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Network Route Optimization

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Abstract
Performance of network whether it is wired or wireless depends upon its optimized route which may be in the form of Shortest Path or Constrained Spanning Tree. This paper presents a detail study about the network route optimization problem with conventional and Metaheuristic approach to get the optimal solution.

Keywords: Shortest paths, Constrained Minimum Spanning Tree, Metaheuristic Algorithm

1. Introduction

In the 21st century where Information Technology is guiding the direction of development and prosperity of the society and therefore country is running on the wheel of Network. This is a network which has materialized the real concept of globalization where distance does not matter and the people are virtually available everywhere. Importance of network cannot be ignored or overlooked as it is the backbone of the current technology. Network Route Optimization is a classical problem of network design which decides the performance of the network including various parameters as cost, delay, reliability, fault tolerance and network flow. Network Optimization is a complex problem[1] [4][6]which belongs to the common intersection of mathematics and theoretical computer science which deals with the analysis of algorithms. At present scenario there is a large class of network optimization problems for which no reasonable fast algorithms have been developed. And many of these network optimization problems arise frequently in real life applications. Network optimization models such as shortest path, assignment, max flow, transportation, transhipment, spanning tree, matching, traveling salesman, generalized assignment, vehicle routing, and multi-commodity flow constitute the most common class of practical network optimization problems. Basic Network Optimization Model can be referred as:

- Shortest Path Model: Node Selection and Sequencing
- Spanning Tree Model: Arc Selection
- Maximum Flow Model: Arc Selection and Flow Assignment

This study focuses on the route optimization of the network, hence in this context Shortest Path and Spanning Tree model is appropriate and considered for study.

2. Shortest Path Model

Route optimization of the network depends on the connectivity of the nodes of the network through existing arcs. In case of unicasting routing, shortest path model play a very important role in selecting the relevant path for transferring the data from the source to the destination efficiently[2]. In wireless sensor networks[3], it is an important task to periodically collect data from an area of interest for time-sensitive applications. The sensed data must be gathered and transmitted to a base station for further processing to meet the end-user queries. Since the network consists of low-cost nodes with limited battery power, it is a challenging task to design an efficient routing scheme that can minimize delay[5][7] and offer good performance in energy efficiency, and long network lifetimes. Shortest Path Problem can be further classified as :

- **Single-source shortest path problem**, where to find shortest paths from a source vertex v to all other vertices in the graph.
- **Single-destination shortest path problem**, where to find shortest paths from all vertices in the directed graph to a single destination vertex v. This can be reduced to the single-source shortest path problem by reversing the arcs in the directed graph.
- **All-pairs shortest path problem**, where to find shortest paths between every pair of vertices v, v' in the graph.

2.1 Conventional Approach to Solve Shortest Path Problem

A method to solve SPP is sometimes called a routing algorithm. The most important algorithms for solving this problem are:

- ***Dijkstra's algorithm*:** Solves single source problem if all edge weights are greater than or equal to zero. Without worsening the run time, this algorithm can in fact compute the shortest paths from a given start point *s* to all other nodes.
- ***Bellman-Ford algorithm*:** Computes single-source shortest paths in a weighted digraph (where some of the edge weights may be negative). Dijkstra's algorithm accomplishes the same problem with a lower running time, but requires edge weights to be nonnegative. Thus, Bellman-Ford is usually used only when there are negative edge weights.
- ***Floyd-Warshall algorithm*:** An algorithm to solve the all pairs shortest path problem in a weighted, directed graph

by multiplying an adjacency-matrix representation of the graph multiple times.

3. SPANNING TREE MODEL

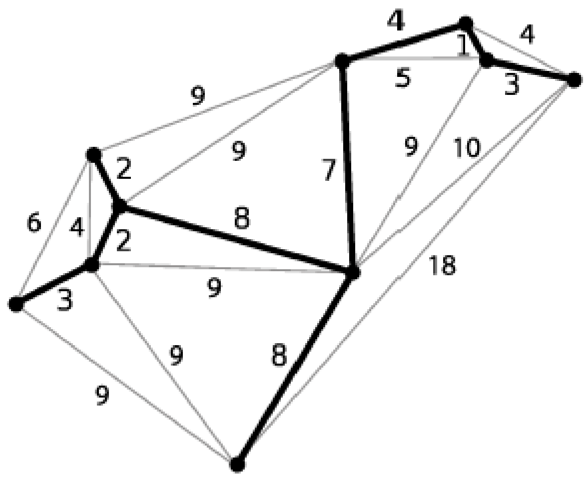
A spanning tree of an existing network is a tree that connects all the nodes together. A single network can have many different spanning trees[8][10]. In case of broadcasting or multicasting where data packets are sent to all or a group of nodes of an existing network, spanning tree model plays a very important role to improve the performance of the data communication process. Spanning Tree Problem can be further classified as:

- **Minimum Spanning Tree**
- **Constrained Spanning Tree**

3.1 MINIMUM SPANNING TREE

Given a connected, undirected graph, a *spanning tree* of that graph is a sub graph which is a tree and connects all the nodes together. A single graph can have many different spanning trees. We can also assign a weight to each edge, which is a number representing how unfavorable it is, and use this to assign a weight to a spanning tree by computing the sum of the weights of the edges in that spanning tree. A *minimum spanning tree* (MST) is a spanning tree with weight less than or equal to the weight of every other spanning tree.

A Minimum Spanning Tree (MST) $T_{MST}(V,E_{MST})$ is a spanning tree of Network N with minimum edge costs, i.e. $\sum_{e \in E_{MST}} c(e) \rightarrow \min$



The minimum spanning tree of a planar graph. Each edge is labeled with its weight, which here is roughly proportional to its length.

Fig-1 Minimal Spanning Tree of a Network

3.2 CONVENTIONAL APPROACH TO SOLVE MST

There are now two algorithms commonly used, Prim's algorithm and Kruskal's algorithm. All three are greedy algorithms that run in polynomial time.

- **Kruskal's Algorithm**: Examines edges in non decreasing order of their lengths and include them in MST if the added edge does not form a cycle with the edges already chosen. The proof of the algorithm uses the path optimality conditions[11]. Attractive algorithm if the edges are already sorted in increasing order of their lengths

Description

- Take a network N (a set of networks), where each vertex in the network is a separate network
- create a set S containing all the edges in the network
- while S is nonempty and N is not yet spanning
- remove an edge with minimum weight from S
- if that edge connects two different trees, then add it to the network, combining two networks into a single network
- otherwise discard that edge.

At the termination of the algorithm, the forest has only one component and forms a minimum spanning tree of the graph.

Performance

Where E is the number of edges in the graph and V is the number of vertices, Kruskal's algorithm can be shown to run in O(E log E) time, or equivalently, O(E log V) time, all with simple data structures

- **Prim's algorithm** is a greedy algorithm that finds a minimum spanning tree for a connected weighted undirected graph. This means it finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized.

Description

- create a tree containing a single vertex, chosen arbitrarily from the Network
- create a set containing all the edges in the network
- loop until every edge in the set connects two vertices in the tree
- remove from the set an edge with minimum weight that connects a vertex in the tree with vertex not in the tree
- add that edge to the tree

Performance

A simple implementation using an adjacency matrix graph representation and searching an array of weights to find the minimum weight edge to add requires O(V2) running time. Prim's algorithm can be shown to run in time O(E log V) where E is the number of edges and V is the number of vertices.

3.3 CONSTRAINED SPANNING TREE (CST)

There are several factors in the network which decides the performance. The objective functions related to cost, time, accessibility, environmental impact, reliability and risk are appropriated for selecting the most satisfactory route in many network optimization problems . General MST does not satisfy all problems :

- Too long a path from one node to another
- Too high the degree of a node
- Capacity on a path between nodes
- Flow control between nodes
- Path control among nodes/ networks

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- Congestion control among nodes/networks
- Reliability in the case of path failure or node failure
- Maximum spanning tree etc..

These important factors which are the essential part of network optimization can further classify the constrained spanning tree in to following class:

A. Degree-Constrained Minimum Spanning Tree

Degree-constrained minimum spanning tree (dMST) is a special case of MST. Given a finite connected network, the problem is to find an MST where the upper bounds of the number of edges to a node is satisfied. The dMST[12] problem is NP-hard and traditional heuristics have had only limited success in solving small to midsize problems.
Degree deg(v) is the number of edges connected to vertex v. DCMST with degree constraint n is a MST with
$deg(v) \leq n$

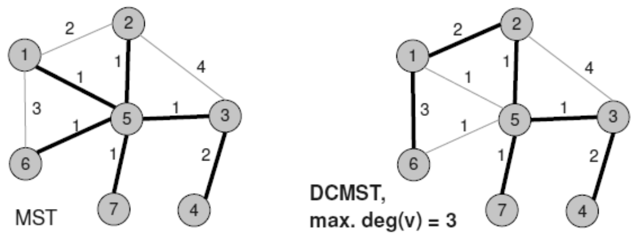

Fig-2 MST and DCMST of a Network

B. Maximum-leaf Spanning Tree

A connected dominating set of a graph *G* is a set *D* of vertices with two properties:

1. Any node in *D* can reach any other node in *D* by a path that stays entirely within *D*. That is, *D* induces a connected sub graph of *G*.
2. Every vertex in *G* either belongs to *D* or is adjacent to a vertex in *D*. That is, *D* is a dominating set of *G*.

A **minimum connected dominating set** of a graph *G* is a connecting dominating set with the smallest possible cardinality among all connected dominating sets of *G*. The **connected domination number** of *G* is the number of vertices in the minimum connected dominating set. Any spanning tree *T* of a graph *G* has at least two leaves, vertices that have only one edge of *T* incident to them. A maximum leaf spanning tree is a spanning tree that has the largest possible number of leaves among all spanning trees of *G*. The **max leaf number** of *G* is the number of leaves in the maximum leaf spanning tree.

C. K-minimum Spanning Tree

Given an undirected graph with non-negative edge costs and an integer, the –minimum spanning tree, or -MST, of is a tree of minimum cost that spans exactly vertices of . A -MST does not have to be a sub graph of the minimum spanning tree (MST) of . This problem is also known as Edge-Weighted -Cardinality Tree (KCT). The k-MST problem is shown to be NP-Hard by reducing the Steiner tree problem to the -MST problem.

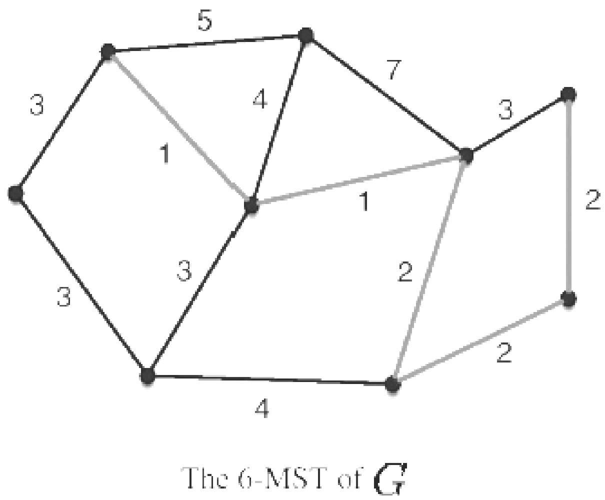

Fig-3 K-Minimum Spanning Tree of a Graph

D. Capacitated Minimum Spanning Tree

Capacitated minimum spanning tree (CMST) problem is a extended case of MST. Give a finite connected network, the problem is to find a MST, where the capacity of nodes are satisfied. Capacitated minimum spanning tree is a minimal cost spanning tree of a graph that has a designated root node ***r*** and satisfies the capacity constraint ***c***[13] . The capacity constraint ensures that all sub trees (maximal sub graphs connected to the root by a single edge) incident on the root node ***r*** have no more than ***c*** nodes. If the tree nodes have weights, then the capacity constraint may be interpreted as follows: the sum of weights in any sub tree should be no greater than ***c*** . The edges connecting the sub graphs to the root node are called gates. To find the optimal solution, one has to go through the lowest cost; such search requires an exponential number of computations all the possible spanning tree configurations for a given graph and pick the one with the lowest cost; such search requires an exponential number of computations.

E. Bounded Diameter Minimum Spanning Trees

Path p(Vs,Vt) is a cycle-free way (e1… en.) Є E^n from Vs to Vt. Diameter dia(G) is the length of the longest path between any 2 nodes in G, dia(G) ≤ (IVI - 1).

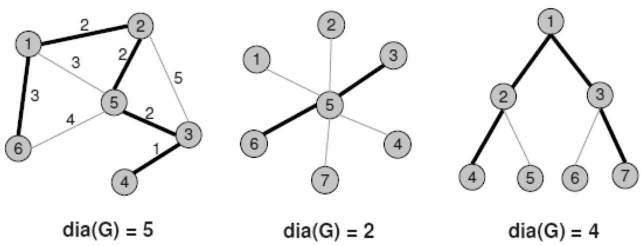

Fig-4 Bounded Diameter MST

F. Minimum Steiner Trees

MST which has to span only a vertex subset D ∈ V may contain additional nodes → **Steiner nodes**

Important application: Delay-Constrained Multicast Routing Problem (DCMR)

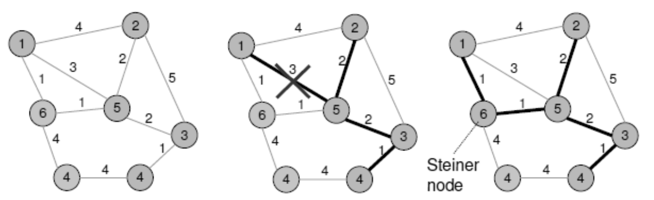

Fig-5 Minimum Steiner Trees

G. Multicriteria Minimum Spanning Tree

In the real world, there are usually such cases that one has to consider simultaneously multi criteria in determining an MST because there are multiple attributes defined on each edge, and this has become subject to considerable attention. Each edge has ***q*** associated positive real numbers, representing ***q*** attributes (weight, distance, cost and so on) defined on it .

3.4 APPROACH TO SOLVE CST

- **Approximation Algorithm**

For the problem of DCMST with a maximum degree K. where K is a number suggested by Fürer & Raghavachari (1994)

- **Linear Programming**

Limited to the size of the network and constraint.

- **Ant Colony Optimization (ACO)**

Ant Colony Optimization (ACO) is an algorithm based on the behavior of the real ants in finding a shortest path from a source to the food.

- **Evolutionary/Genetic Algorithms (EA)**

GAs are stochastic search algorithms based on the mechanism of natural selection and natural genetics. GA, differing from conventional search techniques, start with an initial set of random solutions called *population* satisfying boundary and/or system constraints to the problem. Each individual in the population is called a *chromosome* (or *individual*), representing a solution to the problem at hand. Chromosome is a string of symbols usually, but not necessarily, a binary bit string. The chromosomes *evolve* through successive iterations called *generations*.

- **Particle Swarm Optimization**

PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions

- **Artificial Bee Colony**

ABC is developed based on inspecting the behaviors of real bees on finding nectar and sharing the information of food sources to the bees in the hive. Artificial Bee Colony (ABC) algorithm which is one of the most recently introduced optimization algorithms simulates the intelligent foraging behavior of a honey bee.

APPLICATION

- Maximum Leaf Spanning Tree in Mobile ad-hoc networks
- CMST in central hub, the star configuration network design
- DCMST in Sensor Network
- Multicast routing algorithms
- Cluster Analysis

4. CONCLUSION

This paper conducts a detail study about Network Optimization Problem and its importance. It has clearly stated the various classifications of network optimization and its conventional approach to solve. It is also found that conventional approach has its own limitation and work up to a small size of network with constraints. It is observed that Constrained Spanning Tree is the main problem which is continuously in use by the network communication model. CST covers the multi objective constraints like cost, time, delay, reliability, fault tolerance, environmental impact and network flow. Designing of CST is a NP problem and therefore, how to design efficient algorithms suitable for complex nature of network optimization problems is a challenge. Metaheuristic approach is an alternative option to find the solution.

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