Wireless Mesh Network Channel Assignment

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***Abstract*—For this proposal, we reviewed dozens of research papers in the area of the channel assignment problem for wireless mess network. We are planning to design a new algorithm to handle this problem and evaluation using commonly known graph based simulations first. Then, we will try to utilize NS-3 to get more realistic performances analysis.**

***Index Terms*—Wireless Mesh Network, Channel Assignment**

I. Introduction

Wireless mesh networks are wireless networks consisting of wireless routers and widely used to construct wireless local area networks (WLANs) in our daily lives especially in large public area to provide extended internet coverage or in agricultural or environmental for data collection. However, because of the limited bandwidth, the most important factor affecting network performance is the channel interference. This problem happens not only in the single radio interface but also multi radio interface routers. Now, how to improve networks performance by decreasing channel interference has been an active research topic.

There are two kinds of mesh router. One is single radio interface, and the other is multi-radio interface router. The multi-radio interface routers could decrease channel interference and improve networks performance significantly than single radio routers. Therefore, this research only talks about the multi-radio interface routers wireless mesh networks channel assignment optimization.

Channel interference is the most important reason affecting mesh networks performance and there are five kinds of channel interference. The first one is intra-flow interference when two links connecting to the same router are using the same channel. The second is inter-flow interference that two links connecting different routers but are using the same channel. The third is rate interference that two links in interference range are using the channel but different frequency. The fourth channel interference is external signal source interfering the network routers that we have no control over. The last case is the hidden node interference where the existing hidden node interferes only with one router of the connected link [1] [2].

There are two aspects that could be used to minimize the interference of the mesh networks. The first one is optimizing the mesh networks logic topology by its corresponding traffic topology. In this procedure, several strategies have been proposed to remove links to decrease interference. The spanning tree method is used to form a spanning tree starting from the gateway router and find the spanning tree with shortest response time. The known traffic method is to remove the links with low traffic but high interference with other links. There are also several other methods, the flow-based link optimization, the power control link optimization and high-quality metric link optimization. By these methods, the mesh networks total interference could be decreased.

The other aspect is to lower interference in channel assignment protocol. In the channel assignment procedure, several approaches have been proposed to assign the available channels to the mesh networks [3]. The first one is channel interference index method, in this method, several interference or rank of links or routers have been calculated and used to assign the channels to the links. The second approach is to consider the channel interference and networks partition at the same time, because network partition has a significant consequence where it disconnect the network or increase path length of some routing path. The third approach considers channel assignment and routing strategy at the same time. A good channel assignment and routing strategy combination could decrease the network interference and increase network throughput.

There are several research projects about link optimization and channel assignment strategies [4] [5]. People also discovered partially overlapping mesh networks to optimize system performance [6] [7] [8]. Jointly solving channel assignment and routing protocol of the problem also has been conducted [9]. People also investigated traffic aware algorithms to improve network performance [10] [11] [12]. Some researches considered to optimize router locations [13]. There are also other researches [14] [15] [16]. But they all these methods are heuristic methods which cannot guarantee a better performance. The new graph neural networks, an emerging method used to solve graph problems might be useful in solving the channel interference problem.

II. Related Work

Channel assignment in wireless mesh network has been explored for several years and the most classical algorithms like low-interference [17] or BFS multi-radio [18] are based on network topology. They are centralized, static, not very effective but could achieve global optimum. Many algorithms later on intended to improve different properties in order to get higher throughput, lower interference or robustness. One certain kind of algorithm is aimed at assigning channel among links in a decentralized way so that control servers and root nodes are eliminated but each node could assign channels to links. Imposed code based algorithm [19] encodes a special s-disjunct code into each node to minimize total interference. And also, reinforcement learning [20] could be applied to channel assignment in which every node could learn and teach itself how to assign channels. Some other algorithms attempt to design dynamic assignment methods. One typical algorithm is prob channel usage based assignment [21] which splits two interfaces for one node and they have different mechanism to adjust channels. Another agorithm named Adaptive dynamic channel allocation [22] is quite similar, but it's designed for hybrid mesh network and the core idea here is the channel negotiation among links.

IEEE 802.11 guarantees WIFI 2.4GHZ to contain 3 different non-overlapped channels and most algorithms mentioned above assume that all channels among links are non-overlapped. But Some algorithms want to utilize these partially overlapped channels in order to maximize the mesh network capacity and improve the throughput. One famous algorithm is Min-interference and Connectivity-Oriented Partially Overlapped Channel Assignment [23]. The core idea here is to do a priority-queue among links based on node neighbours, minimum hops to gateways and connectivity factor. And then, the algorithm calculates assumed interference for each channel in the queue and finally do routing selection and assigning channels.

There algorithms mentioned above contain some advanced properties such as dynamic, decentralized or partially overlapped channel usage. However, none of them combines all these advanced properties together. For example, the MC-POCA [24] is still a centralized and static algorithm which could be sensitive to network topology and not that effective.

Research about channel assignment in protocol models for modeling inference has done a lot and the most common model is protocol model because of its simplicity and ease of implementation [25]. However to include cumulative interference, the SIR model has been used. But it doesn't suitable for large-scale multi-hop wireless networks. So to solve this problem, the SIR with shadowing model has been tested [25]. The researchers proposed a model with simple methods to build conflict graph based on the SIR model with shadowing. The researchers also developed simple and effective heuristics methods for finding wireless mesh networks in the constructed conflict graph and they found this model requires the largest number of frequency channels for interference free communication. In single-radio single-channel wireless networks, the greedy maximal scheduling and maximal scheduling algorithm have low-complexity scheduling policies. Researchers also developed a model which transforms multi-radio multi-channel networks to multiple node-radio-channel tuples [26]. This work enables tuple-based greedy maximal scheduling and maximal scheduling algorithm as low-complexity approximation algorithms. Also, this method guaranteed performance. Comparing with the work by Lin and Rasool, this algorithm achieves better performance in enabling a fully decomposable cross-layer control framework [27]. Because using partially overlapped channels in wireless mesh networks could improve the capacity of multi-radio multi-channel wireless mesh networks, this technique has been widely exploited to investigate efficient partially overlapped channel assignment algorithms. Liu and Li has proposed a partially overlapped channel assignment algorithm MC-POCA that could minimize total network interference [28].

III. Experiment

A. *Generate wireless mesh networks*

To evaluate the performance of the proposed channel assignment algorithm, a wireless mesh network was generated. In this problem, a 500*500 area was set up to place the nodes. The total number of nodes has been set to be 1000 and communication range is 20. To generate the positions of nodes, a uniform [29] distribution was applied to generate the nodes x-axis and y-axis values. A random seed was set to control the variability. A 1000*3 matrix was generated with the first column of nodes id, the second column is nodes x-axis and the third column is nodes y-axis.

Then based on the nodes locations, pairwise distance between all nodes were calculated and stored in nodes distance matrix. The dimension of the matrix is 1000000*5, the first column is the potential link index which is used to label all correlations between all nodes. The second column is is the first node index and the third column is the second node index. The fourth column is the calculated distance between the first and second node. The last column is the indicator of the node. The indicator is 0 stands for there is no potential link between these two nodes and the indicator is 1 stands for these two nodes could form a link. The nodes distance is compare with 20 so that if the distance is greater than 20, there won't be a link and if the distance is shorter than 20, it is potential to form a link between these two nodes.

Then based on the nodes distance matrix, distance between each pair of links were calculated. The distance is calculated by calculating the distance between two nodes in one link to two nodes in another link. The link distance data is stored in link distance matrix with dimension (#links*#links)*5. The first column is the first node index of first link, the second column is the second node of first link. The third column is first node of second link and fourth column is second node of second link. The fifth column is distance between these two links.

IV. Proposed work

For this proposal, we have not yet decided and designed the algorithm that we are going to use. We'd like to develop a new channel assignment algorithm that can be used to minimize the interference and possibly increase the total network throughput. In the following subsections, we'll discuss our plan about the potential methodologies, the evaluation methods and the performance metrics.

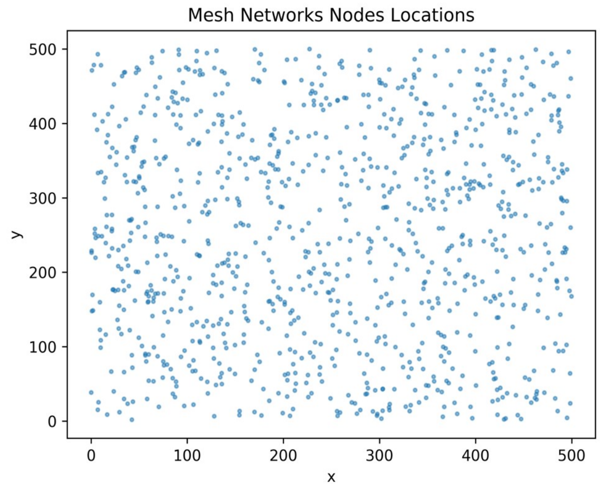

Fig. 1. Uniform distribution generated wireless mesh network nodes locations)

A. Possible Methodology Improvement

1) Partially Overlapped Channel Assignment: The Partially Overlapped Channel Assignment [23] could improve mesh network capacity and throughput significantly, however the algorithm it self is central and static which means it could not be applied to large-scale mesh network, and also calculating the priority queue among links could take too much time. Another drawback of the algorithm is that the links which are calculated later may affect the throughput of those are already calculated and assigned with certain channels.

Our goal is to improve the way to calculate the priority queue among links so that the order of computing interference will not interfere with each other.

2) Q-learning Based Channel Assignment: Q-learning Based Channel Assignment could be deployed to large-scale mesh network and don't require control servers or super-nodes to monitor and assign channels. However, reinforcement learning require huge amount of data to achieve good throughput which is conflict to the infrastructure of wireless mesh network because there may not be enough data for each node to learn in certain time. One possible approach here is to try other unsupervised learning such as k-means or hierarchical clustering which may be more effective.

3) Multi-Radio BFS Channel Assignment: Multi-Radio BFS Channel Assignment is highly sensitive to mesh network topology. In some extreme case when mesh network deployed as U-shape or O-shape, this kind of channel assignment algorithm could not perform as good as normal cases. Our algorithm may attempt some other probability based channel assignments to improve the overall throughput and the robustness of the channel assignment mechanism.

B. Evaluation Methods

We decided to first incorporate the graph based evaluation method that is widely adapted by the community such as in [30] [24] to evaluate the algorithms. In this method, we can use two types of graph, random graph or grid graph. For random graph, there are several parameter's that we can use to explore different aspects that may impact the performance, such as the number of nodes, where each nodes represent each mesh router in the network, the square of dimension that the nodes will be distributed in, and the radio range. It's typically assumed that the interference range is the same as the radio range, which is a reasonable assumption to us as well. The number of nodes is an interesting variable to us because we can explore how density of a network affects the algorithm. A grid graph is different from a random graph in the way the nodes are distributed in the square of dimension space. For a grid graph, the internal nodes will have a degree of 4, side node will have a degree of 3, and corner nodes will have a degree of 2. This allows us to test whether the algorithm can benefit with a well planned network layout.

In addition to the graph based method, we have a stretch goal of using NS-3 to measure the network throughput with the channel assignments obtained by the algorithms. NS-3 is a discrete-event simulator that can utilize existing protocol implementations, supports interaction to the real-world system, and is able to reuse applications and kernel code. It's extremely realistic simulation that we think can be comparable to real world deployment. However, we've learned that it may become time consuming to get ourselves to familiarize with the software. Thus, we made it a stretch goal so that we'll focus more on our algorithm design and implementation.

C. Performance Metrics

For performance, we are planning to use the fractional network interference as our metric. It was also the metric used in [30] [24]. It can be computed as follows:

$$FNI = \frac{I(f)}{|E(G_c)|} \tag{1}$$

TABLE I
PROJECT MILESTONES TABLE

Date	Task
03/05	Design algorithm or improve an existing algorithm
03/05	Research feasibility of learning and utilizing NS-3
03/19	Implement the algorithm
04/03	Evaluated and summarize the results
04/16	Prepare for progress presentation
04/30	Prepare and submit final report

where $I(f)$ is the total interference after the channel assignment, $|E(G_c)|$ is the total number of edges in the conflict graph G_c, which also means the total interference using only one channel for the entire system.

There are two ways to compute $I(f)$. If we assume binary interference, meaning either there is interference or there isn't, we can have:

$$I(f) = \sum_{(u,v)\in M} t(v)t(u)r(u,v) \tag{2}$$

where $t(v)$ and $t(u)$ are the track of the link v and u, $r(u,v)$ is either 0 represent no interference or 1 otherwise. If we assume non-binary interference, we can use:

$$I(f) = \sum_{(u,v)\in M} t(v)t(u)r(u,v)c(f(u),f(v)) \tag{3}$$

where $c(f(u),f(v))$ is the interference factor between channel $f(u)$ and $f(v)$ that we learned in our class.

V. PROJECT MILESTONES AND WORKLOAD DISTRIBUTION

See Table I for our project milestones and Table II for our workload distribution.

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TABLE II
WORKLOAD DISTRIBUTION TABLE

Task	Assigned Members
Design algorithms or improve an existing algorithm	Xiaoyan
Research feasibility of learning and utilizing NS-3	Zhongzheng
Implement the algorithm	Chang
Evaluation and result analysis	Zhongzheng
Prepare for progress presentation	
Progress presentation (algorithm design)	Xiaoyan
Progress presentation (implementation detail)	Chang
Progress presentation (evaluation and results)	Zhongzheng
Prepare and submit final report	
Final report (Abstract, Introduction, and Methodology)	Xiaoyan
Final report (Related Work and Future Work)	Chang
Final report (Technical Implementation and Evaluation)	Zhongzheng

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