Restoring the Connectivity in K-Connected MANET When All Edge Disjoint Minimum Spanning Trees Fail

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ABSTRACT
Due to random mobility of nodes in MANETs, the connectivity of the nodes in very sensitive environments become a serious issue and is subject to increased risk of damage. Sometimes a MANET suffers from the simultaneous failure of multiple multicast paths and gets partitioned into disjoint segments. In order to avoid poor performance of a multicast/ unicast routing protocol and to curb the adverse affect on an application performance, it is essential to restore the network connectivity. In this research work, we proposed a novel strategy, designed and implemented to restore the connectivity in MANET as well as to compute Steiner minimum spanning tree.

General Terms :
Mobile ad hoc networks, Routing , Algorithms, Connectivity, Reconnect.

Keywords:
Edge disjoint minimum spanning trees, K-Connected MANETs, Connectivity Index, Route Failure Tolerance, Steiner minimum spanning tree.

1. INTRODUCTION
A mobile ad hoc network (MANET) is an autonomous system of mobile hosts connected by wireless links. Utilization of multpath routing mechanism to provide improved throughput and route resilience as compared with single-path is a highly recommended in MANET environment. To obtain multiple multicast paths simultaneously, a network should be always multiple route failure tolerant. A MANET of unpredictable random mobility nodes has a greater difficulty to be multiple route failure tolerant. Even though the K-connected MANET is route failure tolerant, high mobility of the nodes may eventually lead the network to be disconnected. To keep on the multicast communication, there should be at least one spanning tree i.e. a MANET should be minimally connected. Therefore, it is required to renovate the disconnected MANET. In this work we propose a novel strategy to restore the network when multiple edge disjoint spanning trees fail simultaneously.

1.1 Related Work
There are innovative routing MANET protocols including optimizing the routing delays with minimum energy utilization and minimum transmission cost multicast trees **[1]**. In the literature study there are many research works on multiple multicast paths for quality of service (QoS) in wireless networks. For example the research work to compute multiple stable link disjoint spanning trees based on link stability is analyzed in our previous work [2]. The computation of edge disjoint minimum spanning trees based on connectivity index with bandwidth requirement of the application is addressed in our previous work [3].The issue of route failure tolerance, multipath multicasting in K-connected MANETs, which in turn affect the multicasting algorithms are studied in our preceding work [4]. The work of Eric Setton et al anlyses the Cross Layer Design of ad hoc networks for real time video streaming [5]. Mohammed Saghir et al investigated the design of the cross layer QoS multicast protocol in MANET [6] [7].

In an extensive literature study that has been carried out on a large no. of research contributions including [1] - [13], we have not come across any contribution on restoring the connectivity in MANET. To the best of our knowledge this work on restoring the connectivity in K-connected MANET for QoS multicasting is a novel work.

The organization of this Paper is as follows: The Section 2 offers the network model and various definitions of interest. The Section 3 describes the novel strategy to restore the connectivity and compute Steiner minimum spanning tree on the reconnected MANET. The illustration of the strategy is given in the Section 4. The Section 5 brings the methodology adopted in the simulation and analysis of the result. The Section 6 concludes this paper.

2. PRELIMINARIES

2.1 Network Model
We study a network where nodes communicate with their neighbors using wireless links. The following assumptions are made: The neighborhood of a node is the set of nodes which can receive a packet transmitted by the nodes. Any packet transmitted by a node is received by all its neighbors. The source node of a multicasting is believed to know the entire information essential to construct the multicast tree. We use the term edge and link interchangeably. The cost of an edge from u to v is same as v to u where (u, v) Є E.

A MANET constructed is studied by adopting the *Random Geometric Graph (RGG) Model.* In this model the nodes at close range have a higher probability of being connected than nodes at farther distances. Let $M(x_m, y_m)$ and $N(x_n, y_n)$ be any two arbitrary nodes of the network. If the Euclidean distance,

$\sqrt{\left(x_m^{\,2} - x_n^{\,2}\right) + \left(y_m^{\,2} - y_n^{\,2}\right)}$ between the two nodes is less than or equal to transmission range (T*R)* of the nodes of the network, then they are said to be neighbor to each other. The transmission power is assumed to propagate in a circular fashion. The nodes can be mobile or stationary. The Random Way Point Mobility model is used for the mobile node simulation. The nodes of the network are distributed in a square area of appropriate dimension.

2.2 Definitions

Some of the important definitions relevant to our discussion are given below.

- **Minimum Spanning Tree (MST) of a Graph G :** Among all the spanning trees of a weighted graph G, the spanning tree whose sum of edge weights is least is called MST of a graph G.
- **Edge Disjoint Minimum Spanning trees (EDMSTs):** Let E1 and E2 be the set of edges of minimum spanning tree-1(MST-1) and minimum spanning tree-2(MST-2) respectively, then MST-1 and MST-2 are said to be edge disjoint minimum spanning trees if E1∩E2= Null Set .
- **K-Connected Graph**: A graph *G* is said to be K connected, if on removal of any K nodes, the graph will become disconnected. The important property of interest relevant to routing in K connected graph is that there exist K disjoint paths between any two nodes of G. A graph G is K-edge connected if it remains connected whenever fewer than K-edges are removed. If a graph is K-edge connected then $K <= \partial(G)$, where $\partial(G)$ is the minimum degree of any vertex $u \in V(G)$. We can write formally, a graph G with edge set E(G) is K-edge connected if G\ C is connected for all $C \subseteq E(G)$ with cardinality of C < K.
- **K-route failure tolerant (K-RFT):** A route between any two nodes is said to have "K- route failure tolerant" if $\exists$ at least K-paths which are reliable without any failures [8].
- **Graph Connectivity Index , $\Lambda(G)$:** Let G be such a graph. Denote by (u,v) the edge of G, connecting the vertices u and v . Then the connectivity index , also called Randi´c index or Randi´c weight or branching index **[3]** , of the graph G, proposed by Randic in 1975, we denote by $\Lambda(G)$ is defined as

$$\Lambda(G) = \sum_{(u,v)\in E} \frac{1}{\sqrt{\partial(u)\partial(v)}}$$

Vertices (u,v) $\in$ E, where $\partial(u)$ is degree of vertex $u \in V$.

3. NOVEL STEINER-KCMST (S-KCMST) ALGORITHM BASED ON CONNECTIVITY INDEX (CI) FOR MULTICASTING

This investigation proposes an effective strategy for restoring the connectivity among the segments. In this strategy, the source node of the Multicast Tree is assigned an additional responsibility to ensure the network partition and take necessary actions to restore the connectivity. This strategy is suitable for a small size network and only a few nodes have random high mobility. In case of a large no. of nodes in a network, random high mobility may lead the network to partition resulting in large no. of segments, then a distributed approach will be suitable.

This investigation is different from the regular Steiner tree problem. In this study we add only edges to connect the pair of nodes and reconstruct the network, called Steiner network. The minimum spanning tree is computed on the newly constructed network, called Steiner minimum spanning tree (S-KCMST).

In this research work we designed an algorithm to restore the connectivity in MANET as well as to compute Steiner minimum spanning tree. Whenever any node in the network gets disconnected (that is If the Euclidean distance $\sqrt{\left(x_m^{\,2} - x_n^{\,2}\right) + \left(y_m^{\,2} - y_n^{\,2}\right)}$ between the two nodes is less than or equal to transmission range T*r* of the nodes)may be due to high degree of mobility, its neighbor shall flood the packets, called "NEIGHBOR-DISCONNECTED PACKET" in the network. As soon as the source finds this packet, it initiates the action to scan the network to ensure that network is disconnected. If network is disconnected and all edge disjoint multicast paths are broken simultaneously, then it signals the corresponding pair of nodes to increase the transmission power till the connectivity is restored and then the source computes Steiner minimum spanning tree on the reconnected network.

Input:

The disconnected Graph, $G^d = (V^d, E^d)$ represented in terms of CI Adjacency (CIA) matrix of the given network. The $N \times N$ CI adjacency matrix, A = a (i,j) of $N \times N$ of a given network is with a(i, j)= connectivity index of vertices (i, j), whenever two nodes (i,j) are connected by some edges and edge is associated with a connectivity index > 0, otherwise zero.

Let MULTICAST-PATH-EXIST be a Boolean variable, its value is FALSE, if all the KC-EDMSTs multicast paths fail, otherwise TRUE. Let initially MULTICAST-PATH-EXIST = TRUE.

Output:

Reconnected MANET Table (RCMT) and Steiner minimum spanning tree based on CI (S-KCMST).

Steps:

a) *Let DISCONNECTED be a Boolean Variable, if network is disconnected or any node sends* NEIGHBOR-DISCONNECTED PACKET then *its value is equals to TRUE, otherwise FALSE, initially DISCONNECTED = FALSE.*

b) *Find whether the network is disconnected (Using algorithm such as Breadth First Search (BFS) algorithm). If yes then DISCONNECTED = TRUE.*

c) *If ((MULTICAST-PATH-EXIST = = FALSE) && (DISCONNECTED = = TRUE)) then Scan the network to find the pair of nodes (i, j) whose links are broken and links are belonging to I optimal EDMST, else go to step e).*

d) *Inform these pair of nodes to increase their transmission power till the connectivity is restored to construct 1-connected network. Go to step b).*

e) *Compute connectivity of the reconstructed network (Steiner Network).*

f) *Store the Steiner Network in RCMT.*

g) *Compute Steiner Minimum Spanning Tree and its CI.*

h) *MULTICAST-PATH-EXIST = TRUE.*

i) *DISCONNECTED = FALSE.*

j) *STOP.*

4. TO ILLUSTRATE THE GENERATION OF STEINER-KCMST

Figure 1 shows a MANET of 7 nodes and 20 edges. Three are three KC-EDMSTs that shall be generated on the network which are shown in Figure 2. Figure 3, Figure 4 and Figure 5 are the first, second and third K-connected edge disjoint minimum spanning trees (KC-EDMSTs) respectively.

In MANETs the nodes are free to move randomly. Thus the network's wireless topology may be unpredictable and may change rapidly. The mobility of the nodes affects the number of KC-EDMSTs, which in turn affect the performance of the routing algorithm as well as limits the possible advantages of multipath multicasting. Therefore, it is desirable to have mobility of the nodes as one of the issues of routing protocol design.

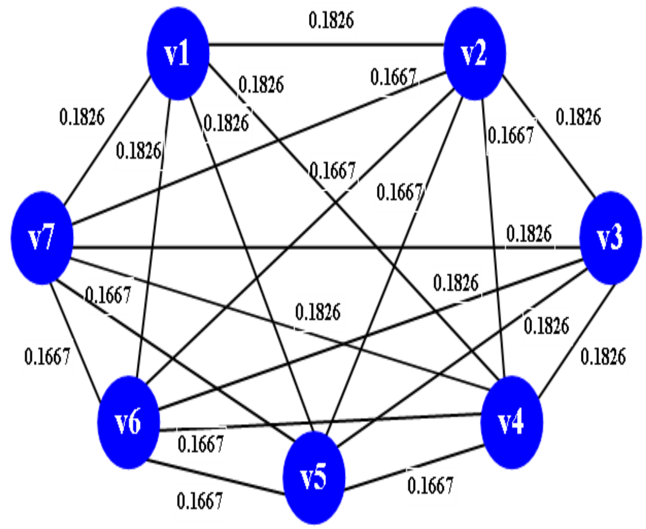

Figure 1 A Random Ad Hoc Network of 7 nodes and 20 edges.

Figure 6 shows a scenario where node v_5 moves out of the radio range such that it does not remains as a neighbor node of any node in the network. This destructs all the KC-EDMSTs resulting in disconnected network. Therefore, it is required to construct the connected network in order to resume back the multicast communication. By adding edges (v_6, v_5) and (v_5, v_4) MANET gets reconstructed and a Steiner minimum spanning tree can be generated, as illustrated in the Figure 7. In this research work, we prefer to get back the edge disjoint minimum spanning tree based on minimum CI which was first optimal

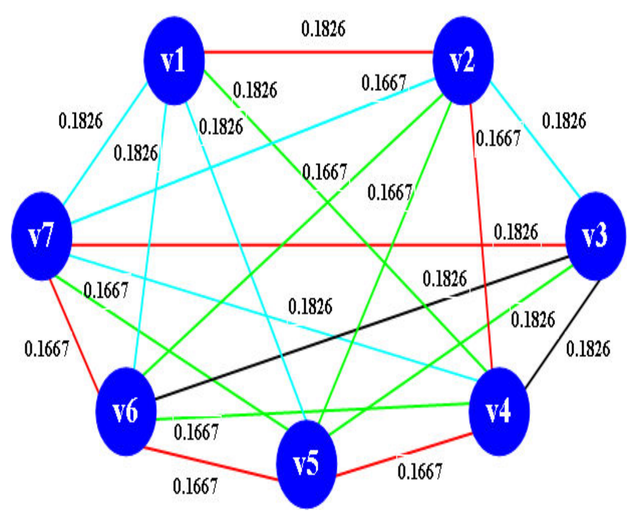

Figure 2 Three KC-EDMSTs are shown with different colors.

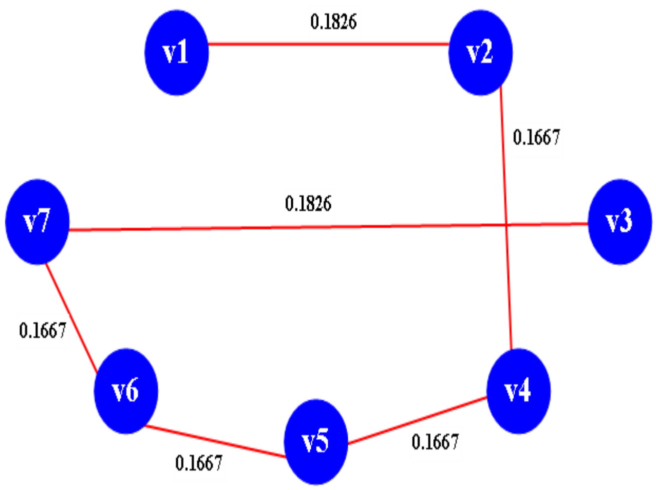

Figure 3 First KC-EDMST with CI=1.0318

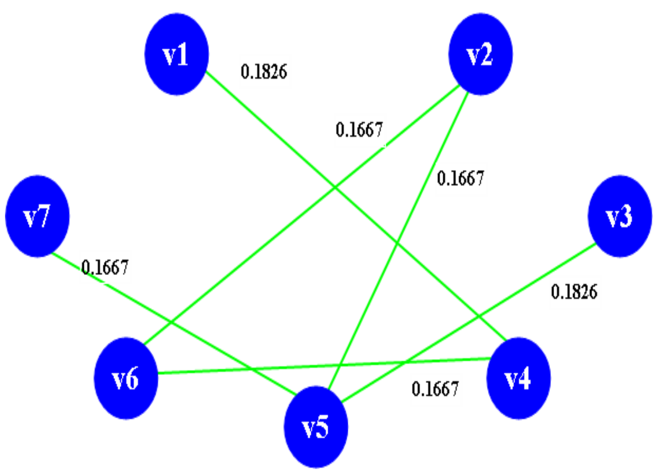

Figure 4 Second KC-EDMST with CI=1.0318

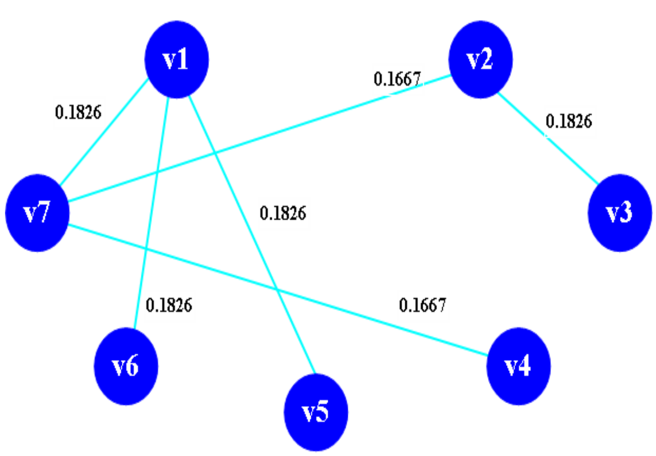

Figure 5 Third KC-EDMST with CI=1.0636

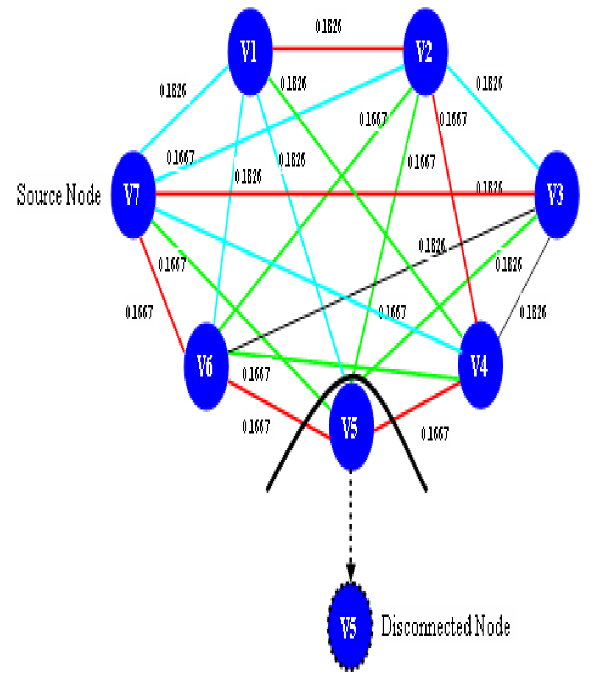

Figure 6 A Disconnected Networks due to mobility of the node $\mathbf{V}_5$

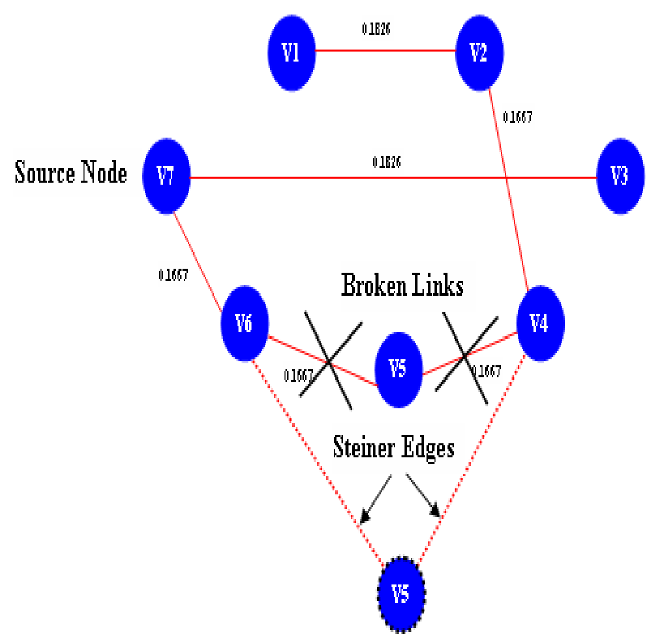

Figure 7 A Reconnected Network by adding Steiner Edges

5. SIMULATION ANALYSIS AND RESULTS

In this study, the K-connected MANETs of different topology and connectivity have been constructed, In the simulation experiments algorithm presented in the Section 4 is automated and significant results are noted. The simulation process starts with a minimal 1-connected network with n (which is fixed for each simulation) number of nodes and n-1 edges. Then progressively, more links are added to built the K-connected MANET where maximum no. of links = n (n-1)/2 edges. The methodology adopted in the simulation process is as follows:

5.1 Methodology

The methodology adopted is as follows:

a) Choose two nodes randomly and add the links between them.

b) Progressively construct the network of size n with no. of edges ranging from n-1 to n (n-1)/2.

c) Calculate the CI of each edge and label the edges with their CI as weight.

d) Compute the K connectivity of the network where K=1, 2, 3,..,(n-1) ***[4]****.*

e) Compute the KC-EDMSTs, their connectivity index and the number of edge disjoint spanning trees in a KC-MANETs using prim's algorithm ***[4]****.*

f) Compute the S-KCMST (using the algorithm given in the Section 3).

g) Analyze the various parameters explicitly no. of EDMSTs, Connectivity index (CI) of each EDMSTs, , the S-KCMST and its CI by plotting the graphs.

5.2 Results

The work has carried out successfully the simulation experiment in MANET environment to reconnect the disconnected MANET to have minimal connectivity.

In the previous discussions we pointed out that due to high mobility eventually K-connected network may get disconnected. Therefore, it is necessary to have at least one multicast path to continue the communication. It is possible to add edges and generate Steiner spanning tree to get a multicast path. In this simulation study many no. of experiments are conducted to study the construction of Steiner connected MANET and to compute S-KCMST.

A network of K value 4 with 7 nodes is constructed. The EDMSTs and their respective CI are computed. When the network is disconnected, it is reconnected to restore the minimal connectivity. A Steiner minimum spanning tree is computed and its CI is noted. The simulation result is shown in the Figure 8. The simulation experiment is repeated several times. The Figure 9 shows another instance of the simulation when network is 5-connected with 7 nodes.

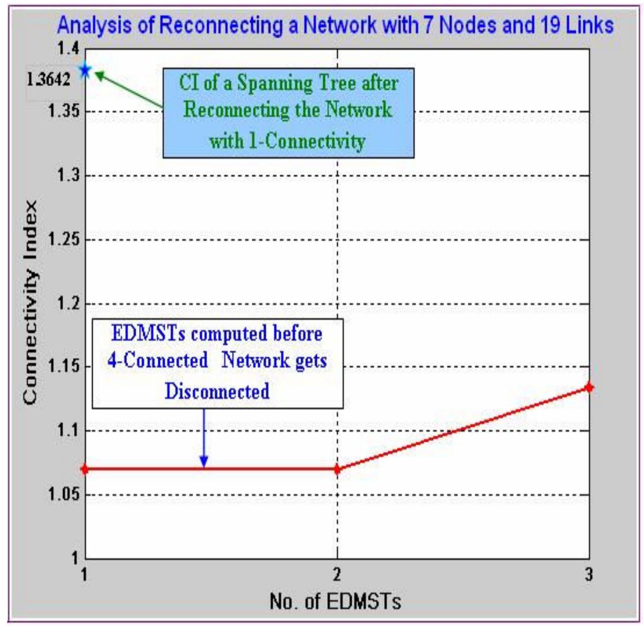

Figure 8 The Generation of Steiner minimum spanning tree

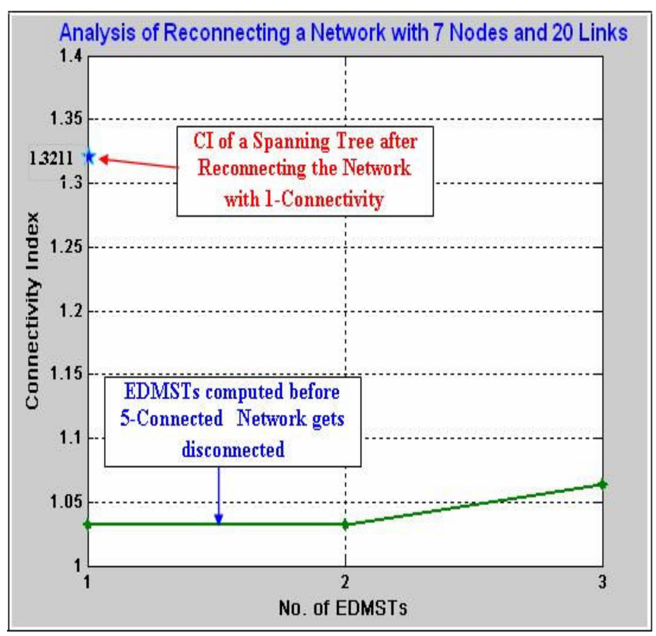

Figure 9 The Generation of Steiner Minimum Spanning Tree

6. CONCLUSION

In multicasting applications if network is K-connected, MANET offers robust, multipath multicasting with high packet delivery ratio. In this research work, the novel algorithm is devised and coded to restore the network connectivity and to compute Steiner minimum spanning tree in K-connected MANET based on CI. Restoring the network connectivity is very crucial in MANET as network has to support multimedia applications for emergency situations.

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