

Constrained Channel Assignment in Multi-channel Wireless Mesh Network

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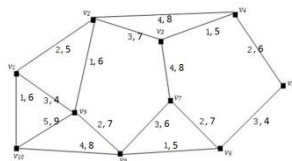
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Article history

Received :28 February 2013
Received in revised form :
29 October 2013
Accepted :5 December 2013

Graphical abstract



Output for two-channel case

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 cosite 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

Abstrak

Satu rangkaian mesh tanpa wayar adalah satu rangkaian pelbagai “hop” yang terdiri daripada nod yang dipanggil “routers” dan “clients”. Dalam rangkaian ini, komunikasi antara sepasang nod berlaku apabila kedua-dua nod berkongsi satu saluran yang sama. Tugas saluran merupakan salah satu aplikasi dalam graf teori iaitu “vertex coloring”. Saluran diperuntukkan untuk setiap nod bagi meminimumkan jalur lebar dan kekangan bagi mengelakkan gangguan elektromagnetik. Kami memberi tumpuan kepada peruntukan saluran untuk “multi-channel” yang mana mempertimbangkan tiga kekangan iaitu “adjacent-channel constraint”, “cochannel” dan “cosite constraint”. Bilangan minimum saluran yang digunakan dalam rangkaian dengan masa penyiapan yang minimum menunjukkan keberkesanan kerja.

Kata kunci: Wireless mesh network; saluran tugas; pelbagai saluran

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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 sent 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 $i = 1, 2, \dots, n$ and $E = \{e_{ij}\}$ for $i, j = 1, 2, \dots, m$. 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 $i = 1, 2, \dots, n$ and $E = \{e_{ij}\}$ for $i, j = 1, 2, \dots, m$. 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.

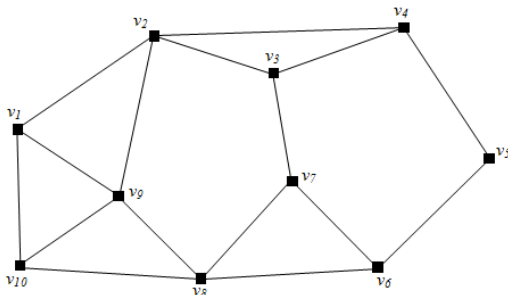


Figure 1 Initial setup of the connected graph

Figure 1 shows a connected graph with ten nodes which represents a simple wireless mesh network. Radio interference happened when the assignment originates from a same node has a same

channel. 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.

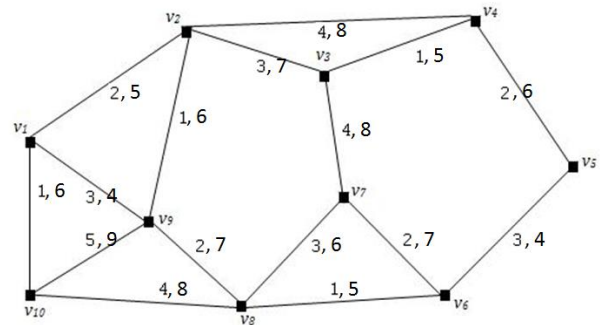


Figure 2 Output for two-channel case

Table 1 Channel assignments for Figure 2

x_{ij}	Channels								
	1	2	3	4	5	6	7	8	9
v_1	1	1	1	1	1	1	0	0	0
v_2	1	1	1	1	1	1	1	1	0
v_3	1	0	1	1	1	0	1	1	0
v_4	1	1	0	1	1	1	0	1	0
v_5	0	1	1	1	0	1	0	0	0
v_6	1	1	1	1	1	0	1	0	0
v_7	0	1	1	1	0	1	1	1	0
v_8	1	1	1	1	1	1	1	1	0
v_9	1	1	1	1	1	1	1	0	1
v_{10}	1	0	0	1	1	1	0	1	1

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_{ijk} as the shortest distance from v_i to v_j using only the nodes v_0, v_0, \dots, v_k as the intermediate nodes. With a_k as the intermediate node, the minimal distance is a_{ijk} . 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 followed by v_1, v_2 , 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 $i=1, 2, \dots, N$ and $j=1, 2, \dots, N$.

Output: Shortest path w_{ij}^{min} between v_i and v_j .

Steps:

```

For i = 1 to N do
  For j = 1 to N do
    Let  $w_{ij}^{min} = w_{ij}$ ,
  Endfor
Endfor
For i = 1 to N do
  For j = 1 to N do
    For k = 1 to N do
      If  $w_{ij}^{min} \neq \infty$  or  $w_{ik}^{min} \neq \infty$  or  $w_{jk}^{min} \neq \infty$  then
        If  $w_{ij}^{min} + w_{jk}^{min} < w_{ik}^{min}$  then
          Let  $n = 1$  do
            Compute  $w_{jk}^{min} = w_{ij}^{min} + w_{ik}^{min}$ 
          Endif
        Endif
      Endfor
    Endfor
  Endfor
Endfor

```

Table 2 describes the symbols used in the Floyd-Warshall algorithm. In this algorithm, w_{ij}^{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

Symbol	Description
w_{ij}	Weight of a link between v_i and v_j
w_{ij}^{min}	Shortest (minimal) distance between v_i and v_j
∞	Value assigned to denote that the link between v_i and v_j does not exist

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

NO.	NODES	NUMBER OF DEGREES
1	v_2	4
2	v_8	4
3	v_9	4
4	v_1	3
5	v_3	3
6	v_4	3
7	v_6	3
8	v_7	3
9	v_{10}	3
10	v_5	2

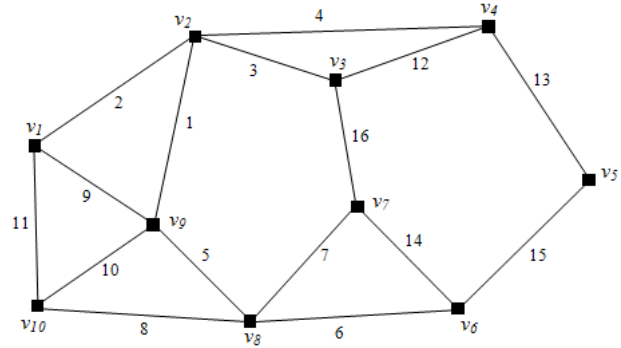


Figure 3 The numbering arrangement of edges

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 $v_{i,adjj}$ and cochannel constraint $e_{ij,sd}$

Output: Channel assignment $v_{i,cm}$ where m is cosine constraint

Steps:

```

For m = 1 to 3
  Let  $v_{i,cm} = 1$ 
  For i = 2 to N do
    For k = 1 to N do
       $w_k = 0$ 
      For j = 1 to (i-1) do
        If  $v_{i,adjj} \& |k - v_{j,cm}| < 1$  then
           $v_{i,cm} = k+1$ 
           $w_k = 1$ 
        End if
      End if
    End for
    If false
      Let  $r = 0$ 
      For j = 1 to (i-1) do
         $v_{i,cm} = k$ 
        If  $e_{ij,sd} < 3$  then
           $v_{i,cm} = k+1$ 
           $r++$ 
        End if
      End for
    End if
    If  $r = 0$  then
      break
    End if
  End for
   $k++$ 
End for

```

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:

$$\mathbf{If} \ v_{i,adj\ j} \& \ |k - v_{j,ch\ m}| < 1$$

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

$$\mathbf{If} \ e_{ij,sd} < 3$$

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

This research has been financially supported by the Malaysian Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia. The authors would like to thank the ministry and university for the support.

References

- [1] Akyildiz, F., X. Wang and W. Wand. 2005. Wireless Mesh Networks: A Survey. *Computer Networks*. 47(4): 445–487.
- [2] Ding, Y., and L. Xiao. 2010. Channel Allocation in Multichannel Wireless Mesh Networks. *Journal of Computer Communications (Article in Press)*.
- [3] Si, W., S. Selvakennedy and A. Y. Zomaya. 2010. An Overview of Channel Assignment Methods for Multi-Radio Multi-Channel Wireless Mesh Networks. *Journal of Parallel and Distributed Computing*. 70(5): 505–524.
- [4] Salleh, S., A. Zomaya, S. Olariu and B. Sanugi. 2005. *Numerical Simulation and Case Studies Using Visual C++ .Net*. USA: Wiley-Interscience.
- [5] Salleh, S., and N. A. Salahudin. 2011. A Queueing Model of Channel Assignment Model in Wireless Mesh Networks. *Worldcomp*. Las Vegas Nevada, USA.
- [6] Das, S. M., D. Koutsonikolas, Y. C. Hu, and D. Peroulis. 2006. Characterizing Multi-Way Interference in Wireless Mesh Networks. *Wintech*. Los Angeles, California, USA.
- [7] Raniwala, A., K. Gopalan, and T. Chiueh. 2005. Centralized Channel Assignment and Routing Algorithms for Multi-Channel Wireless Mesh Networks. *Mobile Computing and Communications Review*. 8(2): 50–65.
- [8] Tang, J., G. Xue, and W. Zhang. 2005. Interference-Aware Topology Control and Oos Routing in Multi-Channel Wireless Mesh Networks. *Mobihoc*.