A New Automatic Tool for Submarine Cable Path Planning and System Design

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***Abstract*—Submarine optical fiber cables are vital for global communications. Traditional manual planning methods are labor-intensive. We develop an automatic cable path planning and system design tool that provides optimal solutions based on rigorous methodology and algorithms. Our approach introduces a penalty function that accounts for harmful human activities and potential natural disasters, employs a realistic model of surface topography as a triangulated manifold, and uses the Fast Marching Method for efficient path planning. Although our current results are optimal given the available data, they could improve with additional data. Our poster describes our methodology and demonstrates real-world optimal cable system designs obtained by our tool interface.**

***Index Terms*—Submarine optical fiber cables, Fast Marching Method, path-planning, cost-effectiveness, survivability**

I. INTRODUCTION

Submarine optical fiber cables play a key role in global communication networks. About 99% of global voice and data traffic go through submarine optical fiber cables. However, such an important infrastructure is vulnerable to human activity and unpredictable disasters like earthquakes and volcanoes.

Currently, the industry approach to cable path planning is manual and laborious, which has several steps. First, an initial path is chosen based on the great circle on the earth's surface between source and destination. Next, a boat is sent to collect data in the surrounding area of the path. Then, experts manually choose a path based on their experience and available data. If more data is needed, the boat is sent again, possibly multiple times, to further refine the path. When experts adjust the path, various factors are taken into account manually, meter by meter, over thousands of kilometers of cable. The final path may differ from the initial path significantly.

In addition to the construction cost of submarine cables, the repair of submarine cable faults can also cost millions of dollars. Cable path designers place great importance on human activity and disasters, not only because of high repair costs but also because of the effects on the economy and the social consequences due to network breakage. For example, the eruption of the Hunga Tonga-Hunga Ha'apai volcano in January 2022 destroyed an around 80-kilometer cable path in Tonga, leading to a month-long loss of communication with the outside world in Tonga [1].

Our approach involves creating a tool through a company called *SeaNet Cable Planning and Design Company Limited* that automatically generates optimal cable paths for a specified set of nodes on the earth's surface. To obtain the optimal submarine cable path plan given the data, we apply the Fast Marching Method (FMM), which is an asymptotically optimal numerical method for solving the Eikonal equation [2], [3]. To speed up computation, we integrate adaptive parallelization into FMM [4]. Furthermore, we also consider network topology, capacity, and latency constraints in the submarine cable system design [5]–[9]. Previous work on network resilience was mainly based on graph theory, where all links are assumed to be straight lines. We optimize both the cable network and the cable paths. Our tool provides an accurate initial path for submarine cable path planning, significantly reducing the time and cost associated with the current manual industry approach.

Initially, cable paths and systems are planned based on publicly available data, such as the United States Geological Survey (USGS, www.usgs.gov) and the General Bathymetric Chart of the Oceans (GEBCO, www.gebco.net). Then, when more data are collected in the relevant areas of the cables, we further improve the paths using the tool.

We envision that human involvement in the path-planning processes will still be needed, but they can use the results of our tool for the initial path instead of the great circle and for path improvement and benchmarking.

II. MODEL AND METHODOLOGY

To model the *earth's surface*, we use a triangulated piecewise-linear 2D manifold $\mathbb{M}$ in a 3D space $\mathbb{D}$. Each point in the manifold $\mathbb{M}$ has a three-dimensional coordinate (x, y, z), where x and y represent the longitude and latitude of this point, and $z = \xi(x, y)$ is the elevation [3], [10].

The *life-cycle cost* of a submarine cable is a total expense over the lifespan of this cable, which is normally 25 years [3]. It comprises the basic construction cost, the cost of maintenance, and the possible expenses of any repairs. The components of life-cycle cost are the design considerations we want to balance. Those considerations can be divided into two parts: 1) construction-related, the total length of cable; 2)

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repair-related, any factors that can lead to possible breakages, like geological phenomena and human activities [1], [3], [10], [11]. The life-cycle cost function is a weighted sum of those considerations. The determination of weight values is based on learning from existing cables and has been demonstrated to be effective [11]. The tool allows users to adjust the weight values according to their choices.

We use *FMM* to find the optimal path based on the given data. FMM, an enhanced form of Dijkstra's algorithm, enables paths to traverse edges between nodes [2], [3], [10], [12].

We use *parallelization of FMM* to address the computationally prohibitive challenges of high-resolution data and ultra-long-distance submarine cable design. To this end, we decompose the target area into several subdomains at a low resolution. Each subdomain is assigned to one dedicated thread. Subsequently, we run FMM to obtain an initial path. Next, we increase the resolution of the region that exactly includes the initial path, and then iterate through the aforementioned procedures until the optimal path is obtained [4].

Curvature constraint are introduced due to the limitation of the cable material and the maneuvering capacity of the laying vessel in real-world scenarios, so sharp bends on the cable path are avoided. To address this, we replace the sharp corner with a circular arc of a predefined radius [13].

To *optimize a cable network*, key tasks involve designing the network topology and positioning branching units (BUs) using Steiner Minimum Tree topology [5], and determining the optimal placement cable landing stations (CLSs) while considering the overall costs of cables, BUs, and CLSs [9]. Latency requirements, which affect the optimal placement of BUs, are addressed in cable network optimization [7]. Bandwidth capacity demands are considered in [8].

III. OUTPUT GENERATED BY OUR TOOL

In the following, we provide demonstrations of optimal cable system design obtained by our tool interface based on the considerations and optimization methodology discussed above. We provide one example (see Fig. 1) of cable path planning between two end-points (Virginia Beach, USA, and Bilbao, Spain) and one (see Fig. 2) of a cable network design for three locations (Hong Kong, Singapore, and Batangas). The location names were added to the tool output in these figures for clarity. The user enters locations that need to be connected by the cable system, and the interface provides the optimal system design based on publicly available data.

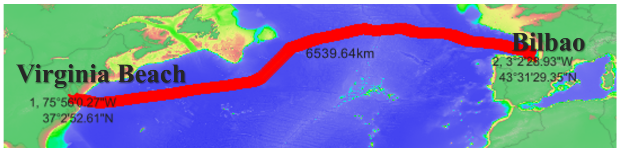

Fig. 1. Cable path from Virginia Beach to Bilbao.

IV. CONCLUSION

We are developing a tool for submarine cable path planning and system design. The tool provides solutions that can provide initial cable path and serve as benchmarks and references for cable system designers for further improvements of the cable path planning and system designs. Moreover, while our methods are focused on submarine cables, they can also adapt to other relevant infrastructures like oil and gas pipelines and electrical transmission lines.

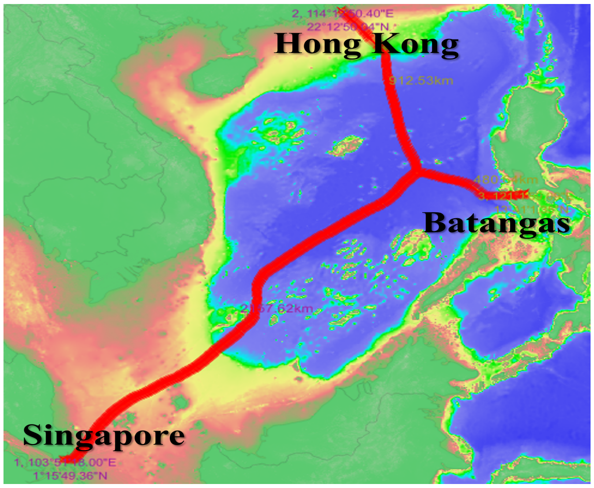

Fig. 2. Cable network connecting Hong Kong, Singapore, and Batangas.

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