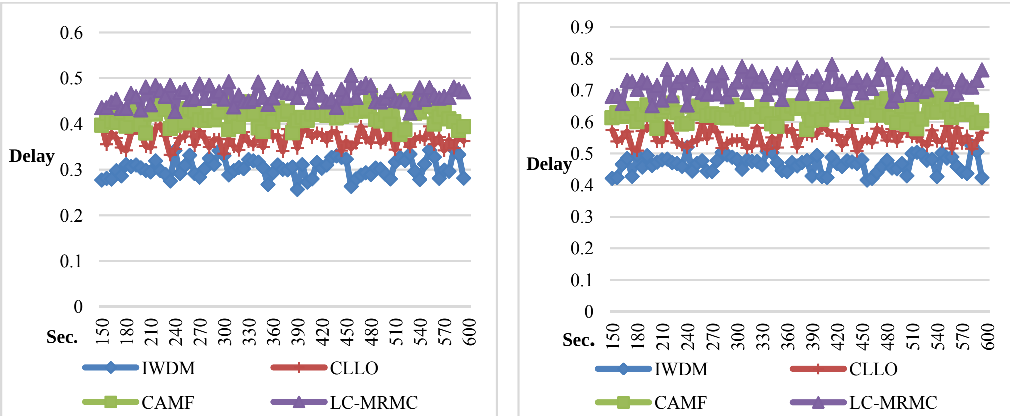
For evaluation of the proposed method with comparable methods quality of service parameters end- to- end delay, packet delivery rate, and throughput will be examined by the following definitions:

- The average of packet delivery ratio: the packet delivery ratio for every receiver is defined as the ratio of the number of actual received packets to that of given received packets. This parameter is averaged for all the receivers.
- The average of end-to-end delay: At first, the end to end delay is assessed for each receiver and then its average is calculated for all the receivers.
- The average of throughput: Firstly the number of received packets per second for each receiver is assessed and then its average for the entire receiver is calculated.

In the simulation performed, a multi-radio multi-channel WMN of 50 nodes (12 and 16 receivers) is used. Also each data point presented in the figures was resulted from the average of 10 times of simulation in which, the number of channels and radios is 11 and 4, respectively. In addition, the transmission range and interference are considered 250 and 500, respectively.

5.1. *The evaluation of the end-to end delay*

In this experiment the aim is to examine the end-to-end delay in different methods. As shown in Figure 3 (a and b), IWDM in the real environments is functionally better than other algorithms. The proposed algorithm due to less interference and the highest possible transmission rate (different rate for each link) has less end-to end delay average compared to other algorithms. With regard to results obtained from all the end-to-end delay evaluations in this scenarios, it can be inferred that IWDM operates better. This superiority becomes more obvious when the number of nodes increases. It implies that IWDM functions well in the operational environments and is extendable. The CLLO algorithm has also less end-to-end delay than CAMF due to joint solution of the two problems of channel assignment and multicast routing. It is noticeable, CAMF assumes that the multicast tree is already available that is why it may not be able to lower the interference properly. In the LC-MRMC algorithm also because of a few numbers of channels and the lack of using the partial overlapping channels, the interference rate among links is too much and therefore leads to increase in end-to end delay. The reason for this superiority is that firstly in IWDM the channel assignment is done using a heuristic function such that the interference becomes minimal and secondly, IWDM considers the first drop (packet) for each receiver. In other word, the first received packet indicates the passage from the path with the least delay and interference and in general leads to create multicast tree with the least number of relay nodes.



AVG	0.303248	0.367938	0.415969	0.461924

AVG	0.467571	0.550791	0.626723	0.717809

a. delay comparison for different methods for a scenario of 50 mesh nods and 12 multicast receivers.

b. delay comparison for different methods for a scenario of 50 mesh nods and 16 malt multicast receivers.

Figure 3. The results of delay in different methods.

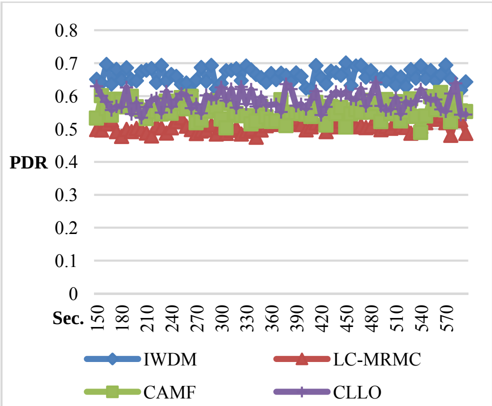
5.2. *The evaluation of packet delivery ratio*

In this experiment the aim is to assess the packet delivery ratio in different methods.

In Figure 4 (a and b) the total number of network nodes is 50 and the network receivers are considered 12 and 16 respectively. In IWDM by increasing the number of network nodes the packet delivery ratio does not decrease significantly.

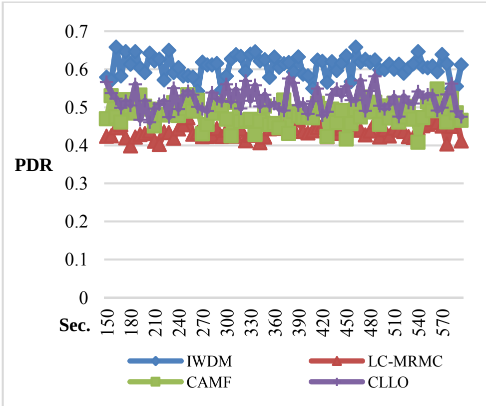
CLLO algorithm due to joint solution to the two problems of channel assignment and multicast routing possesses less interference compared to CAMF. It is noteworthy that CAMF does not solve the two aforementioned problems conjointly and does not consider their impacts to each other that itself will create more interference in the network. In the LC-MRMC algorithm due to using a few number of channels and the lack of using partial overlapping channels the interference among the channels is too much, the average packet delivery ratio (APDR) is lower. It is also observed that when the number of the receivers in the network increases the superiority of proposed method to other methods considerably increases. The IWDM algorithm because of using overlapping channels and selection of links with less interference, its packet delivery ratio is higher.

By using IWDM, the maximum number of packet delivery ratio has been achieved. Also from the results it is inferred that despite the increase in the multicast receiver numbers the packet delivery ratio has not changed considerably.



AVG	0.660078	0.58619	0.554812	0.506255

a. APDR comparison for different methods for a scenario of 50 mesh nods and 12 multicast receivers.



AVG	0.607491	0.519944	0.48182	0.436585

b. APDR comparison for different methods for a scenario of 50 mesh nods and 16 multicast receivers.

Figure 4. The results of packet delivery rate in different methods.

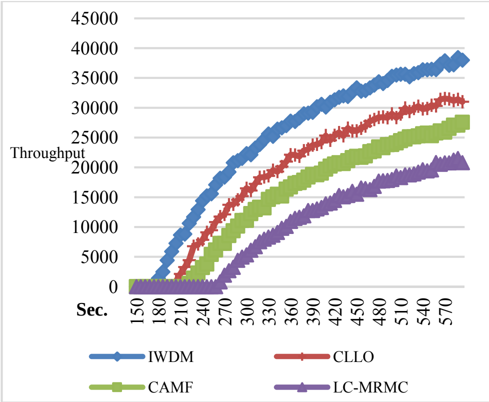
5.3. *The evaluation of throughput*

In this experiment the aim is to evaluate throughput in different methods. Figure 5 shows (a and b) which have 50 mesh node and 12 and 16 receivers. The proposed method due to using partial overlapping channels and consideration of the relation between transmission rate and interference possesses higher average throughput than other comparable algorithms. CLLO is also because of the effort for creating no interfering links and the joint solution of multicast routing and channel assignment have higher throughput average compared to CAMF and LC-MRMC. It is noteworthy that with regard to the considerable increase in the number of nodes and receivers compared to the previous scenarios, throughput in IWDM has not decreased considerably and this issue demonstrates IWDM is a powerful algorithm. Also the results indicate that by increasing the number of receivers the improvement rate of throughput using proposed method will be considerable compared to other methods.

These results demonstrate that IWDM due to using partial overlapping channels and the attempt for the selection of paths with the highest capacity and choosing different and suitable transmission rate among nodes, leads to maximum value of throughput.

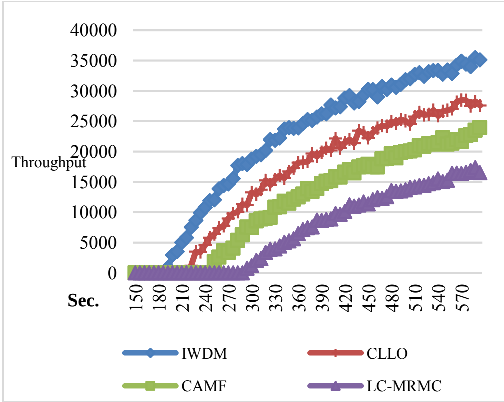
This algorithm because of channel assignment with awareness of transmission rate among nodes and also creating paths with the maximum throughput has lower interference and its throughput also increases. IWDM also due to the effort for constructing tree with the minimum number of relay nodes and using partial overlapping channels possesses higher throughput compared to CAMF and CLLO algorithms that do not consider the transmission rate among nodes.

Algorithm IWDM in comparison with LC-MRMC is also due to more appropriate channel assignment and the joint solution of channel assignment and routing has higher throughput average.



AVG 24601.5 19014.58 14945.4 10260.72

a.throughput comparison for different methods for a scenario of 50 mesh nods and 12 multicast receivers.



AVG 21617.3 15991.47 11722.06 7205.298

b. throughput comparison for different methods for a scenario of 50 mesh nods and 8 multicast receivers.

Figure 5. The results of throughput in different methods.

6. Conclusions and future works

In this paper a meta-heuristic method was presented to solve the multicasting NP-hard problem. The proposed method solves two problems of construction of multicast tree and channel assignment conjointly and uses overlapping channels. The simulation results demonstrate that the proposed methods compared to the methods LC-MRMC, CAMF and CLLO have better functionality in terms of packet delivery ratio, the average of throughput and delay. So far, numerous methods have been presented regarding multicast routing in multi radio multi channel wireless mesh networks but most have merely used orthogonal channels which precludes using the maximum capacity of network. Therefore, in the future studies this problem has to be of great importance. On the other hand, in most reported works two sub-problems of multicast tree construction and channel assignment have been solved sequentially. This will not consider the interaction between layers therefore the optimum solution will not be obtained. In the future researches this problem should receive more attention. Since the IEEE 802.11b standard allows equipments to operate with different rates, the problem of multi rating will be important.

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