Channel Assignment with Topology Preservation for Multi-radio Wireless Mesh Networks

Hongju Cheng*
College of Mathematics and Computer Science, Fuzhou University, China
Email: cscheng@fzu.edu.cn

Naixue Xiong
Department of Computer Science, Georgia State University, US
Email: nxiong@cs.gsu.edu

Guolong Chen and Xiaofang Zhuang
College of Mathematics and Computer Science, Fuzhou University, China
Email: cgl@fzu.edu.cn; xiaofangzhuang@126.com

Abstract—**Channel assignment is one of the most important issues in the multi-radio multi-channel wireless mesh networks. An improper channel assignment may lead to network partition or link failure. In this paper we focus on the channel assignment problem with the original topology preservation for the multi-radio mesh networks, and aim at minimizing the overall network interference. We have formulated an Integer Line Programming (ILP) which can be used to find the optimized solution for the channel assignment problem in small-size network. In this paper we also have developed a distributed algorithm for the channel assignment due to the NP-hardness of the ILP. Extensive simulation results have demonstrated that our algorithms have good performance in both dense and sparse networks compared with related works. The theoretic and experiment results have shown that the proposed algorithms serve as a practical solution to the channel assignment problem in the multi-channel multi-radio wireless mesh networks.**

Index Terms—**Channel assignment, topology preservation, wireless mesh networks**

I. INTRODUCTION

The wireless mesh network [1] is an emerging new broadband technology drawing increasing attention these days. It is deployed in the last mile to extend or enhance Internet access for mobile clients located at the edge of wired networks. The co-channel interference is the main factor that has reduced the network throughput in the wireless networks. The wireless mesh network generally includes multiple channels. The nodes in the mesh network can transmit packets simultaneously on different channels because the interference among distinct channels is tolerant or eliminated. By exploring the advantage of multiple channels and multiple radios, the system performance of the mesh networks is improved significantly compared with the single-channel wireless network. However, all these expecting prospects are based on a careful designed channel assignment scheme so as to utilize these multiple channels and radios.

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Corresponding author: Dr. Hongju Cheng, Fuzhou University, China, email address: cscheng@fzu.edu.cn.

There are already several strategies for channel assignment in the mesh networks, such as *dynamic*, *semi-static* and *static*. The dynamic strategy is to frequently change the channels on the radios according to the requirement of transmission (per packet or a series of packets) [5-9], which requires high synchronization among the nodes and results in delays in order of milliseconds with the current hardware solution [10]. It is difficult to realize the dynamic strategy with current commodity IEEE 802.11 hardware, meaning that an approach in this direction might not be practical [11, 12]. The static strategy is to assign channels to the radios permanently, which is done on the premise of ease of adaptability with commodity 802.11 hardware [9, 13-15]. The static strategy can be easily extended to the semi-static strategy by simply switching the channels with regular intervals. In this paper we aim at designing static / semi-static strategies for the channel assignment supported by the current commercial 802.11 hardware.

It shall be mentioned that two mesh nodes can not communicate directly even though they are in the communication range, in case that they are assigned different channels. An improper channel assignment may lead to network partition or link break. In this paper we have considered to assign channel to nodes while preserving the original topology. *Topology preservation* means that all links in the single channel network will also exist in the final multi-channel network topology after channel assignment. The topology preservation is reasonable with the following considerations: 1) It has avoided the network partition and link break which might arouse severe problems in the network; 2) The routing as well as other protocols in upper layers, which are already fully researched in the single channel network, can be applied directly to the mesh networks with no or minimum modification; 3) It can increase the network connectivity by preserving the original links and adding more links into the network.

Co-channel interference is one of the main obstacles that have influenced the throughput of wireless network. It is intuitive the goal of our channel assignment problem is to minimize the total interference by diversifying

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channels for the links. In this paper, we aim at the static minimum-interference channel assignment problem with the original topology preservation.

The rest of this paper is organized as follows: we introduce the related work in Section II and present the problem formulation in Section III. In Section IV and V we introduce the integer line programming and propose a distributed channel assignment algorithm. Section VI concerns with the simulation result. Section VII is the discussion and Section VIII is conclusion.

II. Related work

The channel assignment problem has been well researched and there exists a wide range of algorithms for the wireless mesh networks in the literature. This problem has proven to be NP-hard [10], and the strategies for channel assignment can be divided into three types, namely, static, dynamic and hybrid assignment [13].

Raniwala et al. [16] proposed a centralized load-aware channel assignment algorithm to find static channel assignment, which required the load and routing information of the network and was hard to realize in practical network. Chen et al. [17] devised a channel assignment strategy which assigns the channels in order to balance the traffic load between different channels. Das et al. [18] presented two mixed integer linear programming models for solving the fixed channel assignment problem with multiple radios.

Kyasanur et al. [13] has presented a distributed interface assignment with the dynamic strategy with no assumptions on the traffic characteristics. Raniwala and Wu et al. [5] divided each code into time slots to form the channels and proposed a dynamic frame length expansion and recovery method termed adaptive distributed channel assignment. Bahl et al. [6] proposed a software based approach that facilitates simultaneous connections to multiple networks by virtualizing a single wireless card. Wu et al. [7] proposed a joint topology control and routing protocol for a multi-radio multi-channel wireless mesh network to exploit both channel diversity and spatial reusability, which resides between medium access control and the network layer and aims to improve the network throughput by coordinating transmission power, channel assignment, and route selection among multiple nodes in a distributed way.

Tang et al. [19] defined the co-channel interference and presented heuristic algorithm for the channel assignment problem such that the induced network topology is interference-minimum among all K-connected topologies. These works has considered the connectivity of the network but ignored the topology preservation, which might need supports from routing as well as other protocols in upper layers.

The works in [2-4] are the most close to this paper. Subramanian et al. [2] has addressed the link scheduling with the objective of minimizing the overall network interference, and proposed both centralized and distributed solution based on the Max k-cut conversion. Sridha et al. [3] has proved the channel assignment problem is NP-Hard, and proposed a load-based scheme for assigning channels to the radios as well as a meta-heuristic based on genetic algorithms. However, all their works has ignored the broadcasting characteristics of wireless communication, which leads to the wrong calculation on the overall interference in the network and might result in un-efficient channel assignment scheme. Das et al. [18] has formulated the channel assignment problem as an optimization problem, presented four metrics based on which mesh channel assignments can be obtained, and proposed an algorithm to maximize the number of logical links that can be active simultaneously.

III. Problem formulation

The topology of the wireless mesh network can be modeled as a simple plane graph $G = (V, E)$, where V is the set of mesh nodes and E is the set of links. We assume that the mesh node uses omni-directional radios and all wireless links are un-directed. There is a link (i, j) between nodes i and j if their distance is smaller than the transmission range. For simplicity, we assume that all mesh nodes in the network have the same transmission range. And thus the link (i, j) represents an undirected link in the graph G in this paper.

Let the set of channels available in the network denoted as K. Without loss of generality, we denote $K = \{1, 2, ..., k_{max}\}$. We also assume that all channels are orthogonal so that the transmissions on different channel can be carried out simultaneously even though they are very close in geographical distance. The wireless mesh network is constructed with stationary wireless routers, in which each router, e.g., router i, is equipped with a number of radios denoted as R_i, where $R_i \leq |K|$, $i \in V$. We assume that each radio is tuned to a channel and any two radios at the same node are tuned to different channels.

Due to the broadcasting characteristic of wireless communication, the transmission on one link may interfere with transmissions along other links. An interference model is required to obtain the interference information in the network. Gupta and Kumar [20] defined the physical and protocol interference model, in which the interference is defined with the ratio of signal and noise or the distance from the transceiver. Tang et al. [19] proposed that two links (i, j) and (u, v) interfere with each others if one of the following distances, $d_{i,u}$, $d_{i,v}$, $d_{j,u}$, $d_{j,v}$, is smaller than the interference range. Note that in this paper we do not make any assumption on the interference model by assuming that the link knows the set of links that interfere with itself, which illustrates that our solution is robust to the interference model.

Definition 1. Link (u, v) is a *potential interference link* of (i, j) if the transmission on (i, j) conflicts with transmission on (u, v) assuming that they are on the same channel. Link (u, v) is an *interference link* of (i, j) if transmission on (i, j) conflicts with transmission on (u, v) and they are exactly on the same channel.

Definition 2. The *potential interference number* of link (i, j) is the number of links who are potential interference links of (i, j). The *interference number* of link (i, j) is the number of links who are interference links of (i, j).

Note that we assume uniform traffic on all links. When there is a uniform traffic in the network, the interference number of the whole network has indicated the overall conflict in the network. And the objective of the channel assignment is just to minimize the overall interference number of the whole network. However, this assumption can be removed and it is discussed in Section VII.

Definition 3. A *conflict graph* $G_c = (V_c, E_c)$ is conduced by $G = (V, E)$ with $V_c = E$ and $((i, j), (u, v)) \in E_c$ if (u, v) is a potential interference link of (i, j) in G.

As mentioned above, a channel assignment defines a corresponding topology. And the corresponding topology shall include all links in the single-channel network when topology preservation is required. However, the mesh network can explore diverse channels and there might be several links between two nodes in the final topology (Notice that the original graph G is a simple graph). Here we introduce a new graph $G'= (V', E')$ to illustrate the final topology after channel assignment, where the node set $V' = V$ and there is a link $(i, j; k) \in E'$ if and only if channel k is assigned to both two endpoints of link (i, j).

At the same time, it is desirable to have a channel assignment whose corresponding topology has relatively low interference. The channel assignment for one node is a set of channels, which can be denoted as a non-empty subset of K. Let $P(K)$ be power set of K, we have the following definitions for the feasible channel assignment and the channel assignment problem.

Definition 4. The function f: $V \to P(K) \setminus \phi$ is a *feasible channel assignment* for graph G if $|r(i)| \leq R_i$, $i \in V$ and G is a subgraph of G', where $G' = (V', E')$ with $V' = V$ and $(i, j; k) \in E'$ if and only if $k \in r(i) \cap r(j)$ and $(i, j) \in E$.

Definition 5. The *channel assignment problem* is to find the best among all the feasible channel assignments so that the sum of interference number for all links (named as the overall interference number) in the network is minimized.

IV. ILP PROBLEM FORMULATION

In this section we present an Integer Line Programming (ILP) formulation for the channel assignment problem. We use the following set of binary integer (0 or 1) variables and constraints in the ILP formulation:

1) Variables $I_{(i,j),(u,v)}$, for each links (i, j) and $(u, v) \in E$. The variable $I_{(i,j),(u,v)}$ is 1 if and only if links (i, j) and (u, v) are the potential links or each other.

$$I_{(i,j),(u,v)} = \begin{cases} 1, \textit{if } (i,j) \textit{ is a potential interference link of } (u,v); \\ 0, \textit{otherwise.} \end{cases} \tag{1}$$

The variable $I_{(i,j),(u,v)}$ can be obtained when the topology graph and the interference model are given. It shall be mentioned that the variables $I_{(i,j),(u,v)}$ are determined by the original network topology and the interference model, and have no direct relationship with the final channel assignment results. However, the variables $I_{(i,j),(u,v)}$ are used to calculate the overall interference number in the network.

2) Variables Y_i^k for each link $i \in V$ and $k \in K$. The variable Y_i^k is 1 if and only if node i is assigned with channel k:

$$Y_i^k = \begin{cases} 1, \textit{if node } i \textit{ is assigned with channel } k; \\ 0, \textit{otherwise.} \end{cases} \tag{2}$$

And the number of distinct channels assigned to one node must meet constraint of the radio number on the node because one radio can works on at most one radio at one time:

$$\sum_{k \in K} Y_i^k \leq R_i; \forall i \in V; \forall k \in K . \tag{3}$$

3) Variables $A_{(i,j)}^k$ for each link $(i, j) \in E$ and $k \in K$. The variable $A_{(i,j)}^k$ is 1 if and only if both node i and j are assigned with channel k:

$$A_{(i,j)}^k = \begin{cases} 1, \textit{if both } i \textit{ and } j \textit{ are assigned with channel } k; \\ 0, \textit{otherwise.} \end{cases} \tag{4}$$

The variable $A^k_{(i,j)}$ can also be used to illustrate link (i, j) is assigned to channel k or not, i.e., variable $A^k_{(i,j)}$ is 1 if and only if link (i, j) is assigned with channel k. Note that a link can be assigned with several distinct channels in our system model which differ our work from the previous [2-4].

The assignment of channel k to link (i, j) must force the assignment of channel k to node i and j, and we have:

$$A_{(i,j)}^k \leq Y_i^k; \forall i \in V, \forall (i,j) \in E; \forall k \in K . \tag{5}$$

$$A_{(i,j)}^k \leq Y_j^k; \forall i \in V, \forall (i,j) \in E; \forall k \in K . \tag{6}$$

4) The channel assignment requires preserving the original topology of the network. That is, each link $(i, j) \in E$ is assigned at least one channel:

$$\sum_{k \in K} A_{(i,j)}^k \geq 1; \forall (i,j) \in E . \tag{7}$$

Our objective is to minimize the overall interference number in the network, which can be formulated as:

$$\sum_{k \in K} \sum_{(i,j) \in E} \sum_{(u,v) \in E} A_{(i,j)}^k A_{(u,v)}^k I_{(i,j),(u,v)} . \tag{8}$$

Then the channel assignment problem can be formulated as:

$$\text{Minimized } \sum_{k \in K} \sum_{(i,j) \in E} \sum_{(u,v) \in E} A_{(i,j)}^k A_{(u,v)}^k I_{(i,j),(u,v)}$$

$$\begin{aligned} \text{Subject to:} \quad & A_{(i,j)}^k = \{0,1\}; \forall (i,j) \in E, \forall k \in K \\ & Y_i^k = \{0,1\}; \forall i \in V, \forall k \in K \\ & A_{(i,j)}^k \leq Y_i^k; \forall i \in V, \forall (i,j) \in E; \forall k \in K \\ & A_{(i,j)}^k \leq Y_j^k; \forall i \in V, \forall (i,j) \in E; \forall k \in K \\ & \sum_{k \in K} Y_i^k \leq R_i; \forall i \in V; \forall k \in K \\ & \sum_{k \in K} A_{(i,j)}^k \geq 1; \forall (i,j) \in E \end{aligned}$$

V. Distributed Algorithm

We present here a distributed channel assignment heuristics whereby all information and operation upon the topology of the network are localized through the entire network. The wireless mesh networks are expected to be the next generation of wireless backbone because not only their capacity is improved but also their robustness and ad hoc operation had overwhelmed all other wireless networks. Distributed algorithms are a nature choice for the wireless mesh networks. Our distributed algorithm is based on two principles: 1) The information and operation shall be maximally localized; 2) The channel assignment operation is simple and eases to realize.

The outline of the distributed algorithm is given as follows. Originally, the nodes are assigned to a special common channel, such as channel 1, to observe the initial network topology. We assume that one link knows its entire potential interference links in the network through local information exchange among the neighbors. The nodes are aware of its adjacent links with them as the endpoints. The potential interference number is calculated for each adjacent link and the value is informed to all potential interference links. After the information exchange, the nodes are aware of the local potential interference number for each adjacent link. Then, a node is allowed to switch the channel for the adjacent link if its interference number is the maximal among all the potential interference links. It shall be mentioned there are two endpoints for one link, and the channel switch operation is completed by the endpoint with smaller node id (the other endpoint will operate according to the corresponding assignment result). The assignment information is broadcasted to its neighbors and is forwarded to all potential interference links. At this point the algorithm proceeds to the next iteration of switch for the link with maximum potential interference number among links that are not yet assigned. The algorithm terminates when all links are assigned a channel.

Before formally presenting the algorithm, we introduce several notations and variables. The variable *pin_value* is used to denote the potential interference number of one link. The variable PIL is used to denote the Set of Potential Interference Links for one link. The table PIL_INFO with triples (*link_name*, *pin_value*, *state*) as the members is used to include the information of the potential interference links for one special link; the *link_name* denotes the link id, the *pin_value* denotes the potential interference number of the link and *state* denotes the link is assigned or not (*assigned* or *unassigned*). Note that it is necessary to build both one variable PIL and one table PIN_INFO for each link adjacent to the node.

The distributed algorithm is listed as follows. There are two processes in the algorithms. One is the Initialize-Process and another is the Assign-Process. In the Initialize-Process the node initializes its channel assignment as {1}. The HELLO message is exchanged to collect the potential interference links for each link adjacent to the node and finally the set PIL is set up with the proper local information. Then the node calculates the potential interference number *pin_value*(i, j) for each adjacent link (i, j) where j denotes the neighbor and i the node itself, mark each link *unassigned* and broadcast an INFORMATION message out again with link name (i, j) and *pin_value*(i, j) included. When an INFORMATION message is received, the node adds triple (*link_name*, *pin_value*, *unassigned*) into the PIL_INFO table for the link. At the end of this process each node i will finally calculated the *pin_value* and build the table PIL_INFO for each adjacent link (i, j) where i denotes the node itself and j the neighbor.

Distributed Channel Assignment (CCA)

Initialize-Process( )

Initialize the assignment as {1}, broadcast a HELLO message to nodes that have potential interference links.

Waiting for HELLO messages, and build a Potential Interference Links Set PIL for each link adjacent to it;

Calculate *pin_value*(i, j) for each adjacent link (i, j) where j denotes the neighbor and i the node itself, mark each link *unssigned* and broadcast an INFORMATION message out again with these information included;

Waiting for INFORMATION from links in set PIL, and add a pair (*link_name*, *pin_value*, *unassigned*) into the PIL_INFO table for each link in PIL.

Assign-Process( )

If an ASSIGNMENT message is received, modify the item state with the same *link_name* as in the message as *assigned* in the corresponding PIL_INFO table.

If a MODIFY message with the channel switch pair as ($k1$, $k2$) is received, set $r(i) \leftarrow r(i) + \{k2\}$; if the network topology is preserved when $k2$ is deleted from $r(i)$, set $r(i) \leftarrow r(i) - \{k1\}$;

If all adjacent links are assigned, stop. Otherwise, select one for channel assignment from the unsigned adjacent links with maximum *pin_value*;

Compare the *pin_value* of the selected link (i, j) with all items in the PIL_INFO table whose state is *unassigned*;

If some links have larger *pin_value* or the same *pin_value* but smaller *node_id*, wait until an ASSIGNMENT message is received, and then modify the state from *unassigned* to *assigned* for the corresponding item in the PIL_INFO table, then return to step 1;

For each channel $k1 \in R_i \cap R_j$, calculate the whole interference number decrease when the channel assignment for link (i, j) is replaced by $k2 \in (K - R_i \cap R_j)$, select the channel switch pair ($k1$, $k2$) with maximum decrease and set $r(i) \leftarrow r(i) + \{k2\}$,

If the network topology is preserved when $k1$ is deleted from $r(i)$, set $r(i) \leftarrow r(i) - \{k1\}$;

Exchange a MODIFY message with j and the channel pair ($k1$, $k2$) included in the message;

Modify the state of (i, j) as *assigned* and send out an ASSIGNMENT message to all links in PIL_INFO table.

The second process is the Assign-Process. If an ASSIGNMENT messages is received, the node modifies the item state with the *link_name* same as that in the incoming message to *assigned* in the corresponding

PIL_INFO table. In case that the node has received a MODIFY messages, it means the corresponding endpoint has modified the channel. If all adjacent links are assigned, stop. Otherwise, the node selects one link *unsigned* and with maximal *pin_value* among its PIL. Note that the link is assigned by the endpoint with smaller node id. The final assignment result is sent the other endpoint of the link with a MODIFY message. After the assignment the node modifies the state of selected link (i, j) as *assigned* and send out an ASSIGNMENT message to all links in PIL_INFO table. This process continues until all links are assigned.

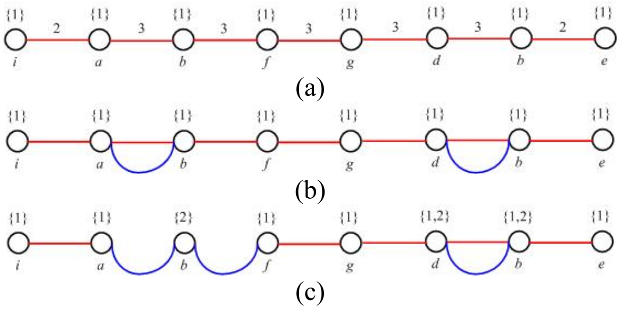

Fig. 3 Example of the execution of the distributed algorithm. (a) The initialized process of the network with all nodes assigned to channel 1. (b) Link (a, b) and (b, d) simultaneously switch to channel 2. (c) Link (b, f) switches to channel 2 and channel 1 is removed from b.

We illustrate the distributed algorithm by applying it to a sample network given in Fig. 3. Assuming there are two channels available. Node i and e has one radio and others two radios. Initially all nodes are assigned with channel 1 (in Fig. 3(a)). The potential interference number for links is marked above the link. Since that links (a, b) and (b, d) have maximal potential interference number among the PILs, node a and b (with smaller node id) can switch the corresponding link to channel 2, as described in Fig. 3(b). In the next iteration, link (b, f) has the maximal *pin_value* and smaller node id, and so it is switched to channel 2 by node b. Note that b can remove channel 1 while preserving the network topology, as we can see from Fig. 3(c). Since the switch on link (d, g) will increase the overall interference number, node d simply mark the link assigned and broadcast it out. The process is similar to link (f, g), (b, e) and (a, i). The final channel assignment result can be observed from Fig. 3(c).

VI. DISCUSSION

In the previous sections we have made the assumption that there is uniform traffic on all links to simplify the key idea behind our solution. In this section, we will illustrate how to relax this assumption with the minimum modification on the algorithms.

As mentioned, the wireless mesh network is generally deployed in the last mile to access the Internet. The mesh node can aggregates the incoming data flow from the mobile user in the corresponding area, and forwards the data to the gateway which has connected both the wireless mesh network and the Internet. Message originated from the Internet to the mobile user can be delivered in the reverse direction. The path selection for such applications is defined by the routing protocol used in the mesh network. The bandwidth reserved for each mobile user is general guaranteed by the network provider, and thus the traffic flow to and from the mesh node can be obtained in case that the number of users and the routing protocol are given. Let $w(i, j)$ be the normalized traffic on link $w(i, j)$. The topology of the network can be modeled as a weighted graph $G = (V, E, W)$, where W is the set of weights for the links. Then the two notations in Definition 2 and 3 can be expressed as following: the *potential interference number* of link (i, j) is the sum of weights for links who are potential interference links of (i, j), and the *interference number* of link (i, j) is the sum of weights for links who are interference links of (i, j). Based on the above notations, the overall interference number can be formulated as:

$$\sum_{k\in K}\sum_{(i,j)\in E}\sum_{(u,v)\in E} A^k_{(i,j)}A^k_{(u,v)}w(i,j)I_{(i,j),(u,v)} \ . \qquad (9)$$

And Integer Line Programming for the channel assignment with the generalized traffic is formulated as:

$$\text{Minimize} \sum_{k\in K}\sum_{(i,j)\in E}\sum_{(u,v)\in E} A^k_{(i,j)}A^k_{(u,v)}w(i,j)I_{(i,j),(u,v)} \ .$$

The constraints for the channel assignment problem with the generalized traffic are same as that with uniform traffic, which are discussed in details in Section III.

VII. SIMULATION RESULT

In order to evaluate the actual behavior of the above algorithms in terms of number of interference on the same channel, we have relied on the experimental simulation to show its performance. The algorithm runs on finite random networks with varying connectivity patterns and number of nodes, as well as channel number and radio number. The IEEE 802.11a/b have provided 12/3 orthogonal channels and the number of available channels in the network is assumed to be 12 or 3, and we the mesh nodes are assumed to have the same number of radios which is no more that the channel number.

The scenarios are built in a square meters area 1000m × 1000m. The mesh nodes are assumed distinct with the transmission range as 252m. We use the interference model described in [19], i.e., two links (i, j) and (u, v) interfere with each others if one of the following distances, $d_{i,u}$, $d_{i,v}$, $d_{j,u}$, $d_{j,v}$, is smaller than the interference range, which are assumed to be twice of the transmission range (514m). In the simulations we have considered two sets of random network, namely, dense and sparse networks, which are generated by placing 25 or 50 nodes in the square meters area. We generalize the network by randomly selecting the node position while preserving the network connectivity. The average node degree is about 4.88 in the sparse network and 7.48 in the dense network. After generalizing the node position, there is an edge between two nodes if their distance is no more than the transmission range, and thus the network topology is built.

Here we use two metrics to illustrate the performance of our algorithms, namely, the fractional network interference and network throughput. The fractional network interference is defined as the ratio of overall interference number and the overall potential interference number in the network [2]. It can be used to measure the final interference resulted after the channel assignment. In the network with uniform traffic and channel capacity, the available bandwidth of one link is in fact determined by its interference number. A simple formula can be used to calculate the available bandwidth for link (i, j):

$$Capacity(i, j) = \frac{1}{1 + interference\,number\,of\;(i, j)} . \qquad (10)$$

The throughput of the network is defined as the sum of capacity of all links in the network.

We compare our algorithms with the proposed Centralized Tabu-Based Algorithm (CTBA) in [2] and the IATC in [19]. The main idea behind the CTBA is to convert the channel assignment problem to the Max *k*-cut problem, and it has two steps: the first is to assign the channel to the conflict graph with random channel switch, and the second first iteratively merge the channels on nodes more channels than the radio number. The IATC is to assign channels to links while maintaining the network connectivity. In the simulation, the connectivity requirement for the network is assumed to be 1-connected. Readers are guided to [19] for details about the algorithm.

Fig. 4 shows the simulation results in the sparse network with channel number as 12 and radio number increasing from 2 to 10. Our algorithm has larger fractional network interference compared with IATC when the radio number is small. However, the IATC provides 1-connectivity which does not guarantee to preserve the original network topology, so it is reasonable that our algorithm has larger interference in case of small radio number. Our algorithm runs better than the CTBA in all cases, as we can observe from the figure.

It can be observed that our CCA reduces the overall interference number with the radios increasing, while the IATC has unstable performance. It shall be noted that when the radio number is 7, the adding of new radios onto the mesh node does not decreasing the overall interference number (as we can observed from the figure in Fig. 4.). The possible explanation is that the new added

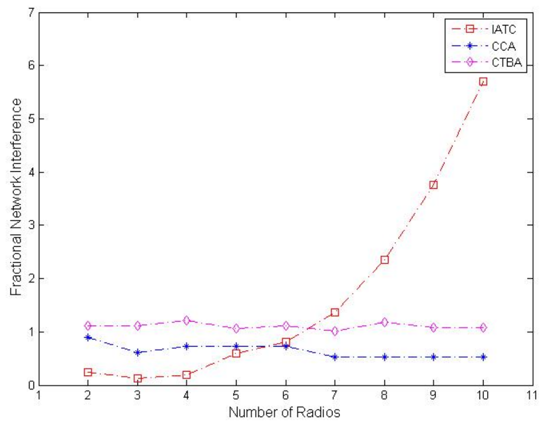

Fig. 4. Fractional network interference in sparse network with 25 nodes and 12 channels.

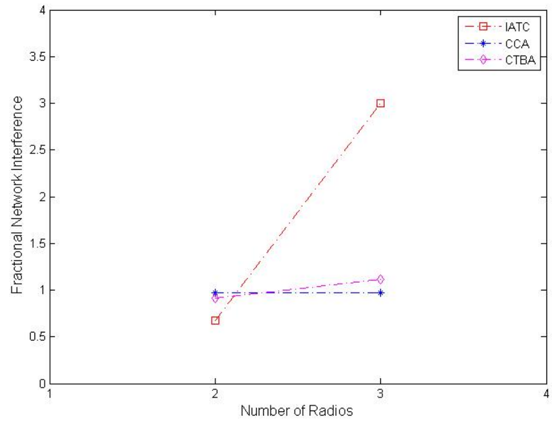

Fig. 5. Fractional network interference in sparse network with 25 nodes and 3 channels.

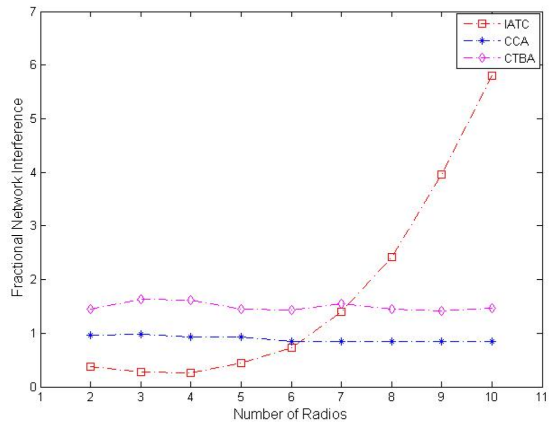

Fig. 6. Fractional network interference in dense network with 50 nodes and 12 channels.

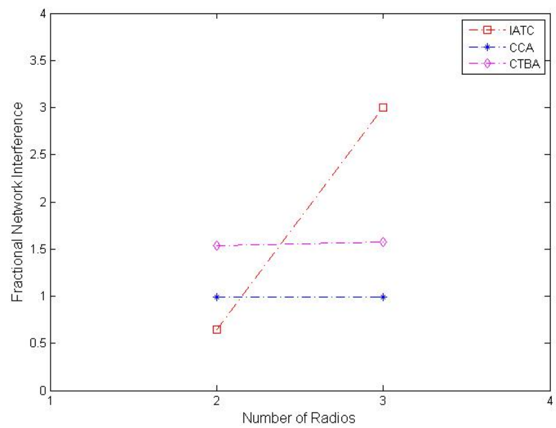

Fig. 7. Fractional network interference in dense network with 50 nodes and 3 channels.

radio shall work on a channel, which potentially might increase the overall interference in the network. The similar conclusion can also be drawn from Fig. 5.

Fig. 6 and Fig. 7 have drawn the results in the dense networks which have larger number of interference links which increasing the computation complexity. Our algorithm also runs stable compared with IATC.

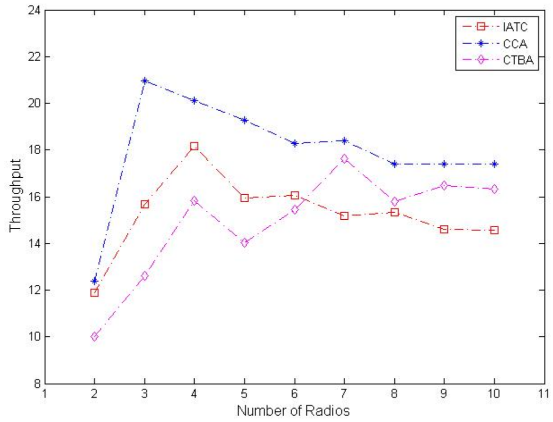

Fig. 8. Network throughput in sparse network with 25 nodes and 12 channels.

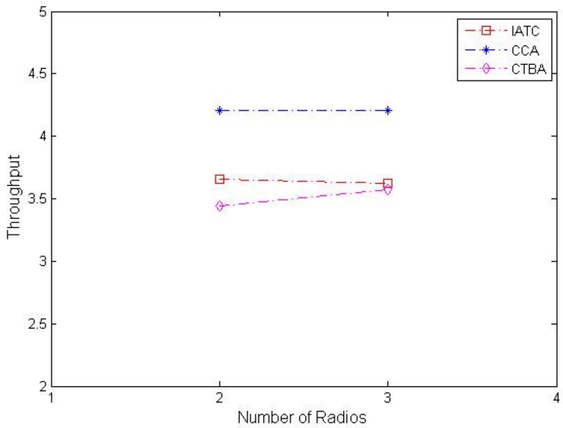

Fig. 9. Network throughput in sparse network with 25 nodes and 3 channels.

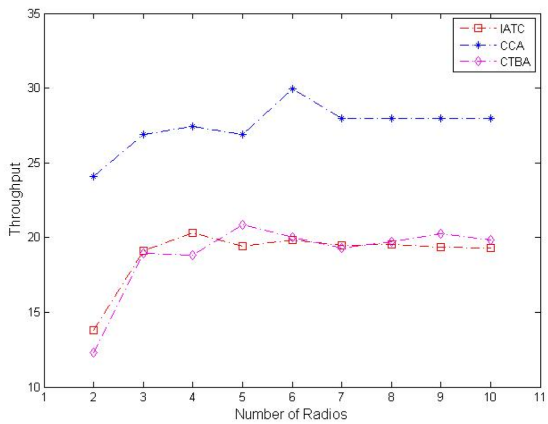

Fig. 10. Network throughput in dense network with 50 nodes and 12 channels.

Fig. 8 and Fig. 9 have illustrated the results in sparse networks. As we can observe, our algorithm runs better in all cases compared with the IATC and CTBA. For example, the throughput is increased by 4.13% and 23.82%according, in case that there are 12 channels and 2 radios. The similar conclusion can also be obtained in dense networks from Fig. 10 and Fig. 11.

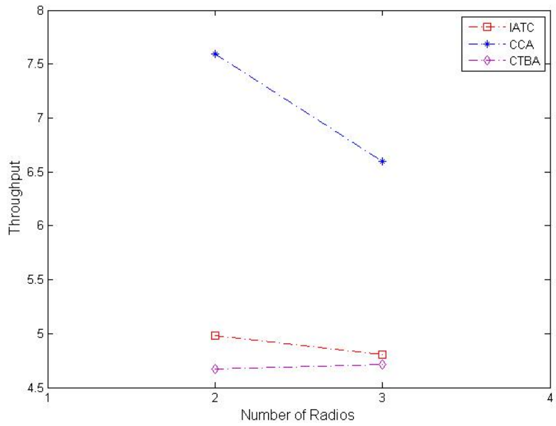

Fig. 11. Network throughput in dense network with 50 nodes and 3 channels.

VIII. Conclusion

The wireless mesh networks are emerging as broadband wireless backbone for the Internet access by exploiting new technologies such as multiple channels and multiple radios. Channel assignment is one important issue in deploying the mesh network. In this paper we aim at minimizing the overall network interference in the channel assignment problem. An Integer Line Programming (ILP) is formulated to find the optimized solution for the channel assignment problem in small size network. And a distributed algorithm is also proposed in this paper in which limited local information is required for an efficient channel assignment scheme. Extensive simulation results have demonstrated that our algorithms have good performance in both fractional network interference and throughput compared with related works. The theoretic and experiment results have shown that the proposed algorithms serve as a practical solution to the channel assignment problem in the multi-channel multi-radio wireless mesh networks.

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Hongju Cheng received the B.E. and M.E. degrees in EE from Wuhan University of Hydraulic and Electric Engineering, in 1997 and 2000, respectively, and the Ph.D. in Computer Science from Wuhan University in 2007. Since 2007, he has been with the Department of Computer Science, Fuzhou University, Fuzhou, China. His interests include mobile ad hoc networks, wireless sensor networks, and wireless mesh networks. Dr. Cheng has published about 10 papers in international journals and conferences.

Naixue Xiong is a research scientist in the Department of Computer Science at the Georgia State University, Atlanta, USA. His research interests include Communication Protocols, Network Architecture and Design, and Optimization Theory. Until now, he published about 90 research articles (including over 30 international journal articles). Some of his works were published in IEEE or ACM transactions and IEEE INFOCOM. He has been a Publicity Chair, PC member, and OC member of over 50 international conferences, and as a reviewer of over 30 international journals.

Guolong Chen received the Ph.D. in computer science from Xi'an Jiaotong University at 2002, and Post Ph.D. in computer science from National Defense and Science University at 2007. Now he is a professor at the Department of Computer Science of Fuzhou University, China. The major research fields of Prof. Chen include computation intelligence, computer networks, information security, etc. Prof. Chen has published more than 50 papers in international journals and transactions.

Xiaofang Zhuang is a graduate student studying at the Department of Computer Science of Fuzhou University, China. Her interests include mobile ad hoc networks, wireless sensor networks, and wireless mesh networks.