Novel and Optimal channel assignment in multi-channel wireless mesh networks

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Abstract

Wireless mesh network have the potential to deliver internet broads and access, resource sharing wireless local area network coverage and network connectivity for stationary or mobile hosts at low cost both for network and customers. In multi radio multi-channel wireless mesh networks, many approaches have been developed to maximize the network throughput with limited channel resources. It is understood that limited spectrum resources can be fully exploited by utilizing partially overlapping channels in addition to non overlapping channels in 802.11b/g networks.

In this work, an extension to the traditional conflict graph model i.e., weighted conflict graph is proposed to model the interference between wireless links more accurately.

We present a novel optimal channel assignment algorithm which has the potential to obtain better solutions. Through simulations, we demonstrate that the network performance can be dramatically improved by properly utilizing the partially overlapping channels. The qos performance of the proposed channel assignment algorithm is compared with existing methods.

Keywords: *Multi-radio multi-channel wireless mesh networks, novel optimal channel assignment algorithm.*

I. INTRODUCTION

Wireless mesh networks (WMNs) consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of the network [1]. Recently, there has been growing interest in using WMNs to extend or enhance Internet connectivity on the last mile. Some commercial deployments are already working to provide low cost connectivity to residents and local businesses. One major problem facing WMNs is the capacity reduction caused by the interference among multiple simultaneous transmissions [2]. When two nearby wireless links communicate on the same frequency band, they cannot transmit data simultaneously. As a result, the throughput of each link may be decreased dramatically due to the interference from the other link. Also, a router cannot transmit and receive simultaneously with a single radio.

To alleviate these problems, in many WMNs, mesh routers are equipped with multiple radios, which can be configured to operate on different channels. Thus, nodes are able to transmit and receive simultaneously in multi-radio multi-channel WMNs.

It is known that 802.11b/g and 802.11a provide 3 and 12 non-over-lapping channels respectively. Although 802.11a provides more channel resources than 802.11b/g, it has several drawbacks. As 802.11a works on higher frequency spectrum (5GHz) than 802.11b/g (2.4GHz), it is more difficult to penetrate walls and other obstructions, and thus has a shorter range. In addition, 5GHz belongs to the regulated frequency spectrum, which makes 802.11a more expensive to operate. As a result, 802.11b/g is more commonly used.

To improve the throughput of WMNs, much research [3-10] has been done on configuring the network interfaces of mesh routers with different non-overlapping channels to avoid interference. However, due to the limited number of channels available, the interference cannot be completely eliminated. This is especially true in the case of 802.11b/g, which provides only three non-overlapping channels.

802.11b/g provides 14 channels, of which only the first 11 channels are permitted in US. According to 802.11b/g, if the channel separation is greater than 4, the two channels are non-overlapping channels (or orthogonal channels). Otherwise, they are partially overlapping channels. Thus, the number of non-overlapping usable channels is at most three (channel 1, 6 and 11). Previous algorithms [3-10] only consider the non-overlapping channels in the channel assignment. A simplified interference model is usually assumed, that is, if two links are within interference range of each other (twice the transmission range R), they can transmit and receive simultaneously only if they use different non-overlapping channels. As a result, the frequency spectrum has not been fully exploited in these cases.

In this paper, we will study how to further mitigate the effects of interference in 802.11b/g mesh networks by fully exploiting the spectrum resource, that is, utilizing both non-overlapping channels and partially overlapping channels, and efficient channel assignment algorithms. We present a greedy channel assignment algorithm based on the weighted conflict graph in 802.11b/g mesh networks, which fully utilizes the spectrum resource. From simulations, we conclude that the network throughput can be dramatically improved by utilizing partially overlapping channels as well as non-overlapping channels. This work includes related work, problem formulation, optimal channel assignment algorithm, results and discussion, conclusion.

II. RELATED WORK

A major problem facing multi-hop wireless networks is the interference between adjacent links. The throughput of a single-radio single-channel wireless network has been studied in [2]. The authors formalized it as a multi-commodity flow problem with constraints from conflict graph, which is NP hard, and gave an upper bound and a lower bound of the problem.

There have been many studies on how to assign limited channels to network interfaces in a multi-radio multi-channel wireless mesh network so as to minimize interference and maximize throughput. They differ in several assumptions made in WMNs, and therefore in the models and related solutions.

One approach assumes a known traffic profile in the network, because the aggregate traffic load of each mesh router changes infrequently. The authors of [3] proposed an iterative approach to solve the joint routing and channel assignment problem, which can calculate a routing scheme as well as a channel assignment scheme, such that all traffic profiles can be satisfied. The problem has been formulated in [4] and [5] by using linear programming with constraints on interference and fairness, which is NP hard. The authors proposed approximation algorithms to get a joint routing and channel assignment scheme.

Other studies assume that the traffic profile of each mesh router is not known, and usually consider channel assignment and routing separately. The authors of [6] assumed that the traffic from the Internet gateway to clients is dominant, and thus they first constructed a load-balanced routing tree from the original network topology, and then proposed a distributed load-aware algorithm to assign channels to the links on the tree. In [7], the peer-to-peer traffic was assumed to be dominant in the network. The authors first constructed a k-connected backbone from the original network topology, and then assigned channels on the constructed topology. There have also been some heuristic channel assignment algorithms proposed in [8] [9] to minimize the interference in the wireless mesh network when the backbone topology is already determined.

Besides these static channel assignment algorithms, which assign channels to interfaces without change for a long time, there have been several dynamic channel allocation algorithms proposed, which allow interfaces to switch channels frequently. The authors of [10] proposed an on-demand channel allocation protocol in a wireless mesh network, where each node has two interfaces. In their framework, one interface of each node is devoted to controlling channel negotiation only while the other interface is used for data transmission. On the other hand, the frameworks proposed in [11] and [12] do not require a separate control interface, and the channel negotiation happens on the same interface for data transmission. As the overhead of dynamic channel switching cannot be neglected, static channel allocation strategies are more widely used in a static wireless mesh network. Thus in this paper, we focus on static channel assignment algorithms.

Previous channel assignment algorithms are based on non-overlapping channels. The benefit of using partially overlapping channels in WLANs has been studied in [13], [14] and [15]. In [13], the authors measured the interference between different APs when partially overlapping channels are used. They proposed channel assignment algorithms with partially overlapping channels for APs in [14] and [15], which aim at minimizing the interference between different WLANs. A similar problem has also been studied in cellular networks [16]. The authors addressed the channel assignment problem of minimizing interference between same channels and adjacent channels. Different from these previous studies, we focus on utilizing partially overlapping channels to improve network throughput in WMNs, and study efficient channel assignment algorithms, which fully exploit the channel resources.

There have been several well-known test beds of WMNs. The MIT Roof Net [17] is a well-known test bed for wireless mesh networks built on the MIT campus. Microsoft has also constructed a test bed in their office building [18]. In these test beds, the wireless interference has been studied only on same channels. In this paper, we study the interference between partially overlapping channels.

The throughput of WMNs can be improved by using directional antennas. In [19], the authors proposed using directional antennas to establish point-to-point links. They observed that even in the presence of side-lobes, it is possible to transmit (receive) along all links of a node simultaneously under the same channel. They further considered multi-radio multi-channel WMNs using direction antennas, and proposed algorithms for channel assignment, which well utilize the special properties of directional antennas [20].In this paper, we focus on omni-directional antenna WMN, which is more commonly used due to its low cost. There have been many studies on routing metrics in WMNs. In [21], the authors provided a comparison of different routing metrics for static multi-hop wireless networks. WCETT (Weighted Cumulative ETT) has been proposed in [22], which has been shown to be more efficient than other traditional metrics in multi-radio multi-channel WMNs. Our work is focused on the channel assignment problem, which is below the routing layer in the network stack.

III. PROBLEM FORMULATION

This section explains about problem formulation, algorithms. Since we are focusing here on channel assignment algorithms, we assume that the network topology has been determined through careful planning or by some topology control algorithms beforehand such as [6] and [7]. We abstract the mesh network topology as a graph $G(V,E)$, where V represents mesh routers, and E represents wireless links. Each pair of mesh routers of a link has a separate interface de voted to constructing the link. Similar to [7], we assume the wireless mesh network has dynamic traffic, that is, the connection demands have random sources, destinations and arrival times. This is because there will be substantial random and unpredictable traffic within the mesh network caused by peer-to-peer and newly emerging applications in addition to the traffic from and towards the Internet.

If there are enough channel resources, the problem becomes assigning the vertices of the weighted conflict graph with channels (or colours) while satisfying that the distance between the channels of adjacent vertices is no less than the weight on the edge between them, such that the span between the minimum and maximum channel used is minimized. This problem can be modelled as T-Colouring problem [23], which is NP-hard. In reality, the channel resource that we can use is usually limited, so our goal becomes minimizing the interference in the network with limited channel resource. The channel assignment problem can be formulated as follows.

Let $(F(S,T), l)$ be the weighted conflict graph of $G(V,E)$ and C be the set of channels. We define a label A on S, $A(s_i) \in C$ is the channel on which link $s_i \in S$ is working. We also call A as a channel assignment scheme for the wireless mesh network.

Let $I(s_i, s_j, A(s_i), A(s_j))$ be the interference indicator between links $s_i, s_j \in S$, that is, it indicates whether these two links will interfere with each other under channel assignment A. This can be calculated by Algorithm 1 based on the weighted conflict graph.

Algorithm 1

```
step1:  if  $s_i s_j$ is not an edge in F then
step2:  I = 0  // no interference
step3:  else
step4:  if | $A(s_i)-A(s_j)$| ≥ $l(s_i s_j)$ then
step5:  I = 0
step6:  else
step7:  I = 1    // interfere with each other
step8:  end if
step9:  end if
```

For the simplicity of presentation, we define the following two objective functions:

$$H_1(\langle F,l\rangle,A) = \sum_{i}\sum_{j\neq i}\frac{I\left(s_i,s_j,A(s_i),A(s_j)\right)}{2} \qquad (1)$$

$$H_2(\langle F,l\rangle,A) = \max_{i}\sum_{j\neq i} I\left(s_{i,}s_{j,}A(s_i),A(s_j)\right) \qquad (2)$$

H_1 defines the total interference within the network, that is, the total number of link pairs that interfere with each other, while H_2 denotes the maximum link interference. Therefore, we are trying to find the channel assignment A that minimizes H_1 or minimizes H_2. These problems are NP hard, because the graph colouring problem is an NP complete problem. In the next section, we will solve for approximate solutions with objective H_1. The proposed algorithms can be easily modified for objective H_2.

IV. OPTIMAL CHANNEL ASSIGNMENT ALGORITHM

In this session we are discussing about optimal channel assignment and greedy algorithm. Generally speaking, our greedy algorithm is a series of decisions, each of which assigns a channel to a link, until all links have been assigned channels. Each decision is usually composed of two steps-*select* and *assign*. In the *select* step, a link that has not been assigned a channel is chosen according to metric α, and in the *assign* step, a proper channel is assigned to the selected link according to metric β. In each step, the link and its channel selection are determined by maximizing (or minimizing) their corresponding metrics α and β.

We define the metric α of a link as the expected level of interference between this link and all the other links in the network. As during the greedy channel assignment process, some links may not have been assigned channels yet, we use the expected value to evaluate the interference when selecting a link. Given the weighted conflict graph $(F(S,T), l)$,the expected interference of link $s \in S$, denoted by $\alpha(s)$, is computed as follows:

$$\alpha(s) = \sum_{s'\in S_1} \bar{I}_1(s,s') + \sum_{s'\in S_2} \bar{I}_2(s,s')$$

where S_1 is the set of links that have already been assigned channels, and S_2 is the set of links not assigned channels yet. $\bar{I}_1(s, s')$ (or $\bar{I}_2(s ,s')$) denotes the expected interference between s and s', which has been assigned (or not assigned) a channel. They are calculated in the following ways:

$$\bar{I}_1(s,s') = \frac{1}{|C|}\sum_{i\in C} I(s,s',i,A(s'))$$

$$\bar{I}_2(s,s') = \frac{1}{|C|^2}\sum_{i,j\in C} I(s,s',i,j)$$

Therefore, in each step, we select the link s that has the minimum expected interference $\alpha(s)$.In the *assign* step, we define the metric $\beta(c)$ for each candidate channel c that can be assigned to the selected link. $\beta(c)$ indicates the interference between the selected link and those links already assigned channels.

$$\beta(c) = \sum_{s'\in S_1} I(s,s',c,A(s'))$$

We select the channel c that has the minimum $\beta(c)$, thus minimizing the interference added to the network when we assign channels to the selected link. As described in Algorithm 2, given the weighted conflict graph *(F(S,T),l)* and the channel set *C*, the greedy algorithm obtains a channel assignment scheme *A*. This algorithm is able to and a solution very fast because it never changes a link's channel once it is assigned. Next, we will present a genetic algorithm, which has the potential to obtain near-optimal results.

Algorithm 2 Greedy-Algorithm **$(\langle F(S,T), l\rangle, C)$**

```
step1:  A(s) = null for all s Є S
step2:  $S_1 = \{\}, S_2 = S$
step3:  while $S_2 \neq \{\}$ do
step4:  Calculate α(s) for each link s Є $S_2$
step5:  Select $s^*$ such that $\alpha(s^*) = min_{s\in S_2}\ \alpha(s)$
step6:  For link $s^*$, calculate β(c) for each channel c
        Є C
step7:  Select $c^*$ such that $\beta(c^*) = min_{c\in C}\ \beta(c)$
step8:  $A(s^*) = c^*$
step9:  $S_1 = S_1 \cup \{s^*\}, S_2 = S_2 - \{s^*\}$
step10: End while
```

V. RESULTS AND DISCUSSION

In this session we are discussing about results. To evaluate the performance of our proposed method an NS-2 simulation scenario has been created and simulation results are compared with existing TCP flow assist tool [4] and wireless mesh network with Meshchord [20]. The improvement in QoS performance in wireless mesh networks by adopting multi-radio channel approach in TCP congestion control mechanism is investigated.In simulation, the peers are equipped with 802.11b multi radios, the link data rate is 11Mbps, and two-ray ground radio propagation is used. For routing messages between far-away peers, we used the dijkstra's routing algorithm in combination with our proposed algorithm. The simulation parameters are shown in Table 1.

Table 1 : Simulation Setup

Topology	***500x500 Grid***
No of Nodes	50
Data transfer	TCP
Data rate	100Kbps to 1500Kbps
Transmission Range	50 m
Channel assignment	Multi channel optimal channel assignment.

A. *Performance Evaluation*

Figure 1 shows the improvement in throughput performance as a result of efficient congestion control mechanism and multi-channel approach that are integrated in our proposed method.

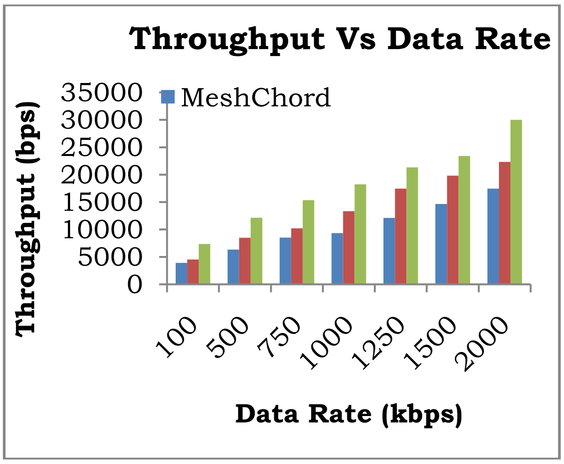

Fig. 1: Throughput Comparison of Data Rate.

Figure 2 highlights the effective packet delivery ratio achieved with our proposed method. Even when the maximum node data speed increases 100 to 1500 Kb/s, proposed system still enables nearly 99 percent of the packets to reach the destination.

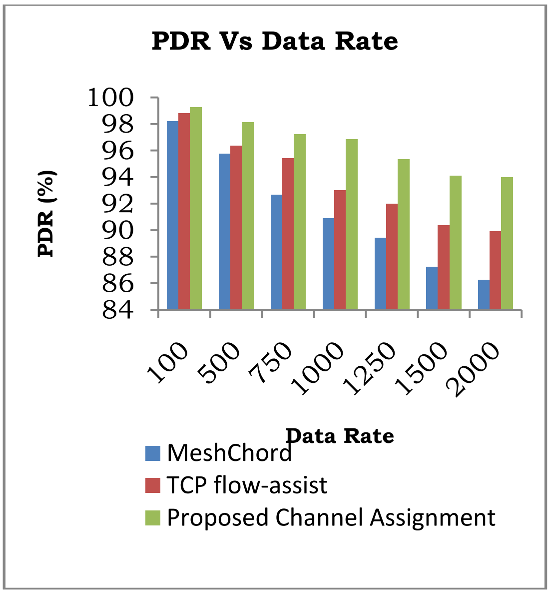

Fig. 2: Packet Delivery Ratio Comparison

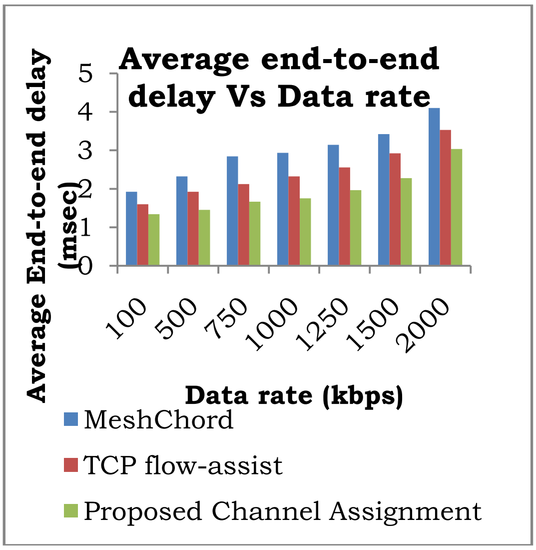

Fig. 3: Average end-to-end Delay Comparison

In Figure 3 we can observe that the proposed system delivers as many as possible packets at extremely low delay.

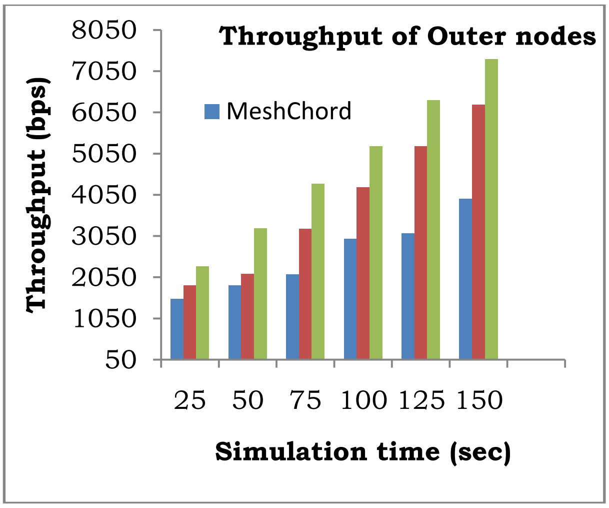

Fig. 4: Throughput of Outer Nodes

Figure 4 affirms the efficient channel assignment achieved with our proposed method by having good throughput performance for multi-hop nodes i.e., the nodes that are more than one-hop away from the gateway.

VI. CONCLUSION

In this work, we study the interference between overlapping channels and propose the weighted conflict graph, which can model the interference more accurately compared to conflict graph. Based on this model, we proposed a novel optimal channel assignment algorithm which utilizes both orthogonal and partially overlapping channels in the channel allocation. The proposed channel assignment algorithm assigns channel to TCP flows in such a way that channel interference is minimized.

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