Constrained Channel Assignment in Multi-channel Wireless Mesh Network

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Abstract
A wireless mesh network is a multi-hop network consisting nodes called mesh routers and mesh clients. In the network, communication between a pair of nodes happens when both nodes share a same channel. Channel assignment is an application in graph theory on the vertex coloring. The channels are allocated in such a way to minimize the bandwidth with the constraints of avoiding the electromagnetic interference. In this paper, we focus on the channel allocation for multi-channel which considers adjacent-channel constraint, cochannel and co-site constraint. The minimum number of the channels that are used in the network with minimum completion time shows the effectiveness of the work.

Keywords: Wireless mesh network; channel assignment; multi-channel

1.0 INTRODUCTION
A wireless mesh network (WMN) is a communication network that able to be applied in many applications such as broadband home networking, community networks, last-mile internet access, etc [2]. WMNs consists of mesh clients which represents laptop, cell phones and other wireless devices while mesh routers represents the traffic or connection between the nodes (channels). The WMN routers effectively form a multi-hop wireless access backbone [6]. Some of the special nodes are connected with gateways which directly connected to the Internet.

Channel assignment in a wireless mesh network is a graph theoretical application associated with the assignment of limited resources to the mesh routers and mesh clients. The resources consist of radio channels which are assigned according to frequencies. The number of channels, or a bandwidth, in a particular node is limited according to the average demand from the senders. The demand may be fulfilled most of the time in the normal traffic but may not be sufficient when the traffic is busy. The efficient system to manage the channel is important so that the unused node can be assigned to the neighboring nodes that are in need.

A pair of nodes can communicate with each other if their Network Interface Cards (NICs) are tuned to the same channel in the transmission range of each other and that the channels are not in the interference state [5]. Electromagnetic interference will occur if several nodes use the same channel at the same time when they are within the transmission range. Therefore, different channels are assigned to links that originate from the same node in order to avoid the interference. A message that was send by the sender is said to be successfully assigned if both the sender and its receiver receives one channel each. Otherwise, the message is considered a failure, and it is blocked.

In this paper, we focus on simulation and channel assignment for multi-channel which considers the adjacency channel constraint. Multi-channel communication in a wireless mesh environment with routers having multiple radio interfaces significantly enhances the network capacity [7], [8]. The paper is organized into five sections. Section 1 is the introduction while Section 2 describes the problem. A brief explanation about channel...
assignment is discussed in Section 3 and this is supported by a simulation work in Section 4. Finally, Section 5 is the summary and conclusion.

### 2.0 PROBLEM STATEMENT

Given a network in the form of a connected graph $G(V, E)$ with $n$ nodes and $m$ edges, where $V = \{v_i\}$ for $i = 1, 2, \ldots, n$ and $E = \{e_{ij}\}$ for $i, j = 1, 2, \ldots, m$. The channels are assigned in such a way that they are constantly reused once a particular assignment is completed. In what way can the channels be assigned to the randomly arriving messages with minimum use of channels in order to transfer data communication with minimum completion time by considering the electromagnetic constraints? In our paper, we consider three electromagnetic constraints which are adjacent channel constraint, cochannel constraint and cosite constraint that will add to the reality and practical situation of wireless mesh networks.

### 3.0 CHANNEL ASSIGNMENT

Channels are assigned to the link of edges which their nodes have same channels to communicate. In the network, channels are limited resources that we want to minimize the channels but satisfy the demand to transfer the data communication [5].

We refer a wireless mesh network as the connected graph $G(V, E)$ with $n$ nodes and $m$ edges, where $V = \{v_i\}$ for $i = 1, 2, \ldots, n$ and $E = \{e_{ij}\}$ for $i, j = 1, 2, \ldots, m$. The nodes in the graph are the nodes in the network while the edges between the pairs of nodes denote the nodes are within the transmission range of each other to enable them to communicate directly.

Channels are assigned to the nodes in such a way to avoid the electromagnetic interference [4]. To achieve this objective, the channels are assigned with the adjacency, co-channel and co-site constraints in order to avoid the interference which will be considered in our present model.

#### 3.1 Single Channel Communication

Single channel communication refers to communication between a pair of nodes in the network using a single channel. The channel can be used for one-way transmission of data at any given time. However, the opposite way transmission on the channel is possible at a different timeslot to avoid data collision. Single channel communication in a network is achieved by assigning different number of channels to the nodes in the network.

Therefore, the assignment of different channels from a single node will avoid this problem.

#### 3.2 Multi-Channel Communication

High volume of data transfer between the nodes in a network may not be able to support by single channel. This is because single channel allows one-way communication which results in slow movement of data. Multiple channels help for speeding up the data transfer since they allow duplex type of communication where the movement of data between the nodes can be performed in two opposite directions simultaneously. A variable $x_{ik}$ is defined as follows:

$$x_{ik} = \begin{cases} 1 & \text{if } v_i \text{ is assigned with channel } k \\ 0 & \text{otherwise} \end{cases}$$

In our simulation, each node $v_i$ in the network is assigned with $k$ channels where $k$ is the degree of the node in the graph. Hence, the distribution of channels among the nodes is not even as it depends on the adjacency matrix of the graph. We also consider the adjacency constraint whereby no two links that originate from the same node can use the same channel at the same time. Obviously, the adjacency constraint is the edge coloring problem in graph theory.

Figure 2 shows the case of two channels per link between the pair of nodes. The channels are assigned in such a way that no two adjacent edges share the same channel. From the figure, nine channels are required in the two-channel case. Channel assignments for Figure 2 are described in the Table 1.

![Figure 2](image)

**Figure 2** Output for two-channel case

**Table 1** Channel assignments for Figure 2

<table>
<thead>
<tr>
<th>$x_{ik}$</th>
<th>Channels</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v_1$</td>
<td>1 1 1 1 1 1 0 0 0</td>
</tr>
<tr>
<td>$v_2$</td>
<td>1 1 1 1 1 1 0 1 0</td>
</tr>
<tr>
<td>$v_3$</td>
<td>1 0 1 1 1 1 0 1 0</td>
</tr>
<tr>
<td>$v_4$</td>
<td>1 1 0 1 1 1 0 1 0</td>
</tr>
<tr>
<td>$v_5$</td>
<td>0 1 1 1 0 1 0 0 0</td>
</tr>
<tr>
<td>$v_6$</td>
<td>1 1 1 1 1 0 1 0 0</td>
</tr>
<tr>
<td>$v_7$</td>
<td>0 1 1 1 1 0 1 1 0</td>
</tr>
<tr>
<td>$v_8$</td>
<td>1 1 1 1 1 1 0 1 0</td>
</tr>
<tr>
<td>$v_9$</td>
<td>1 0 0 1 1 1 0 1 0</td>
</tr>
</tbody>
</table>

#### 3.3 The Floyd-Warshall Algorithm

The Floyd-Warshall algorithm starts by finding all the minimal distances between the pairs of nodes without passing through any
intermediate nodes [4]. All the values are recorded in the minimal distances table. The algorithm starts with \( v_0 \) which allowing one node to be the only intermediate node. We define \( a_{ik} \) as the shortest distance from \( v_i \) to \( v_k \) using only the nodes \( v_0, v_6, \ldots, v_k \) as the intermediate nodes. With \( q_k \) as the intermediate node, the minimal distance is \( a_{q_k} \). The minimal distances between the pairs of nodes are determined by comparing the previous values with the present ones [4].

New updates are recorded in the minimal distance table. This is follow by \( v_i, v_j \), and so on until the last node, \( v_N \), is reached. The process repeats with two nodes and so on, using the earlier results for comparison. At each step, a comparison is made with the values in the table and any new minimal distance values are recorded in the table. The algorithm follows:

Input: Weight \( w_{ij} \) between \( v_i \) and \( v_j \), for \( i = 1, 2, \ldots, N \) and \( j = 1, 2, \ldots, N \).
Output: Shortest path \( w_{ij}^{\text{min}} \) between \( v_i \) and \( v_j \).
Steps:

For \( i = 1 \) to \( N \) do
  For \( j = 1 \) to \( N \) do
    Let \( w_{ij}^{\text{min}} = w_{ij} \).
    Endfor
  Endfor
For \( r = 0 \) to \( N - 1 \) do
  For \( i = 1 \) to \( N \) do
    For \( j = 1 \) to \( N \) do
      For \( k = 1 \) to \( N \) do
        If \( w_{ij}^{\text{min}} < w_{ik}^{\text{min}} + w_{kj}^{\text{min}} \) then
          Let \( n = i \) do
            Compute \( w_{ij}^{\text{min}} = w_{ik}^{\text{min}} + w_{kj}^{\text{min}} \).
          Endif
        Endfor
      Endfor
    Endfor
  Endfor
Endif
Endfor
Endfor
Endfor

Table 2 describes the symbols used in the Floyd-Warshall algorithm. In this algorithm, \( w_{ij}^{\text{min}} \) is the minimal distance between \( v_i \) and \( v_j \). The path between \( v_i \) and \( v_j \) may have no intermediate node, \( v_k \), or it may have more than one node, depending on its distance.

### Table 2 Symbols used in the Floyd-Warshall algorithm

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w_{ij} )</td>
<td>Weight of a link between ( v_i ) and ( v_j )</td>
</tr>
<tr>
<td>( w_{ij}^{\text{min}} )</td>
<td>Shortest (minimal) distance between ( v_i ) and ( v_j )</td>
</tr>
<tr>
<td>( \infty )</td>
<td>Value assigned to denote that the link between ( v_i ) and ( v_j ) does not exist</td>
</tr>
</tbody>
</table>

### 4.0 SIMULATIONS AND RESULTS

Simulation has been performed by using Microsoft Visual C++ on a connected graph whose nodes and edges are randomly determined. The nodes are scattered at random locations. If a pair of nodes in the transmission range, there will be a connection between the nodes. In this simulation, we set the value of the transmission range as 100. The graph represents the model of the wireless mesh networks.

Table 3 shows the nodes based on the degree of the nodes. The nodes were arranged with decreasing number of degrees where the highest degrees were chosen as priority to assign the channels followed by the lowest degree.

Figure 3 shows the numbering arrangement of edges for the simulation. The edges show their connection between a pair of nodes that sharing a same channel. The arrangement determines the adjacent constraints which describe in meshAdj.in file where 1 represents that the edges are adjacent or otherwise 0.

### Table 3 The arrangement of nodes based on number of degrees

<table>
<thead>
<tr>
<th>NO.</th>
<th>NODES</th>
<th>NUMBER OF DEGREES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( v_2 )</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>( v_8 )</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>( v_9 )</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>( v_7 )</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>( v_3 )</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>( v_4 )</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>( v_6 )</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>( v_7 )</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>( v_{10} )</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>( v_2 )</td>
<td>2</td>
</tr>
</tbody>
</table>

#### 4.1 Channel Allocation Algorithm

The following routine shows the scheduling policy that successfully assigns the channels to the edges according to this priority policy:

Input: Adjacent constraint \( v_{i,adj} \) and cochannel constraint \( c_{m,adj} \)
Output: Channel assignment \( v_{j,channel} \) where \( m \) is co-site constraint
Steps:

For \( m = 1 \) to \( 3 \)
  Let \( v_{i,channel} = 1 \)
  For \( i = 2 \) to \( N \) do
    For \( k = 1 \) to \( N \) do
      \( w_k = 0 \)
      For \( j = 1 \) to \( (i-1) \) do
        If \( v_{i,adj} \& |v_{j,channel} - v_{i,channel}| < 1 \) then
          \( v_{j,channel} = k+1 \)
          \( w_k = 1 \)
          Endif
      Endfor
    Endfor
  Endfor
  If false
    Let \( r = 0 \)
    For \( j = 1 \) to \( (i-1) \) do
      \( v_{j,channel} = k \)
      If \( c_{m,adj} < 3 \) then
        \( v_{j,channel} = k+1 \)
        \( r++ \)
    Endfor
  Endfor
Endif
In this simulation, we decide the value of adjacent channel constraint as 1 to avoid interference while assigning the channels to each node. It is visualized as:

\[
\text{If } v_{i,\text{adj}} \& |k - v_{j,\text{ch}}| < 1
\]

The cochannel constraint is checked using the Floyd-Warshall algorithm where the value is 3 using the following code fragments:

\[
\text{If } c_{j,\text{adj}} < 3
\]

Cosite constraint is applied for channel 2 to each node by adding the value of the constraint which is 3, and go through the same rules for adjacent and cochannel constraint. The output for this simulation is shown in Figure 2.

### 5.0 SUMMARY AND CONCLUSION

Channel allocation in a wireless mesh networks contributes significantly to the performance, stability and effectiveness of the network. The main objective is to optimize the performance of the network in such a way to avoid the electromagnetic interferences.

Our paper describes the multi-channel communication which considers the three constraints which are adjacency constraint, cosite and cochannel constraint. Through simulation, we assigned the channels to the network using greedy allocation in order to minimize the channels for data communication.

### Acknowledgement

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### References


