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K-Fault Tolerant Network Design

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Abstract- The need of multiple paths between any pair of nodes in a network is important to ensure that the network can endure link faults. However, multiple paths between a pair of nodes, which ensure improved consistency of the network, increases the network cost. A K-Fault tolerant network is proposed to design a network layout which includes the control on reliability and cost. The designed low cost network layout is able to withstand K link failure. An n × n matrix is used to signify the cost of link between the respective nodes.

Keywords – Fault tolerance, link failure, minimum cost, average link cost

I. INTRODUCTION

The mesh network layout has all nodes connected to all other nodes. Fault tolerance in terms of node and link is one of the most important benefits of mesh networks. Each node in the network can in dependently communicate with any other node and can act as a router. The link failure in the network can arise due to connection error or any other external interference. This leads to the fact that the network should be able to withstand link failures and communicate uninterruptedly. The design of network layout is based on minimizing the cost and maintaining the reliability requirements to handle the faults that may occur in the network.

A number of design algorithms for topological network optimization have been developed [1], [2], [3]. A popular heuristic for generating a minimal cost starting network is due to [4] and is called Link Deficit algorithm. The [5] presents a technique for designing a K-connected network assuming all the nodes of the network are equi-spaced and lie on a circle. Authors in [6] proposed a channel assignment technique in wireless network with higher reliability and minimum cost irrespective of the alignment and positioning of the nodes. . The work [7] designs a channel selection technique and combines with a distributed acquisition algorithm. The paper [8] presents and analyzes a new irregular Fault-tolerant multistage interconnection network which dynamically re-routes and presents multiple paths between source and destination nodes. The topological optimization of communication networks subject to reliability constraints is delivered in [9]. In [10] the author presents a decomposition approach to the problem where the total network cost is minimized considering the reliability constraint. The authors [11] proposed a method for numbering the nodes assumed to be placed in a straight line with equal space between one another and the connectivity that is sought is even.

This paper focus on two factors –link failure and communication cost. It has been assumed; that all the links have the same reliability which is between 0 and 1. Through simulation it has been proved that the proposed algorithm can effectively discover an optimal solution for the problem.

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The paper is organized as follows. The basic definitions essential for this work is presented in Section 2. The problem statement is defined in Section 3. Section 4 presents the proposed algorithm. The result of the proposed algorithm is explained with an example in section 5. Section 6 discusses the result analysis. Section 7 concludes the paper.

II. Basic Definitions

i. A link failure is defined as an unexpected disintegration of link due to some error in link or unstable external condition which causes communication disruption.

ii. A network topology is K-FT if there is K+1 number of disjoint-paths between every pair of nodes which ensures that all nodes are reachable even if there are K link failure in the network.

iii. A graph G is connected if every node in G is reachable from all other nodes and the graph is K-FT if all the sub-graphs, which have K less links than the graph G remains connected.

iv. The degree of a node is defined as the number of links incident/emergent on it.

III. Problem Statement

The Cost matrix Costij for a network of n nodes where $i, j \in n$ is given and a K-FT network topology is to be designed such that the overall cost of communication is minimized.

Assumptions

i. The nodes are stationary.

ii. The probability of a node failure is 0.

iii. The cost of communication between each pair is given.

iv. The channels are bi-directional. $Cost_{ij} = Cost_{ji}$ for all $i,j \in n$ && $Cost_{ii} = \infty$.

v. All links have equal bandwidth.

The problem is to find a cost optimized network layout for the given set of nodes such the network can endure K number of link failures. Given n and $Cost_{ij}$ for all i, j the problem is to assign links to the node such that network topology is K-FT and the total communication cost is minimized.

IV. Proposed Method

The proposed method designs a cost efficient K-FT network layout where the number of nodes is known and the cost of communication between every pair of nodes is provided. The proposed method computes the average link sum of each node and identifies the minimum communication cost for each node. The nodes are numbered according to the descending minimum link cost. For two nodes with the same link cost the node with higher average link cost value will be numbered before the other one. Now, to devise a K-FT network topology each node should have K+1 links. If a node has m number of links such that m<K then the link deficit of that node is (K+1-m). A single link (i,j) is added to the network at each step, so that no node has link deficit > 0. A node i with smallest number of links or maximum link deficiency, is chosen. I f two nodes have same link deficiency (which is maximum for the network) then the smallest numbered node is selected. The minimum cost link (i,j) from node i is added to the network. In case of a tie in the link cost, the one joining the smallest numbered node is considered. The algorithm stops when all nodes have minimum K+1 links.

A. Variables

The following variables have been used in the proposed algorithm

i. n: number of nodes

ii. K: Maximum number of link failures tolerable without interruption in communication. $1 \leq K \leq n-2$

iii. $Cost_{ij}$: Link Cost between node i and node j where $i,j \in n$ && $i \neq j$

iv. $node_i$: i^{th} node

v. $AvgLink_i$: Avg of node i's link cost $\forall$ node j where $i,j \in n$ && $j \neq i$

vi. Min_Link_i: The minimum cost of a link assigned to node i where $i \in n$

vii. Net_Cost: Cost of the network topology

viii. $Count_i$ = number of links assigned to node i.

ix. L = list of links added to the network topology

B. Algorithm

Input: n , $Cost_{ij}$,K

Output: K-FT optimal cost network topology.

Step 1: //Initialization

Net_Cost=0

L = {Ø}

for i = 1: n

{

$Count_i$ = 0 // no link is assigned to any node yet

}

Step 2: Compute $AvgLink_i$ for $i \in n$

Sort all nodes on the basis of Min_Link_i using QuickSort in descending order.

Step 3: for m=1:n {

All nodes are numbered from 1 to n with maximum link value to lowest as $node_m$

If $Min\_Link_i = Min\_Link_j$ where $i \neq j$ && $i,j \in n$

// The node with smallest $AvgLink_i$ will be numbered first.

if $AvgLink_i > AvgLink_j$

$Node_i \leftarrow node_m$

$Node_j \leftarrow node_{m+1}$ // since $Node_j$ is the next node in the sorted series

}

Step4: for i=1:n

The $node_i$ is chosen as the starting node since al node has 0 number of links.

$Count_i$ += 1 // the number of links added to node i is added by 1

Step 5: $node_j$ is chosen such that $Cost_{ij} < Cost_{ix}$ && (l/ink(i,j) $\in$ L || /link(i,x) $\in$ L) where $j \neq x \neq i$ and $j,x \in n$

If $Cost_{ij} = Cost_{ix}$ for some j,x

{

Then choose nodej if $Count_j$ is minimum.

If $Count_j = Count_x$

{ If $x<j$

{

Choose $node_x$

$Count_x$ += 1

Net_Cost + = $Cost_{ix}$

L = L ∪ { link(i,m) }// link(i,m) is added to the network

}

Else

{

Choose $node_j$

$Count_j$ += 1

Net_Cost + = $Cost_{ij}$

L = L ∪ {link(i,j) } // link(i,j) is added to the network

}

Step 6: Repeat Step 4 and Step 5 until $Count_i \geq K+1$ $\forall i \in n$

Step 7: for i = 1: n

{ If $count_i > K+1$ && $count_j > K+1$ && link(i,j) ∈ L

L=L− {link(i,j)}

Net_Cost - = $Cost_{ij}$

}

Step 8: Stop

V. A Case Study

The working of the proposed algorithm is explained with a case study.

Input: n=5

K=2

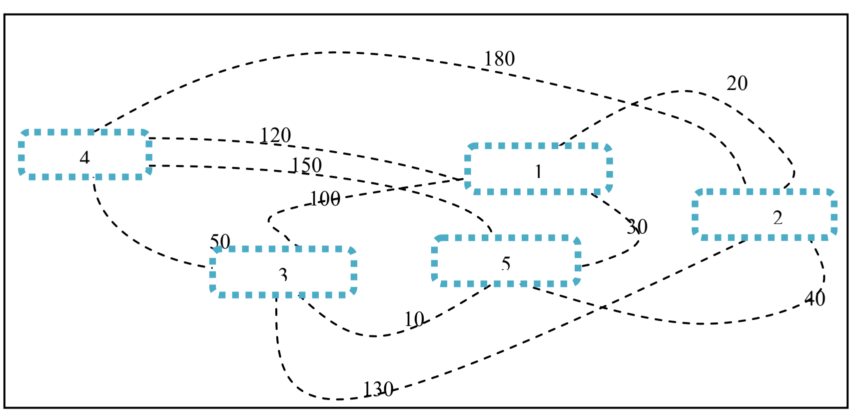

Figure 1. Given wireless mesh network with cost of links for n=5

As from figure 1 the nodes are initially numbered from 1 to 5. Using step 2 the AvgLink for each node is obtained.

1: $AvgLink_1 = 67.5$ & $Min\_Link_1 = 20$

2: $AvgLink_2 = 92.5$ & $Min\_Link_2 = 20$

3: $AvgLink_3 = 70$ & $Min\_Link_3 = 10$

4: $AvgLink_4 = 500$ & $Min\_Link_4 = 50$

5: $AvgLink_5 = 230$ & $Min\_Link_5 = 10$

Using step 3 the Min_Link is sorted and the nodes are numbered as follows

4: $AvgLink_4 = 500$ & $Min\_Link_4 = 50$ is numbered 1

2: $AvgLink_2 = 92.5$ & $Min\_Link_2 = 20$ is numbered 2

1: $AvgLink_1 = 67.5$ & $Min\_Link_1 = 20$ is numbered 3

5: $AvgLink_5 = 230$ & $Min\_Link_5 = 10$ is numbered 4

3: $AvgLink_3 = 70$ & $Min\_Link_3 = 10$ is numbered 5

$node_1$ is selected since all nodes have same link deficit 3(since K=2) . The $node_5$ is selected since it has least cost w.r.t $node_1$ i.e. $Cost_{15}$ is minimum.

Similarly using step 4 and step5 the final network topology obtained is shown in figure 2 and the cost of the network is 550.

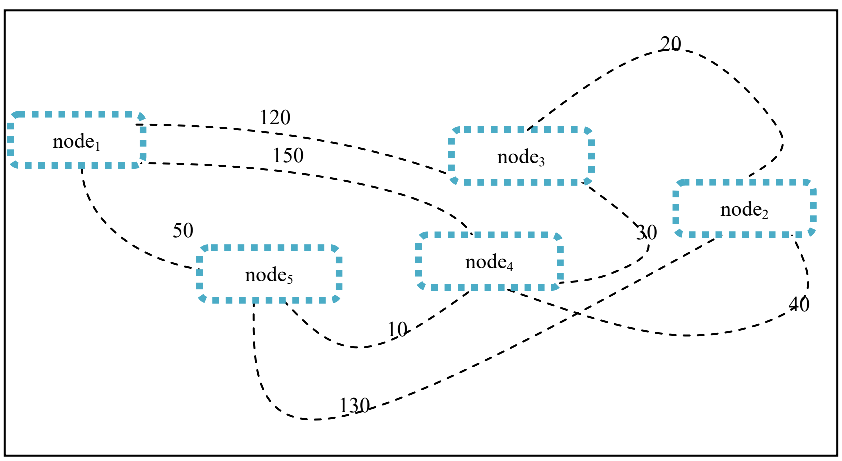

Figure 2. Resultant 3-connected network with cost 550

VI. Result Ananlysis

In last section, the proposed method develops a wireless network with 5 nodes which can withstand 2 links failure. It is observed that the proposed method is able to develop cost effective reliable network layout (as shown in Table 1). The algorithm is compared in terms of the cost of the network with [11].

Table -1 Comparative analysis for cost optimization fault tolerant network design

Algorithm	**n=5,K=2**
	Cost

Proposed Algorithm	**550**
Algorithm [11]	**620**

Table 1 show the peak signal to noise ratio of performance of our proposed method of watermarked image and original image with various watermark image, where our watermarked images peak signal to noise ratio has a better performance than others.

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