SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

The STSM applicant submits this report for approval to the STSM coordinator

Action number:
STSM title: Euclidean Steiner trees with soft obstacles – Obtaining a spine for a communication network avoiding disaster prone areas
STSM start and end date: **07/01/2018 to 14/01/2018**
Grantee name: Luis Carlos Artur da Silva Garrote

PURPOSE OF THE STSM

The geographical areas more prone to natural disasters such as hurricanes, floods or earthquakes can often be associated with a probability of occurrence of such disasters in some amount of time.

In this STSM we propose to represent these areas in the Euclidean plane as soft obstacles and the purpose is to obtain a Steiner tree to connect a set of nodes (terminal nodes) avoiding, if possible, these disaster areas with the minimum cost.

The SPINE concept was introduced in [1] as a way to improve the availability of transport networks. In this work the purpose is to design the spine from scratch in order to know how to connect a set on terminal nodes that represent communication equipment, avoiding disaster prone areas, through the minimum length infrastructure (a Steiner tree). The obtained tree corresponds to the final layout of fibbers or microwave links of the transport network with high availability (guaranteed by the quality and redundancy of the equipment that should be deployed). Additional Steiner nodes that appear in the solution may have additional cost if communications equipment is required in those nodes. In a first approach these nodes will have zero cost.

To address this problem we prepared a graphic interface (see Figs. 1 to 6) where the soft obstacles can be represented in a grid map as polygonal obstacles or according to a specific function that better fits each disaster area (e.g. a bi-dimensional Gaussian distribution), being the cost of each cell in the grid specified according by that function.

A heuristic and/or meta-heuristic is going to be used as a first approach to tackle the problem and some work was done before this STSM.

A bi-criteria approach can also be explored because it could be interesting to obtain not only the minimum cost tree but also the shortest Steiner Euclidean tree, as well as other intermediate trees which are non-dominated solutions of the Pareto front.

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DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The key goal of this STSM was to design a reliable backbone for communication networks (a SPINE) in an environment where high probability disaster areas are represented as soft obstacles. This can be seen as a Euclidean Steiner tree problem with soft obstacles. Also, after successfully solving the problem (through a heuristic approach) we planned to use real-world data to validate the results.

We divide the types of obstacles into two classes: solid and soft obstacles. Solid Obstacles are non-traversable obstacles i.e., areas that cannot be crossed by a connection between nodes. Soft obstacles are obstacles through which a connection between two nodes can be stablished but with an increase of the cost of the overall solution. The class of soft obstacles can be further divided into homogeneous and non-homogeneous obstacles. In homogeneous obstacles the cost is constant and for non-homogeneous obstacles the cost varies accordingly to a defined model (e.g., Gaussian function). Optimal approaches to solve the problem without obstacles and with solid obstacles were presented in [2][3].

Due to the limited STSM duration, the work carried in the 7 days period included:

- Discussion and validation of previous work in Euclidean Steiner trees with solid obstacles.
- Discussion and initial work on Euclidean Steiner trees with soft obstacles (homogeneous type).

The previous work in Euclidean Steiner trees with solid obstacles consisted in two heuristic approaches. The first approach uses a Minimum Spanning Tree (MST) avoiding obstacles as a Steiner tree candidate and then iteratively inserts Steiner points where they minimize the tree's length. The second approach incrementally builds the Steiner tree taking into account local minimal connections with possible Steiner points.

During the STSM, The Euclidean Steiner trees with soft obstacles problem was defined as follows: given a division of the plane into polygonal faces (polyhedral surface) with weights assigned to faces and given a set of terminals that need to be interconnected, compute a weighted minimum Steiner tree. The cost of the tree in the context of this problem is defined as the Euclidean distance multiplied by the underlying weight of each obstacle represented.

In order to provide a solution to the problem of the Euclidean Steiner trees with soft obstacles we followed a similar approach to the first one described for solid obstacles where an initial solution was given by a MST and then Steiner points where inserted to improve that solution and minimize the tree's cost. To structure and plan the work ahead, the problem was subdivided in modules/tasks.

- **Task 1** – The computation of the shortest path between two points in a polygonal/polyhedral representation of the soft obstacles.
- **Task 2** – The computation of the MST considering the soft obstacles with the shortest path algorithm developed in Task 1.
- **Task 3** – The computation of a new solution that minimizes the tree's cost by inserting Steiner points.

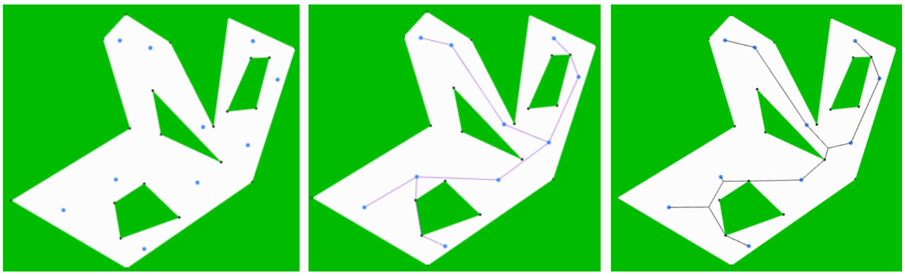
During the STSM, the work on the first task was initiated and some preliminary results are show in the next Section.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

This results section is divided into two main subsections: Euclidean Steiner trees with solid obstacles and preliminary results for Task 1 and Task 2.

Euclidean Steiner trees with solid obstacles

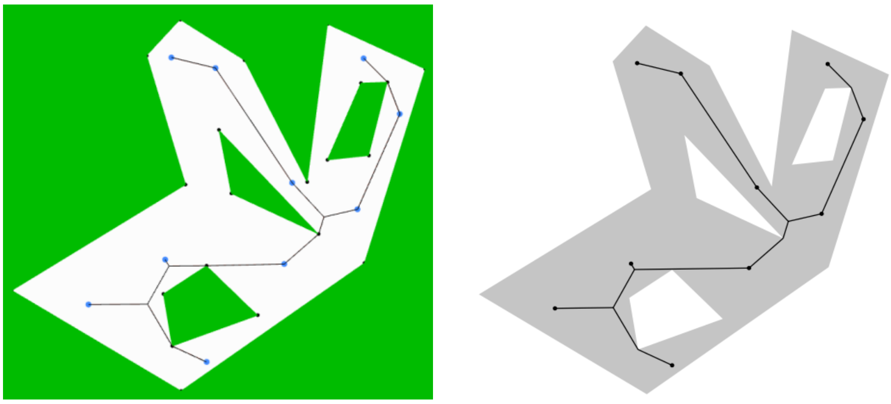
Our Euclidean Steiner tree with solid obstacles approach presented here uses a MST avoiding solid obstacles as a Steiner tree candidate and then iteratively inserts Steiner points where they minimize the tree's length. The dataset was provided by Prof. Martin Zachariasen and is related to the work published in [3]. Figure 1 shows the initial conditions of one problem of the dataset, the MST solution and the final Steiner minimal tree (SMT).



Terminal Nodes + Obstacles | MST | SMT

Fig. 1 – Euclidean Steiner trees with solid obstacles based on a MST.

In Fig. 2 a qualitative comparison between the proposed heuristic and the optimal solution is presented for the scenario presented in Fig. 1. Although it is not referred in the figure, the trees have the same.



Heuristic (Approach 1 and 2) | Optimal

Fig. 2 – Comparison of the final result between the heuristic approach and the optimal solution [3].

Preliminary results for Task 1 and Task 2

The shortest path approach is based in [4]. The scenario's environment is defined as a set of polygons where each polygon is defined by their extremal points. This approach converts the Euclidean shortest path problem with soft obstacles into a graph problem by discretizing the obstacle's edges. The obtained results during the STSM are shown in Fig. 3 for only one obstacle.

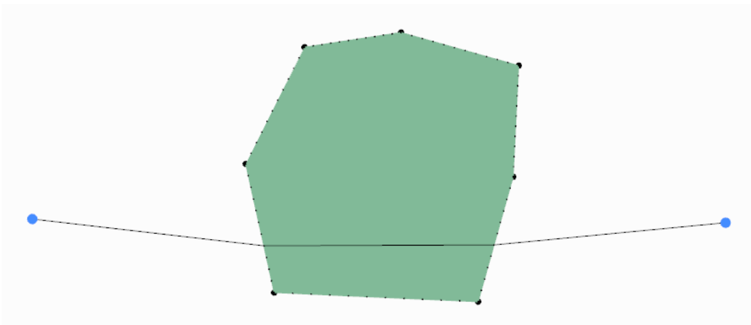
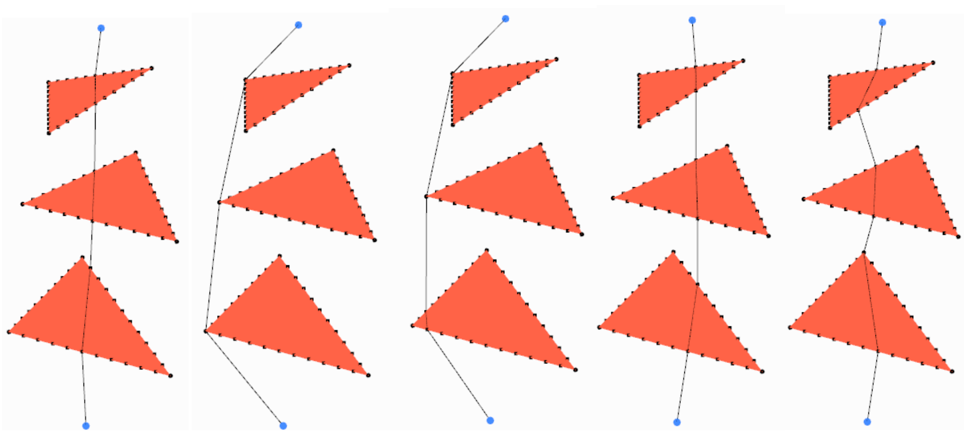


Fig. 3 - Preliminary solution developed during the STSM for the shortest path with one obstacle.

After the STSM, the next step was to generalize the developed shortest path algorithm for any number of obstacles (see Fig.4). The main challenge related to this step was to verify which obstacles need to be considered between each pair of nodes taking into account the extremal points from different polygons.



C_{free}=1 C_{obs}=1 C_{free}=1 C_{obs}=2 C_{free}=1 C_{obs}=1.5 C_{free}=1 C_{obs}=1.25 C_{free}=3 C_{obs}=1

Fig. 4 - Preliminary shortest path solution with multiple obstacles (10 segments per polygon's edge).

In this particular approach we apply a constant cost to all the obstacles (C_{obs}), a potential constraint that can easily be removed to include a cost for each obstacle. It was also considered a cost (C_{free}) assigned to the space outside obstacle. The graph for the problem presented in Fig. 4 is shown in Fig. 5.

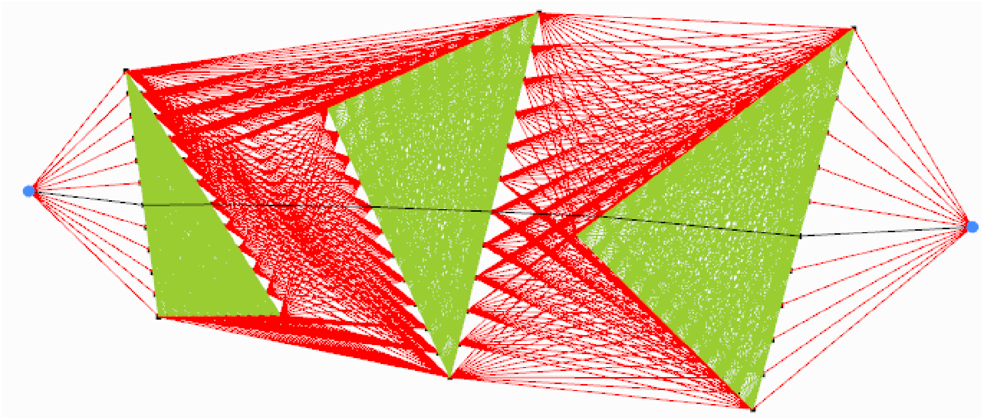


Fig. 5 – Graph representation of the shortest path problem with soft obstacles, containing only valid connections. In red are the paths outside the obstacles (with C_{free}) and in green the paths inside the obstacles (with C_{obs}).

Having a preliminary solution for the Task 1, the next step was to generate a MST considering soft obstacles. The proposed algorithm is shown in Algorithm 1 and uses the Prim's Algorithm [5] to compute the final MST.

Input: Terminal Nodes (N); Obstacles (O)

$M \leftarrow$ InitializeNodeDistanceMatrix();
foreach $(a_i, a_j) \epsilon N$ **do**
  $collides \leftarrow$ collisionDetection((a_i, a_j),O) ;
  if $collides$ **then**
    $P \leftarrow$ ShortestPath_SoftO((a_i, a_j),O);
    $M(i, j) \leftarrow$ distance(a_i,P,a_j)
MSTO $\leftarrow$ Prim(M)

Output: MST avoiding soft obstacles ($MSTO$)

Algorithm 1 – Algorithm to obtain a minimum spanning tree avoiding soft obstacles – MSTO (N,O).

The first step of the algorithm is the computation of a triangular matrix containing the Euclidean distances between the terminal nodes (**InitializeNodeDistanceMatrix**). Then for each pair of nodes, a collision is computed between the line segment defined by the nodes and the obstacles (**collisionDetection**). If a collision is detected then a new path is computed that connects the two nodes using the previously presented shortest path algorithm (**ShortestPath_SoftO**).The path is stored to be used later and the distance is updated in the triangular matrix (**distance**). The Prim's algorithm is then used on the triangular matrix to compute the MST considering soft obstacles (MSTO). A qualitative comparison between MST avoiding solid obstacles and through soft obstacles is shown in Fig. 6.

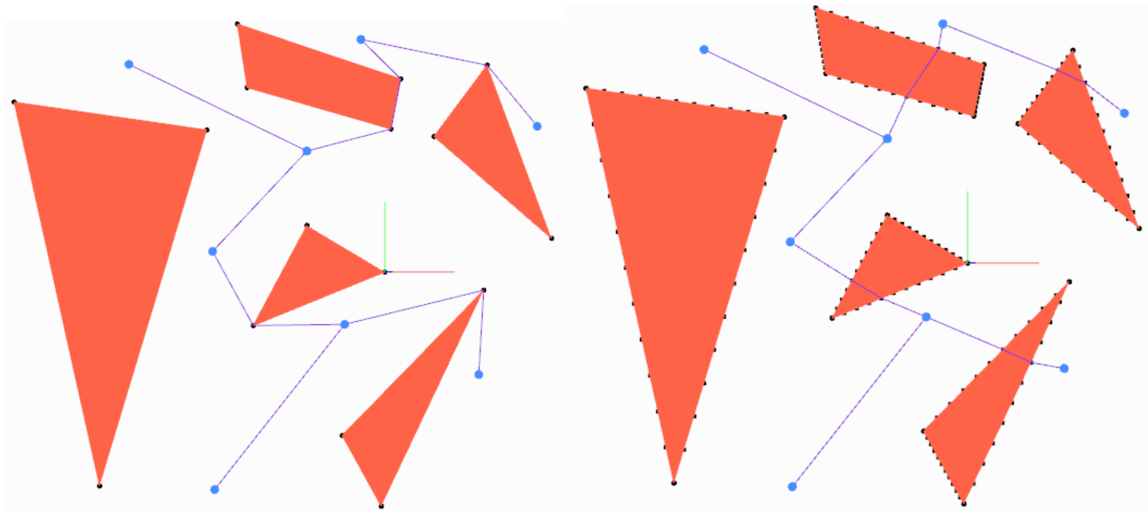


Fig. 6 –MST approaches considering obstacles: left side is the MST avoiding solid obstacles and right side contains the MST through soft obstacles (with 10 segments, C_{free}=1 and C_{obs}=1.25).

FUTURE COLLABORATIONS

This report presents the initial work regarding the Euclidean Steiner tree problem with soft obstacles. We plan to conclude the three tasks listed in a previous Section of this document in the next few months. Also, we are planning to use real data from hazard databases available online, such as the Japan Seismic Hazard database [6] (see Fig. 7), and extract from these databases soft obstacles[1] representing critical regions to be avoided by a reliable backbone network (the Steiner tree).

Fig. 7 – Japan Seismic Hazard Information http://www.j-shis.bosai.go.jp/map/?lang=en .

The expected output of this research collaboration is at least one paper.

[1] Obtained by Balázs Vass (PhD student, Budapest University of Technology and Economics).

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