Fixed Channel Allocation in Wireless Mesh Network Subject to Efficient Spectrum Usage and Reliability Constraint

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ABSTRACT
Reliability is one of the major issues with wireless networks. Failure in multiple radio channels often lead to poor communication even complete disruption in services. Increasing reliability of a network may point to the requirement of multiple paths between two terminals in the network. Hence, a link fault tolerant network design with low cost is important. Fault tolerance of a network is defined as the ability of the network to endure any link or node failure and cater uninterrupted connection for all services. The paper presents a technique to counter the issue of fault tolerance in a wireless mesh network (with static subscriber stations) so that it can sustain malfunction in multiple radio channels and optimize the spectrum usage. A K-fault tolerant network has at least K+1 number of distinct routes between two nodes. So, given a set of nodes and the cost of links there is a need to design a network assigning minimal number of links satisfying some specified connectivity requirements between a pair of terminals.

General Terms
Channel allocation, Wireless Network.

Keywords
Fault tolerance, link deficiency.

1. INTRODUCTION
The communication network is designed by finding out the best layout of the elements to optimize the performance criteria like message delay, traffic and reliability and fault tolerance measure. The performance criteria of the above mentioned system is largely determined by the network topology [1].

An elementary problem in the design of wireless network is to build a minimum cost network that is suitable for some specific connectivity requirements and has minimum interference. Wireless networks are more prone to channel failure (due to high noise) leading to disruption in a communication session. Hence an essential criterion for any reliable wireless network design is that the network must stay linked even on failure of one or more channels. One of the most important challenge is the efficient fault tolerant network design problem, where a wireless mesh network with its nodes and costs on its links (number of hops), and a connectivity requirement k for each pair i, j of subscriber stations are provided. The objective is to find a minimum cost subset of links (by assigning fixed set of channels) that guarantees that there exist at least k-1 disjoint paths for each pair i,j of nodes, where all $k \in \{0,K\}$, for some integer K [2]. This paper is concerned with assigning fixed channels to wireless network such that it minimizes the overall cost needed to design a network over the topological configurations with k connectivity constraints.

Many techniques for building k-connected networks are proposed in the literature. Steigletiz, et. Al .[3] proposed a heuristic scheme that numbers the nodes randomly. This random element in the technique may generate many topologies from the same input data. In the strategy proposed by [4] the nodes are numbered arbitrarily. Then from the number assigned, a k bit Gray code is generated for each node. Two nodes are connected when their respective Gray codes differ only by one bit position. Thus every node has k links. However the limitation of this method is that the number of nodes in the network has to be 2×k. The accumulated cost for each node is calculated and sorted in the increasing order in another method proposed in [5]. Nodes are numbered using the index value of the sorted list. Links are established between nodes. However in this method redundant links are more in number than required. The authors [6] study survivable network design problem and show that it is hard to approximate and provide an elementary construction for the same. In the work [7], the nodes are numbered randomly and the nodes of the network are assumed to be placed at equal distance from one another in a circular fashion. So the method is applicable only when the nodes of the network form a regular polygon. The paper [8] proposes a design technique to tackle the link fault problem of Mobile Adhoc Networks. But the link assignment delay is very high and the technique is best on approximation. The authors [9] present a method for generating k-connected communication network with optimal number of links using the concept of bipartite graph. The paper [10] has considered the topological optimization of communication networks including the reliability constraints of links. The work [11] presents a decomposition approach to minimize the total network cost considering the reliability constraint

In this paper, we have proposed a method for the topological design of a communication network at a minimal cost. The performance of the algorithm proposed by [3] and [4] as mentioned above has been analyzed based on two criteria - firstly the cost of the generated network and secondly the time complexity of the algorithm. Furthermore, by studying extensively it is found that the algorithm [4] do not always generate lowest cost network. Therefore, in this paper we have proposed an algorithm to assign fixed channels to generate a k-connected wireless network with minimum cost in all conditions.

This paper is organized in four sections. Section 2 proposes an algorithm which provides a low cost K-connected network within specific time bound. Simulation and result analysis of the proposed method is given in Section 3. Finally section 4 describes conclusions and future work.

2. PROPOSED ALGORITHM FOR K-FAULT TOLERANT FIXED CHANNEL ASSIGNMENT

Now, we present the technique for fixed channel allocation, developing a K-connected network topology. The geographical location of the nodes in the network is available. The cost of assigning a link between each pair of nodes in the network is provided as a 2D matrix. The nodes' priorities are assigned based on link_sum [12] and are sorted. Then the nodes with minimum cost are placed in the same cluster. The maximum number of cluster formed is K+1. Then links are assigned to every pair of nodes within a cluster. Then links with least cost are between nodes of different clusters, but each node can be assigned K+1 links. The sender and the receiver communicate through same link.

Algorithm

Objective: For a given wireless mesh network with static nodes, given the cost of links assignment for every pair of nodes and a connectivity requirement K for each pair i,j of nodes. The goal is to find a minimum cost K-Fault tolerant wireless communication network that ensures that there exist at least K+1 disjoint paths for each pair i,j of nodes. It is also ensured the number of links assigned is also minimum.

Input:

N- nodes of the network

Cost matrix indicating the number of hops associated with each pair of nodes

Connectivity requirement K (in this problem) and K < N.

Output:

Minimum cost K-connected network topology.

Steps:

Step1 Nodes are numbered randomly 1 to N.
Step2 Priority of nodes identified by their link sum. The node with maximum link has highest priority and minimum link sum has lowest priority.
Step3 For i=1 to K+1// for K+1clusters
Step4 Find the least cost link from max_priority node (not already clustered).
Step5 If two links have same cost
Step6 Select the link which connects to a lower priority node.
Step7 End if
Step8 Add the concerned nodes in cluster.// links considered only if at least one node in the pair is not already grouped
Step9 If two nodes have same priority
Step10 Randomly select one.
Step11 End if
Step12 If number of node in a cluster = ceil(N/K+1)
Step13 Place the other node in any other cluster.
Step14 End if
Step15 End for
Step16 Assign links between every pair of nodes in a cluster. But no node can have more than K+1 links(unless all nodes except one has K+1 links).
Step17 For i = 1 to K+1 && i≠ Ø// only non-empty clusters will be considered.
Step18 For every node in cluster i
Step19 Find the node with maximum link deficit
Step20 Find the least cost link possible between a node in cluster i and any node in the other cluster(s), assign the link.

//Once a node has K+1 link, no more links will be assigned.

Step21 End for
Step22 End for
Step23 Stop

The performance of the proposed method is compared with the Link Deficit algorithm [3] and modified link deficit algorithm [4] in the subsequent section with the help of an example.

3. A CASE STUDY

We illustrate the Proposed Algorithm for 8 distinct nodes. The network connectivity is assumed to be 3 so K=2. The geographical locations of eight nodes are considered and are randomly labeled 1 to 8 as shown in Figure 1.The objective is to design a low cost 3-connected network. The link assignment cost is provided (shown in Figure 2)

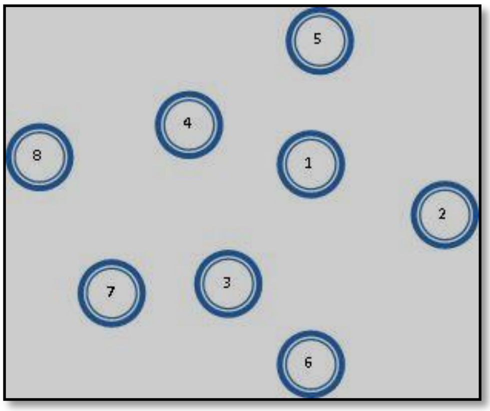

Figure1. Geographical locations of eight nodes.

	1	2	3	4	5	6	7	8
1	8	3	4	3	4	10	12	14
2	3	8	7	10	11	7	9	15
3	4	7	8	5	9	3	4	9
4	3	10	5	8	8	10	7	5
5	4	11	9	8	8	15	18	10
6	10	7	3	10	15	8	9	11
7	12	9	4	7	18	9	8	5
8	14	15	9	5	10	11	5	8

Figure 2. The link assignment cost matrix

Figure 3. shows the partitioning of nodes into 3 clusters based on link cost. For example the maximum priority node is 5(link sum=73). The least cost link (1,5) that could assigned to it has value 4. So, 1 and 5 are grouped together in cluster 1. The next node with maximum priority is 8 and it has link assignment cost 5 with node 4 and 7, Since 4 has lower priority than 7 , place 4 and 8 in cluster 2. Next node 7 is selected and according to least cost link assignment, 3 and 7 are clustered together (cluster 3). Similarly node 2 is place with node 1(cluster 1) and node 6 is placed with node 3(cluster 3).

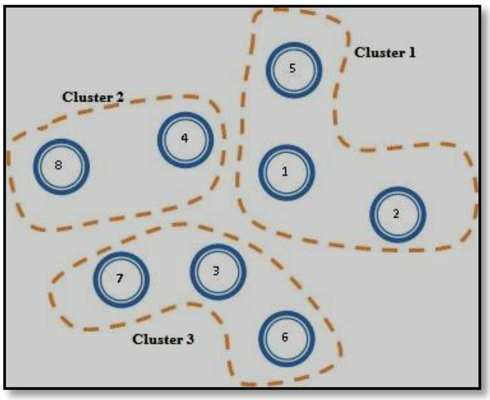

Figure 3. Nodes partitioned into 3 clusters based on link assignment cost

All nodes within a cluster are assigned link for every other node in the same cluster (shown in Figure 4.). Now node 4 and 8 has highest link deficit (since they have been assigned only one link. Node 4 and 8 are connected to cluster 1 and 3 using least cost link possible (shown in Figure 5). The remaining node with maximum link deficit is 2 and 6 and they are assigned a link.

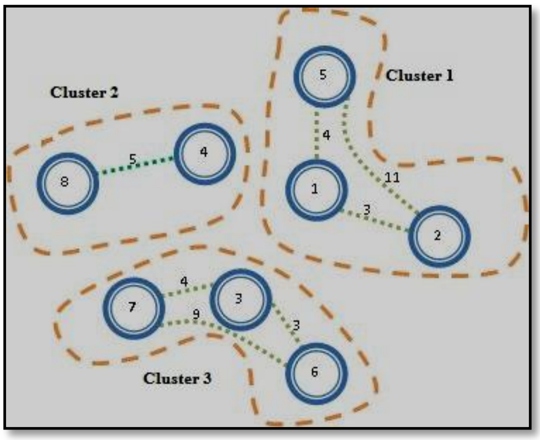

Figure 4. Link assigned to every pair of nodes in each cluster

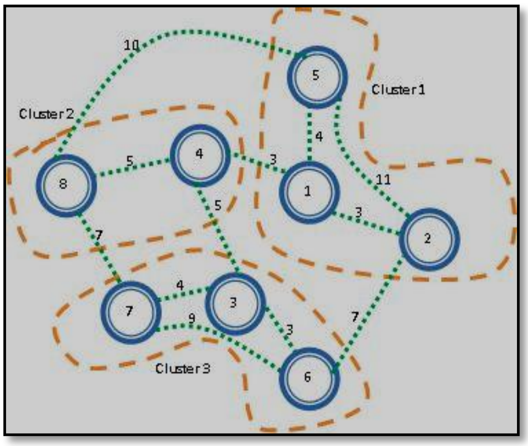

Figure 5. Link assigned to all nodes to make the network 2 fault tolerant with a cost of 71.

The cost of the network for the same case study generated by the modified Link Deficit Algorithm [4] is 73 and Link Deficit algorithm [3] is 82 respectively which is more than our result i.e. 71.Moreover our algorithm ensures minimum number of links (which is 12 in this case) is assigned to achieve the goal. But algorithm [4] uses 13 links.

4. PERFORMANCE EVALUATION

The proposed method designs a wireless network with 5 nodes pertaining to 2 radio channels failure.

Input: n=5 ; K=2

n=7, K=3

It is found that the proposed method always generates a minimum cost reliable wireless network layout when compared with Ref. [3] and [4] (Table 1 and Table 2).

Table 1. Cost of proposed FCA

Algorithm	n=5,K=2	n=7,K=3
	Cost	Cost
Proposed FCA	71	130
Algorithm [3]	82	175
Algorithm [4]	73	150

Table 2. Comparative analysis of proposed FCA in terms of cost and number of links used

Algorithm	n=5,K=2	
	Cost	Number of links
Proposed FCA	71	12
Algorithm [3]	82	12
Algorithm [4]	73	13

The result presented in Table 1 and Table 2 clearly depicts that the cost of the network is optimized and the number of links used to develop K-Fault tolerant network is also minimum. This ensures that the available spectrum is also used efficiently.

The comparative result of the proposed FCA is depicted using bar graph (shown in Figure 6).

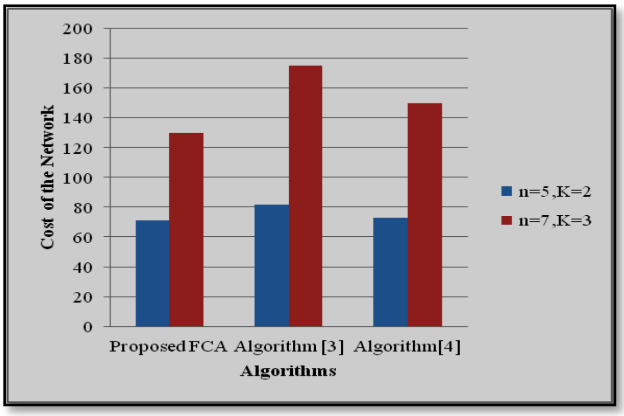

Figure 6. Link assigned to all nodes to make the network 2 fault tolerant with a cost of 71.

5. CONCLUSION

In general geographical locations of nodes play a vital role in the cost of the network. The Link Deficit Algorithm is used to generate a low cost K-connected network. But it does not ensure minimum cost network. The modified Link Deficit generates a minimum cost network for some specific cases but is not applicable for all network topologies for e.g. when a node of a Minimum Spanning Tree has degree higher than K. The proposed algorithm finds minimal cost K–connected wireless network with time complexity less than $O(N^2)$ (since K<N) and is applicable to all possible network topologies. In future we can extend this algorithm considering the effects of other parameters like delay, bandwidth etc. on the network topology design.

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