Wireless Mesh Network Channel Assignment

* A CSE812 Course Project

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***Abstract*—This report is for our Wireless Mesh Network Channel Assignment course project. In this report, we will introduce the channel assignment problem, discuss the our algorithm structure and our scoring function, and present our evaluation metrics and results with our analysis. In short, we found that by using our scoring function, there are some performance improvement using the graph based simulation.**

***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 algorithm 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.

One important model we used is the conflict graph. The conflict graph is the the graph structure instead of presenting wireless mesh network nodes as nodes in graph and links as links, nodes in graph are presenting links in wireless mesh network and if there is interference between two links, there is a link between two nodes in the corresponding conflict graph [25] [26]. The reason using conflict graph because it could simplify the problem and make it easier to form a model for the simplified problem,.

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 [27]. 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 [27]. 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 [28]. 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 [29]. 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 [30]. The inference model is used from previous research and compared the results. In the interference model, if the physical distance between two links less than the interference range which is communication range, these two links will conflict each other. The interference is also correlated to the channel separation. Assume the interference range is $R^{''}(\tau)$:

$$R^{''}(\tau) = \sqrt[k]{(P_t * G_r * G_t * h_t^2 * h_r^2)/CS_t h} = Irrr(\tau) * R$$

In this equation, R is the co-channel interference range, and Irrr() is the reduced interference range. The Irrr value could be calculated theoretically. Also, interference relationship between links could be calculated by channel interference ratio ir(p, l), and the equation of the ir could be classified by three cases presented in the function below:

$$ir(p,l) = \begin{cases} 0 \quad if \quad p \cap l \neq \varnothing \cup \tau \geq 5 \cup d(p,l) > R^{''}(\tau) \\ \frac{R^{''}(\tau)}{d(p,l)} \quad if \quad 0 < d(p,l) \leq R^{''}(\tau) \\ \alpha \quad otherwise \end{cases} \tag{1}$$

The first case is: when link p and link l share the same interface, or the channel separation between channels used by these links is equal or greater than 5 or the physical distance between these two links is greater than communication range, then these two links have no interference. The case two is when the link p and link l physical distance is less than communication range or interference range, these two links will inference each other. Also, the interference ratio $R^{''}(\tau)$ will be calculated by the interference range and physical distance between these two links d(p, l). In case three, the interference ratio ir(p, l) will be set to a large value α, like 10, so avoiding using POCs (partially overlapped channels) on distinct interfaces of the same node [31].

III. METHODOLOGY

A. Channel assignment structure

Sequential Forward Selection is the methodology that we used in our report. SFS is a classic methodology in feature selection areas but it still could be used in our channel assignment. The major difference is that feature selection regards all features as the same weights, so none of the feature has the priority. However, for our channel assignment, the descending priority queue decide which channel to be assigned first, and each link has a rank.

Another important thing is that SFS in feature selection usually will terminate at when there are k features extracted. But we can not tell how many links should be assigned and others not, unless we design another evaluation function or evaluation methods. Here the experiment part will discuss the evaluation in detail.

Algorithm 1: SFS Channel Assignment

1) Start with a ranked link queue in which all links are not assigned with any channel.
2) Assign the best channel for each link in the list $\omega_i^+ = \arg\max_{\omega\in[1,12]} J(Y_k + \omega)$
3) Update $Y_{k+1} = Y_k + x^+$; $k = k + 1$
4) Repeat Step 2&3 until it satisfies certain evaluation function $E(Y)$

B. Interference Range

The partially overlapped channel assignment methodology which we base on regards the link interference range to be the node interference range of 2 closest nodes of the 2 links. There are several drawbacks of this method. First of all, partially overlapped channel will have large amounts of interfered link pairs, which means that there will be much more errors in channel assignment. Next, current assigned links may interference other empty links within the interference range. For example, if assigning side channel 1 to the current link, channel $5-12$ can be continuous bandwidth for upcoming channel assignment. However, if assigning channel 5, only channel 1 and channel $11, 12$ will be no-interference channel for upcoming channel assignment.

C. Score function

In this project, we proposed a new methodology for score function when assigning channel to certain links. Other than choose the node interference range of 2 closest nodes of links, we check all possible links no matter assigned or empty links.

1) $e_0(s,t)$ affected by other transmitters:

$$Pr_t = Pt_s G_s G_t \left(\frac{\lambda}{4\pi D_{st}}\right)^2 \tag{2}$$

In the Equation 2, Pr_t is the receiver power of t; Pt_s is the transmission power of s; G_s and G_t are antenna gains; λ means the wavelength; D_{st} is the distance between s and t.

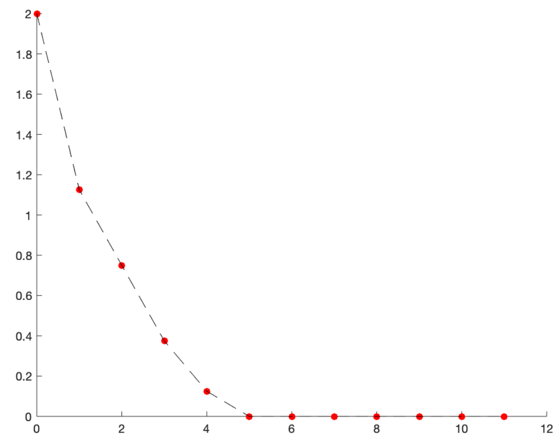

Fig. 1. $g(\omega - \omega_i)$ function example

For one of other transmitters within link $e_i(p,q)$ which can effect the receiver of e

$$Pr_t(i) = Pt_p G_p G_t \left(\frac{\lambda}{4\pi D_{pt}}\right)^2, i \geq 1 \tag{3}$$

For the receiver node t, the signal combined with interference from other links can be expressed as

$$\hat{Pr_t} = Pr_t + \sum_{i\in A(0)} Pr_t(i) \tag{4}$$

$A(0)$ is a set in which all links have been assigned with certain channels and their interference ranges all covers link $e(s,t)$

P_{rt} is the desired receiver signal power when there is no interference links while $\hat{P_{rt}}$ is the actual receiver signal power in the mesh network.

Now we get the constraint from the above equation, suppose the ratio

$$\frac{\hat{Pr_t}}{Pr_t} \leq \xi \tag{5}$$

Actually, ξ is the SNR (Signal Noise Ratio) of the receiver signal, which is predefined because wireless mesh network utilizes OQPSK or 64QAM demodulation.

To measure how $e(s,t)$ is affected by other links by assigning channel ω, design a score function as following:

$$SD(\omega) = \sum_{i\in A(0)} \frac{Pr_t(i)}{Pr_t} g(\omega - \omega_i) \tag{6}$$

In Figure 1, we define $\delta = \omega - \omega_i$ to be 0 when $\delta \geq 5$. Note function $g(u)$ is not continuous and u could only be integers in $[0, 11]$ corresponding to channel differences.

2) e_0 affects those links assigned with channel: For one of the links interfered by $e_0(s,t)$, let's say $e_j(m,n)$, the original signal that n receive can be expressed as

$$Pr_n(j) = Pt_m G_m G_n \left(\frac{\lambda}{4\pi D_{mn}}\right)^2, j \geq 1 \tag{7}$$

After $e_0(s,t)$ is assigned with frequency ω

$$P_j(0) = Pt_s G_s G_n(\frac{\lambda}{4\pi D_{sn}})^2, j \geq 1 \tag{8}$$

The receiver n of any link $e_j(m,n)$

$$\hat{Pr_n}(j) = Pr_n(j) + P_j(0) \tag{9}$$

Different from measuring how $e_0(s,t)$ affect other links and set up a threshold ξ, here we should discuss how each link is affected by $e_0(s,t)$

There are two ways to define the constraints in this scenario.

Firstly, we can deduce the constraint for each link $e_j(m,n)$

$$\frac{\hat{Pr_n}(j)}{Pr_n(j)} \leq \delta(j) \tag{10}$$

Also, we could apply Minkowski metric to measure the distance of two vectors:

$$\underline{\hat{Pr}}_n = [\hat{Pr_n}(1), \hat{Pr_n}(2), \dots, \hat{Pr_n}(j)]$$

$$\underline{Pr}_n = [Pr_n(1), Pr_n(2), \dots, Pr_n(j)]$$

$$L_k(\underline{\hat{Pr}}_n, \underline{Pr}_n) = \left(\sum_{j \in B(0)} |\frac{\hat{Pr_n}(j)}{Pr_n(j)} - 1|^k \right)^{1/k} \tag{11}$$

Then the constraint could also be written as

$$L_k(\underline{\hat{Pr}}_n, \underline{Pr}_n) \leq \delta \tag{12}$$

To measure how assigning ω to $e_0(s,t)$ will interference other links, we can also define a score function

$$SS(\omega) = \left(\sum_{j \in B(0)} \left[|\frac{\hat{Pr_n}(j)}{Pr_n(j)} - 1| * g(\omega - \omega_j) \right]^k \right)^{1/k} \tag{13}$$

3) $e_0(s,t)$ affects links without assigning certain channel: Assigning channel to links may not only interference with those links already assigned with channels, but it may affect those idle links. Once we assign channel ω to e_0, other links might also be interferenced even on the very beginning of the channel assignment.

We already formulate the relationship between $e_0(s,t)$ and other links in its interference range

$$P_j(0) = Pt_s G_s G_n(\frac{\lambda}{4\pi D_{sn}})^2, j \geq 1 \tag{14}$$

Since all nodes in $e_0(s,t)$ interference range but haven't assigned channels could be future link receivers possibly, we can assume only receiver antenna gain and distance count for interference.

$$P_j(0) \simeq \frac{G_n}{D_{sn}^2} \tag{15}$$

Also, the channel ω assigned to $e_0(s,t)$ should be considered. For example, if we choose Channel 1 with 2414 ± 11MHz, there will be fewer partially overlapped channels than we choose Channel 5 with 2432 ± 11MHz. And we can define a function $f(\omega)$ measuring this kind of relationship.

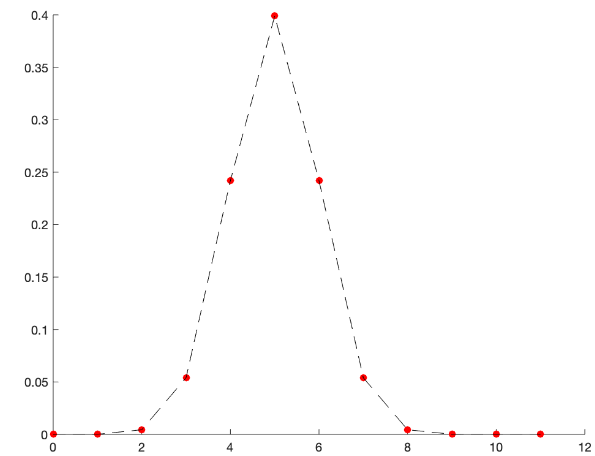

Fig. 2. $f(\omega)$ function example

Define the score function as following

$$SE(\omega) = \sum_{j \in B(0)} \frac{G_n(j)}{R_j D_{sj}^2} f(\omega) \tag{16}$$

In which, R_j denotes that the smallest index the node appears as a receiver in the link priority queue. Generally, it represents the likelihood the node will be selected as the receiver of a link which is interfered by e_0

$f(\omega)$ is the discontinuous function predefined. The reason why side channels like 1 or 12 get a relatively small $f(\omega)$ value is if we choose side channels, there will be continuous channel bandwidth for those unassigned empty links.

4) Select which channel ω to apply: Define the score function for each channel that could be selected

$$J(\omega) = \widetilde{SS(\omega)} + \widetilde{SD(\omega)} + \widetilde{SE(\omega)} \tag{17}$$

In which, $\widetilde{SS(\omega)}$, $\widetilde{SE(\omega)}$ and $\widetilde{SD(\omega)}$ represent the normalized score function $SS(\omega)$, $SE(\omega)$ and $SD(\omega)$ respectively.

Then our strategy to choose the proper channel ω for $e_0(s,t)$ can be

$$\omega = \arg\min\{Score(\omega)\}, \omega \in [1, 12] \tag{18}$$

5) Wavelength λ: According to frequency, we can get the wavelength range for mesh network

$$\lambda = \frac{c}{f} \tag{19}$$

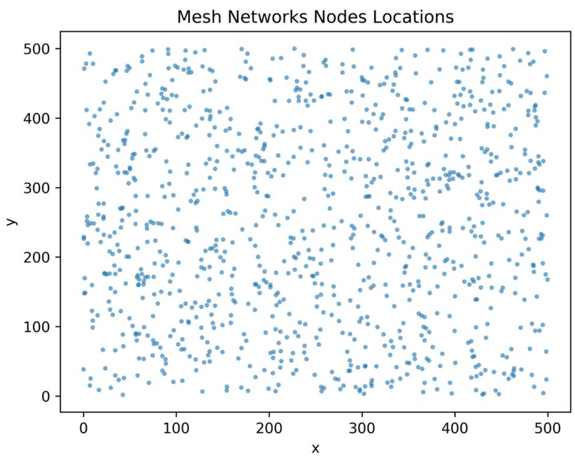

Fig. 3. Uniform distribution generated wireless mesh network nodes locations)

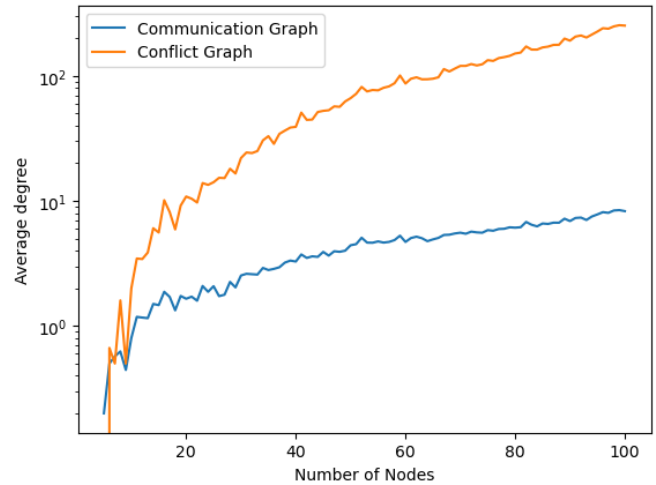

Fig. 4. Number of nodes vs. Average Degree of the Nodes in the Random Graph

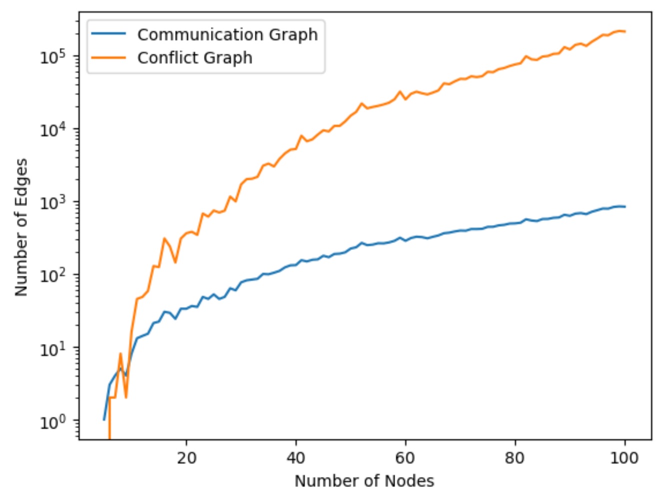

Fig. 5. Number of nodes vs. Number of Edges of the Nodes in the Random Graph

We can get the wavelength range is about $[0.1208, 0.1244]$m, which is very narrow. So we can just use the fixed wavelength λ for our channel selection algorithm.

IV. Technical Results and Analysis

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 [32] 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.

B. Graph Analysis

In our proposal, we discussed that random graph of large network size is one of the important factor that may impact a channel assignment algorithm's performance. We first want to analyze how difficult large network size can potentially be. We started with some graph statistic analysis on the average degree and average edges of an random graph with varies number of nodes. We set the area to be $1000m \times 1000m$ and both communication range and interference range to be $250m$.

As shown in Fig. 4 and 5, note both figures are shown y-axis on log space, it was easily observable that both the average degree of the nodes in a network and the average number of edges grows drastically as the number of nodes increase. If we

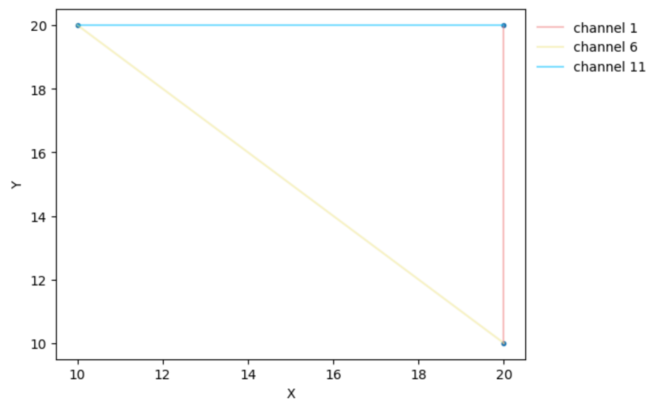

Fig. 6. Visualization of the channel assignment result on a simple 3 nodes graph with SFS

look at the grows for the conflict graphs that were generated from the communication random graph, the increase was even more severe. This have introduce how important it is for the algorithms to handle large network size, because the larger the conflict graph, the higher the interference can become if not handled properly.

C. Graph Visualization

In order to ensure that our algorithm preformed as intended, we implemented the graph visualization utility function that helps us visualize the algorithm result. As shown in Fig. 6, the algorithm indeed assigned the channels correctly to this simple 3 nodes graph that has optimal solutions. The channel assigned were channel 1, 6, and 11, which are all 5 channel apart from each other. Thus, the interference was minimized to 0.

D. Performance Metric

To measure our performance, we are using Fractional Network Interference (FNI) as our metric. FNI was usually used for the graph based performance analysis, such as in [33] [24] [34]. It can be computed as follows:

$$FNI = \frac{I(f)}{|E(G_c)|} \tag{20}$$

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. Therefore, FNI can represent the number of conflicts remaining by the channel assignment algorithm relative to a single channel network.

As discussed in our proposal, there are two ways to compute $I(f)$. One assumes a binary interference, meaning either there is interference or there isn't. However, since we are using the overlapping channels for in our algorithm, we will use the second non-binary interference calculation:

$$I(f) = \sum_{(u,v)\in M} t(v)t(u)r(u,v)c(f(u), f(v)) \tag{21}$$

TABLE I
INTERFERENCE RANGE TABLE FROM LECTURE1-4 SLIDE 18

	I_0	I_1	I_2	I_3	I_4	I_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

where $t(v)$ and $t(u)$ are the traffic of the link v and u, $r(u,v)$ is the level of interference between the two links, $c(f(u), f(v))$ is the interference factor between channel $f(u)$ and $f(v)$.

E. Graph Based Simulation

Due to the difficulties of simulating the mesh network, and our lack of experiences with NS-3, we were unable to successfully evaluated our algorithm using NS-3 simulation. As the result, we were doing our evaluation using graph based approach and making some assumptions for the mesh network node parameters, such as antenna gain, transmission power, receiver threshold, and signal noise ratio (SNR). However, the affects of these assumptions were minimal because our evaluation on our method and the base method were using the same assumed parameters.

We have two other assumptions about the $r(u,v)$ and $c(f(u), f(v))$ mentioned in Eq. 21. Because we weren't able to performance our evaluations on NS-3 or a real deployment, it would be practically impossible for us to come up with the measures for the level of interference between two links and the interference factor between two channels. However, from what we've learned in class, we know that as distances increases, the interference would decrease. And the interference will also decrease as the channel separations increase, as shown in Table I that are taken from the lecture slides. Therefore, we think it is reasonable to make the following assumption because they keep the relative ordering of the interference magnitude that the FNI will be larger when there are greater interference remaining after the channel assignment.

$$r(u,v) = \begin{cases} 1 - (dis(u,v)/ir) & \text{if } dis(u,v) < ir \\ 0 & \text{otherwise} \end{cases} \tag{22}$$

$$c(f(u), f(v)) = 1 - abs(f(u) - f(v))/4 \tag{23}$$

where $dis(u,v)$ gives the distance between link u and v, ir is the interference range.

Once we've decided all the parameters needed, we randomly generate graphs from 5 nodes to 100 node using 1000m x 1000m as the area and 250m for both communication range and interference range. From the generated graph, we ran the base algorithm and our algorithm and computes the FNI for network graphs of the difference sizes to explore how the network size affects the algorithms. Then we also measured how the algorithms improves while it's assigning channels to each link on 100 nodes. The next subsection will discuss our results in detail.

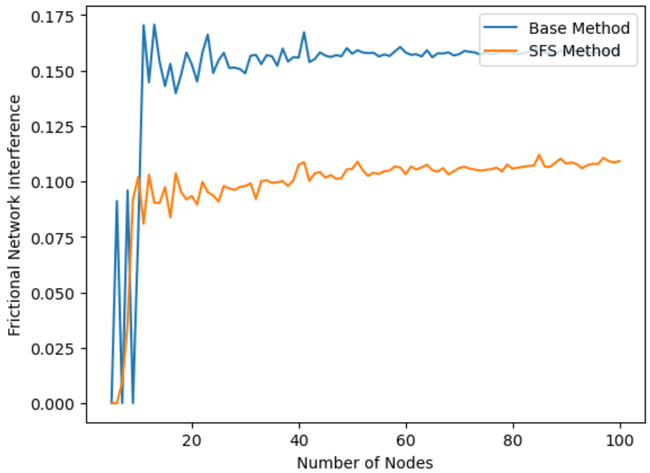

Fig. 7. Number of Nodes vs. FNI

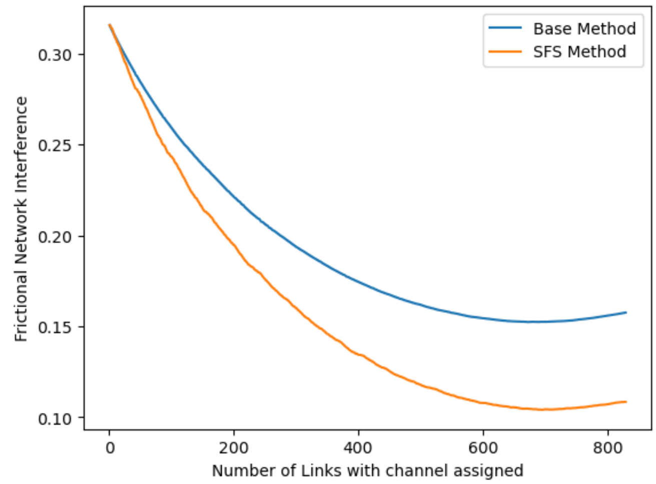

Fig. 8. Number of Links with Channel Assigned vs. FNI

F. Exploration of Different Network Size

As mentioned previously, by varying the size of the network, we can explore how it will impact the algorithms. Fig. 7 shows the results that we got.

As you can see in Fig. 7, both the base algorithm and our SFS algorithm can handle the increases of the number of nodes. As the network grows larger, the FNI starts to flatten. Since FNI is the fraction between the total interference remaining after the channel assignment and the total interference as if it's single channel network, the result means the two algorithm can scale up to larger networks.

It's also worth noting that our SFS had a lower FNI compare to the base algorithm as number of nodes increases. We think the reason is because our scoring function takes considering of the previous links that were assigned to a channel and also the impact it would have on the future links' channel assignments. However, the base algorithm only considers if the current link is in the interference range of the previously assigned channels. Therefore, the selection of channel from our scoring function helps to select a better channel, and led to the better FNI values.

G. Intermediate Improvement for 100 Nodes

Fig. 8 shows how the algorithms improves as they starts to assign channels to the link. As the figure shows, both the base and the SFS method decreases FNI as expected. However, SFS method had a more significant decreasing rate compared to the base algorithm. We think it is due to the same reason as in Section IV-F that our scoring function performed as what we expected it to.

V. Future Work

A. Issue for Priority queue

One possible drawback is that the priority queue used to store links could be messed up if there are too many links have the same rank. For example, in large grid mesh network, our methodology may not work since there ranks may be the same for most mesh nodes. The possible solution for this problem is taking the topology factor into consideration. For example, those channels which are in the middle of the whole mesh network.

B. New Floating Structure

Another drawback is once we assign a channel, we don't have the chance to cancel it even the current assignment will reduce the total performance. The SFFS (Sequential Forward Floating Algorithm) may address this problem since it can exclude certain assigned links in some situation.

Algorithm 2: SFFS Channel Assignment

1) Start with a ranked link queue in which all links are not assigned with any channel.
2) **Inclusion**
   Assign the best channel for each link in the list $\omega_i^+ = \arg\max_{\omega \in [1,12]} J(Y_k + \omega)$
3) **Conditional Exclusion**
   Check the link which we just assigned with channel, if we get worse evaluation result $E(Y - x^+) < E(Y)$, then keep it and return to Step 1. Otherwise, withdraw the assigned channel in Step 2 and recalculate the Priority link queue based on the new available $num\_neighbour$
4) **Continuation of conditional exclusion**
   Again check the last assigned link, if $E(Y - x_j^+) > E(Y)$, then withdraw the assigned channel in Step 3 and recalculate the Priority link queue based on the new available $num\_neighbour$. When $E(Y - x_j^+) \leq E(Y)$, return to Step 2.
5) Algorithm ends when it satisfies evaluation function $E(Y)$

VI. Summary and Lessons Learned

In summary, we designed our own scoring function that take considering of the impact of the channel assignment of the current link to the future links' channel assignment. This way, it helps to minimize the overall total interference once the algorithm finishes. Although, there is the drawback that we discussed in Section V, our SFS algorithm achieved better performance in the graph based simulation than the base algorithm.

There were a lot that we learned from this project. One of the most important lesson and one that we have done was to start early. Our algorithm have taken some substantial amount of run time for us to obtain our evaluation results, especially to compute the performance for large number of nodes. It will be a great advice for any future student in this course to start their evaluation as early as possible, so that the long run time won't be an issue, especially when taking considering of time for debugging as well.

VII. Work Distribution

Table II and Table III showed our work distribution for the project and this report.

TABLE II
Workload Distribution Table

Task	Assigned Members
Literature Review	Xiaoyan
Graph Generation	Xiaoyan
Algorithm Design (SFS and SFFS)	Chang
New Scoring Function	Chang
Algorithm Implementation	Chang
Graph Analysis	Zhongzheng
Algorithm Steps Visualization	Zhongzheng
Performance Evaluation	Zhongzheng

TABLE III
Workload Distribution Table for the Report

Report Section	Assigned Members
Abstract	Zhongzheng
Introduction	Xiaoyan
Related Work	Xiaoyan
Methodology	Chang
Technical Results and Analysis	Zhongzheng and Xiaoyan
Future Work	Chang
Summary and Lessons Learned	Zhongzheng

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