Topological Design of Computer Networks

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Abstract: An important aspect of communication network development has been the reduction in cost and the improvement in speed and quality of transmission link .A topological network design problem is solved by selecting the subset of links while minimizing the total cost subject to k connectivity and diameter constraint. Diameter is set to two links only as we want to design a fast network whose speed would be comparable to the complete connected network (having the diameter of one link) at low cost. A fault tolerant network is able to maintain connectivity under the failure condition only if there are multiple links disjoint paths for each node pair. Designing is a well-known optimization problem and difficult to solve. For N number of nodes, maximum numbers of links are n*(n-1)/2, and the maximum number of topological configurations of n nodes are $2^{n*(n-1)}$.

I. INTRODUCTION

An important aspect of communication network development has been the reduction in cost and the improvement in speed and quality of transmission link [3].

The objectives of computer networks are as follows:

- To provide sharing of (distant) resources such as information (database) or processors (CPUs). Resource sharing is perhaps the most common objectives for providing networks, within the constraints of cost and reliability of transmission links.
- To improve reliability of networks through backup and redundancy. if one processor breaks down , another processor in network can take its place. Similarly, if one link on a route fails, another route can be used.
- To provide inter process communication, such as among users (or processes) and processors. Network users, located geographically apart, may converse in an interactive session through the network. In order to permit this, the network must provide (almost) error-free communication.

II. PROBLEM STATEMENTS

Communication network design problem is divided into two processes and is stated as:

1. First process deals in designing the network topology using greedy based approach subject to k-connectivity and 2 links diameter while optimizing the network cost.
2. Second process uses genetic algorithm in assigning the capacity to the links in the resultant topology from the first process subject to the average message delay and flow requirements constraints while minimizing the cost.

Input:

1) Graph G (V, E): G represents the network where V is the set of N number of nodes in the network and E is the set of L total numbers of links.
2) Traffic matrix T [N][N]: Traffic requirement for each node pair. T[i][j] is the traffic required between node i and j.
3) Distance matrix: D [N][N]: Distance between each node pair. D[i][j] is the distance between node i and j.
4) T_{max}: maximum admissible average delay.
5) Diameter : 2

Minimize objective:

Network _cost= ∑q Cost (Dq)Xq+ ∑q ∑k D(Cqk)Xqk where Cost (Dq): Cost of the link between the node pair q. Dq is the length of the link.
Xq: A decision variable and its value 1 if there is a link between the node pair q, otherwise 0.D (Cqk): Cost of the capacity type k for a link of node pair
q. Xqk: A decision variable and its value is 1 if capacity type k is assigned to q, otherwise 0.

Subject to Constraints:

Network _diameter =2
Connectivity k >=√ N
T_{max}< T where T_{max} is the maximum admissible Average

message delay of resultant topology.
$Flow_q<C_{qk}$ means traffic flow at link of node pair q
should be less than capacity type assigned to the link.

Over the design variables:

- Links
- Capacities

Output:

Network Topology.

Now first we will develop an algorithm to minimize the cost by which we will get an optimal network topology. Then we will develop the proposed algorithm by using genetic algorithm to assign the capacity to the links in the above network topology.

III. PROPOSED ALGORITHM

The proposed approach searches a subset of low cost links to design a k-connectivity network having two link diameters. The starting node from where the design starts significantly affects the cost of the resultant network. Keeping this in mind, we have proposed to start the topology design with the node whose eccentricity is the highest among all nodes in the network. Eccentricity of a node is the distance/cost from a node to its farthest node in the network. Using this way we can appreciably reduce network cost because no two distant nodes would ever be connected as the chosen farthest node is always connected to its k nearest nodes. Step by step details of proposed algorithm is given below.

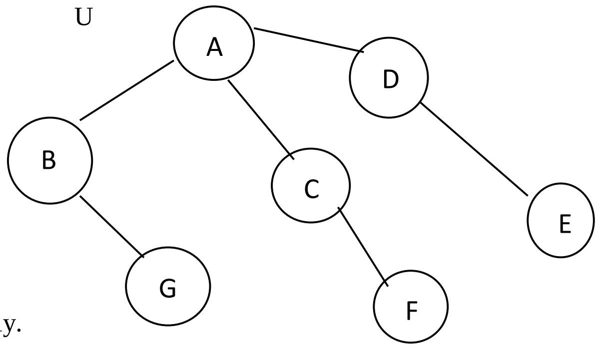
1. Start with the highest eccentricity node s in set V. Set V=V-s.
2. Find (k-degree(s)) number of nearest nodes from s and store them in set C.
3. Connect s to all its nearest nodes in set C either directly or via some other node depending upon the degree of the nearest nodes and node s.
4. Set P=V-{C}.
5. Remove the farthest node d of node s from the set P.
6. Connect node d to the nearest direct connecting node v of node s depending upon the degree of node s ,node d , direct connecting nodes of s and direct connecting nodes of d.
7. Repeat step 4 and 5 until set P is not empty.

8. Repeat all above steps 1 to 6 until the set V is not empty.
9. Resultant graph would be a k-connected network having two links diameter.

Next, working of step 3 and step 5 of above procedure which connects node s to other nodes in the graph either directly or via an intermediate node is described by algorithm create link as given in fig.1. Step3 and Step5 of above algorithm is about creating a link between two nodes u and Depending upon the degree of u and v, there are four cases which tell us about the different situations in which a path satisfying the diameter constraints is created between u and v. illustration of these four cases are given below.

Case1: if Degree (u)! =FULL and Degree (v)! =FULL

U

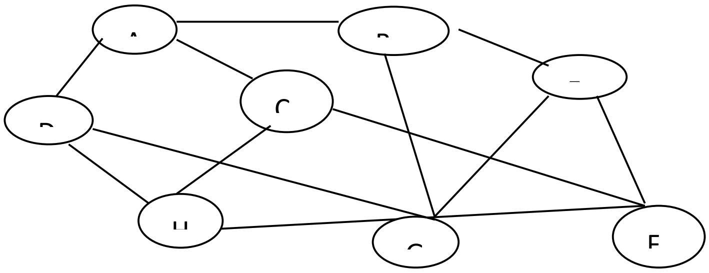


V

Connect u and v directly.

Case 2: if Degree (u) = FULL and Degree (v) =FULL

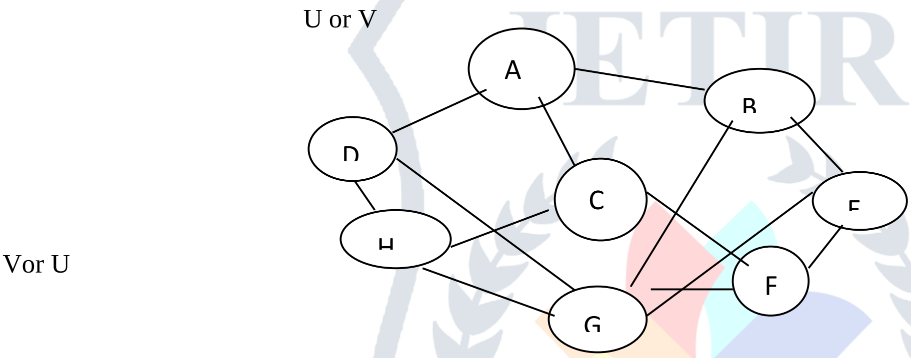
This is the case when we are forced to take an extra line in the topology to satisfy the diameter constraint.
Case 2.1: if Degree (direct_connecting_nodes(u)=FULL and Degree(direct_connecting_nodes(v)=FULL



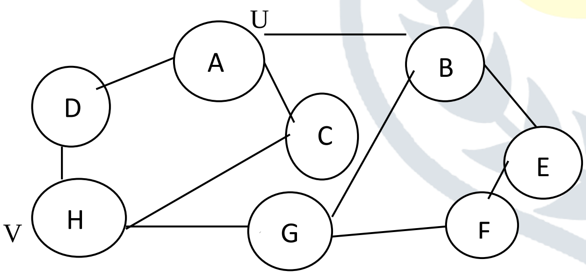
Choose low cost link among the links (BH, BC, BF, BD, HG, HE, HA) which connect u and v.
Case 2.2: if degree (direct_connecting_nodes(u)=FULL

and degree(direct_connecting_node(v)!=FULL

OR
Case2.3: if degree (direct_connecting_nodes(u)!=FULL and degree(direct_connecting_nodes(v)=FULL



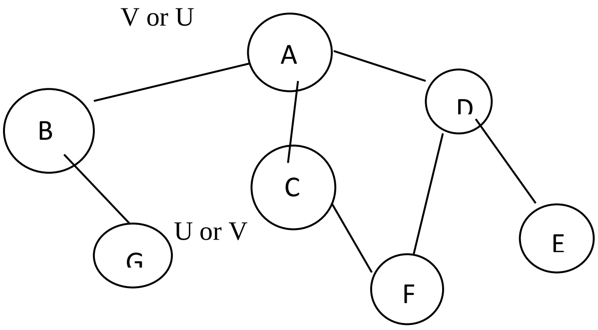
Case 2.4: if degree (direct_connecting_nodes(u)!=FULL and degree(direct_connecting_nodes(v)!=FULL



Chose the low cost link among the links (BC, BD, BF, HG, HE) which connect u to v.

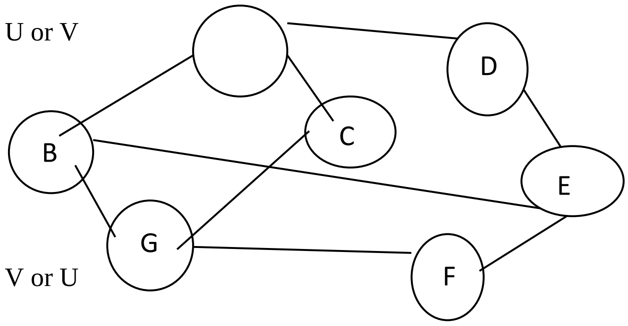
Case 3: If Degree (u)! =FULL and Degree (v) =FULL or if Degree (u) =FULL and Degree (v)! =FULL

Case3.1: if degree (direct_connecting_nodes(v))!=FULL or Degree(direct_connecting_nodes(u))!=FULL



Choose a low cost link among the links (GF, GE) which connect u to v.

Case 3.2: if degree (direct_connecting_nodes(v)=FULL or degree(direct_connecting_nodes(u)=FULL



Choose a low cost link among links (GD, BD, FD, and CD) which connect u to v.

DESIGN EXAMPLES:

In this section we illustrate the proposed method for 7 nodes, 9 nodes, 13 nodes networks also compare the results with the mesh topology, the technique proposed by wassim for two links diameter for wiring cost, communication cost and network quality.

Example 1:

Number of nodes N=7

Connectivity k =√N= 3

Let us consider 7 nodes with some label as shown in the figure-1. Table 1 gives the cost matrix constructed out of the cost associated with the pair of nodes

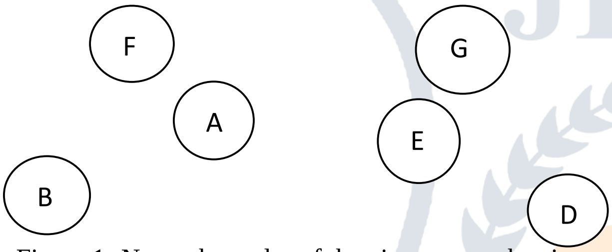


Figure 1- Name the nodes of the given network using some label.

TABLE-1 COST ASSOCIATION WITH EVERY PAIRS OF NODES

	A	B	C	D	E	F	G
A	0	5	3	7	4	2	9
B	5	0	5	10	8	6	12
C	3	5	0	6	4	5	10
D	7	10	6	0	4	8	5
E	4	8	4	4	0	5	5
F	2	6	5	8	5	0	8
G	9	12	10	5	5	8	0

Highest eccentricity node is B. so B is chosen first. Degree of B is 0. Connect B to A, C and F directly as these are the k low cost node B. Now G is the highest cost node from B. Connect G to one of the low cost node F. Another high cost unconnected node to G is D. Finally connect D to its low cost node C among A, B, C. and E to A.

Figure-2 shows the network in which node B is connected to every other nodes either directly or using one intermediate node only.

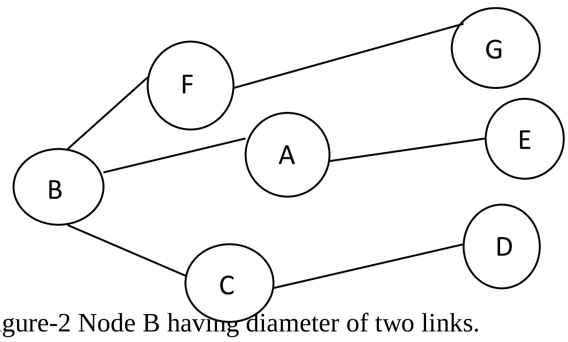


Figure-2 Node B having diameter of two links.

After excluding B for every node for finding out the eccentricity, next highest eccentricity node is G now connect n-d i.e. 2 nearest nodes directly to the node G. so E and D are connected to node G. Now farthest node from G is among rest nodes in set P as per the algorithm is C.
Connect C to nearest node among set C which contains the directly connected nodes to G. So among F, E, D. C is connected to node E and A is connected to E. Now node B and G have diameter of two links.

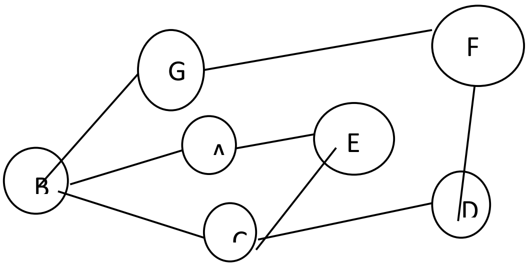


Figure-3 Network having diameter of two links for node B and node G.
Same procedure is applied for every node until all the nodes have the diameter of two links. So the final network is shown in figure-4 having the diameter of network of two links only.

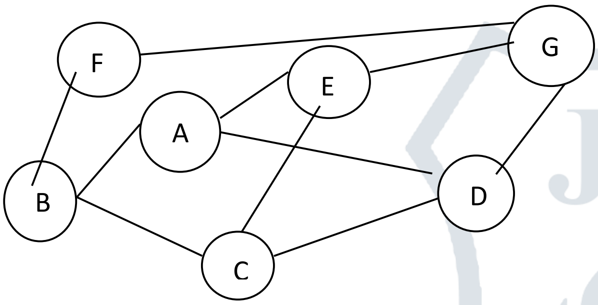


Figure-4. Resultant network having diameter of two links.

RESULTS:
Number of links=11
Cost of the network C=54
Connectivity k=3
Best case diameter=2
Worst case diameter=3

Example: 2
Number of nodes N=13
Connectivity k=$\sqrt{N}$=4
Let us consider 13 nodes with some label as shown in the figure-4. Table2 gives the cost matrix constructed out of the cost associated with the pairs of nodes.

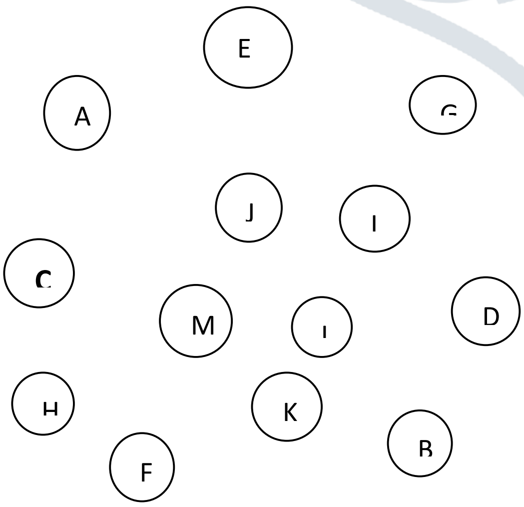
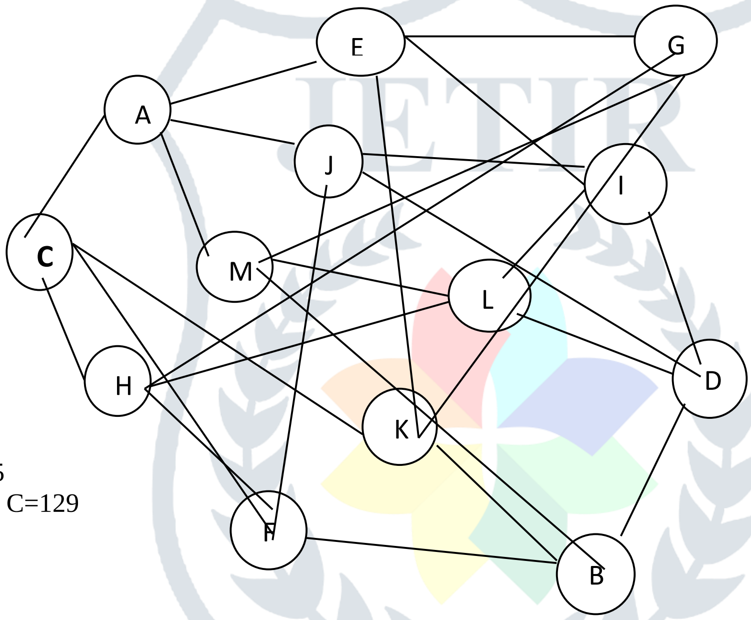


Figure-5 Name the nodes of the given network using some label

TABLE-2 COST ASSOCIATED WITH EVERY PAIRS OF NODES

	A	B	C	D	E	F	G	H	I	J	K	L	M
A	0	15	5	10	4	9	8	7	10	6	8	10	6
B	15	0	10	8	12	6	10	8	8	9	7	8	8
C	5	10	0	12	6	8	7	6	9	5	4	6	4
D	10	8	12	0	8	8	6	7	5	6	6	5	7
E	4	12	6	8	0	8	4	6	5	4	6	6	5
F	9	6	8	8	8	0	7	4	6	5	4	5	4
G	8	10	7	6	4	7	0	6	6	5	4	5	3
H	7	8	6	7	6	4	6	0	6	5	3	5	3
I	10	8	9	5	5	6	6	5	0	4	5	3	4
J	6	9	5	6	4	5	5	5	4	0	3	4	2
K	8	7	4	6	6	4	4	3	5	3	0	4	2
L	10	8	6	5	6	5	5	5	3	4	3	0	3
M	6	8	4	7	5	4	3	3	4	2	2	3	0



RESULT:
Number of links=25
Cost of the network C=129
Connectivity =4
Diameter =2

Algorithm create_link(s,d)

Begin
1. S=direct_connecting_nodes(s)
2. D=direct_connecting_nodes(d)
3. If ((Degree(s)<k))and (Degree(d)>k)) then
Connect(s,d)
Else if ((Degree(s<k)) and (Degree (d ≥k))) then
If (deg (D<k) then

m=find_nearest(s,D)

Connect (s,m)
Else
m=find (s,d,D)
Connect (s,m)
Else if ((Degree(s) ≥k) and (Degree (d) <k)) then
If (deg(S) <k)
m=find (d,S)
Connect (d,m)
Else

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m = find (d,s,S)
Connect (d,m)
Else if ((Degree(s) ≥k) and (Degree (d) ≥k))
If (9deg(S) <k) and (deg (D) <k))
m =find _nearest(d,S)
m1 =find _nearest(s,D)
If (m<m1) then
Connect (d,m)
Else
Connect (s, m1)
Else if ((deg(S) <k) and (deg (D) ≥k))
m =find_nearest(d,S)
Connect (d,m)
Else if ((deg(S)≥k)&& deg(D<k))
m= find_nearest(s,D)
Connect(s,m)
Else if ((deg(S) ≥k) and (deg (D) ≥k))
m=find (d,s,S)
m1=find (s,d,D)
If (m<m1) then
Connect (d,m)
Else
Connect (s, m1)
End
```

Direct_connecting_node(s):This function returns an array containing all direct connecting nodes of a node.

Deg(S): This function return the degree of a node who has lowest degree among all nodes stored in S.

3.3 EXPERIMENTAL COMPARISION:

In this section, our proposed approach is compared with the existing approaches [17],[16] as these are the only approaches which design a network of two links diameter. Network design cost and number of links used to design a network are considered as two parameters for comparison. Comparative analysis for link optimization and design cost of two networks designed in previous section is given in table 2. It is found that our proposed approach always results into less number of links and low design cost than the existing approaches.

TABLE 2: Comparative analysis for link optimization and design cost for two networks

Approach	N=7		N =13	
	Number of links required	Resultant design cost	Number of links required	Resultant design cost
Propose approach	11	54	27	128
Approach in [17]	14	80	39	193
Approach in [16]*	12	71	36	245
Does not result into k-connected network when (k> (n/2)).				

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