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

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Background

1. Submarine cables carry about 99% of global data transmission.
2. Submarine cables are vulnerable to disasters and human activities.
3. The expense of cable construction and repair is very high.

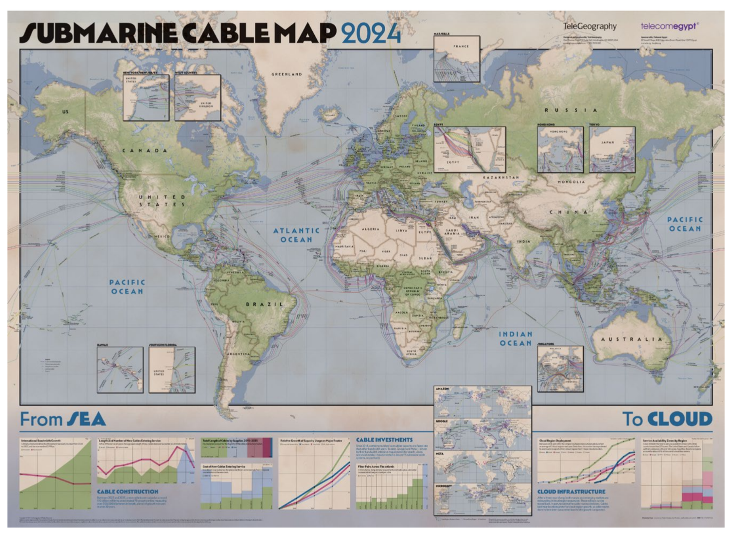

Fig. 1 Submarine cable map (credit:TeleGeography)

Motivation

Hengchun earthquake

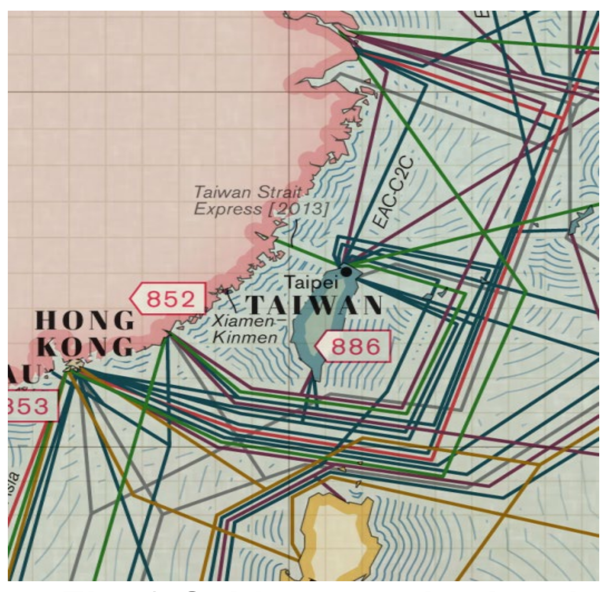

Fig. 2 Cables were broken by Hengchun earthquake (credit:TeleGeography)

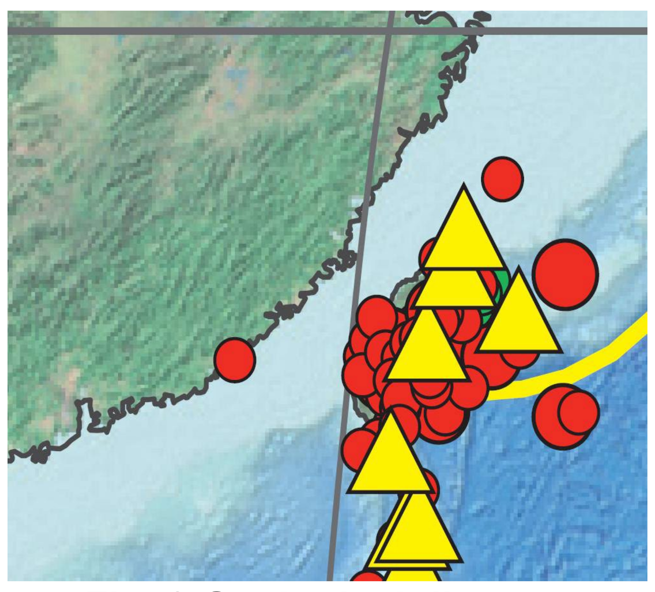

Fig. 3 Geological disaster records around Taiwan (credit: U.S. Geological Survey)

- Hengchun earthquake caused severe disruption of Internet and phone services in southeast Asia (for several weeks from 26-Dec).

Illustration of cost and risk tradeoff

- Straight line (great circle) links may not be optimal for cable path planning.
- Longer cables can improve network survivability.

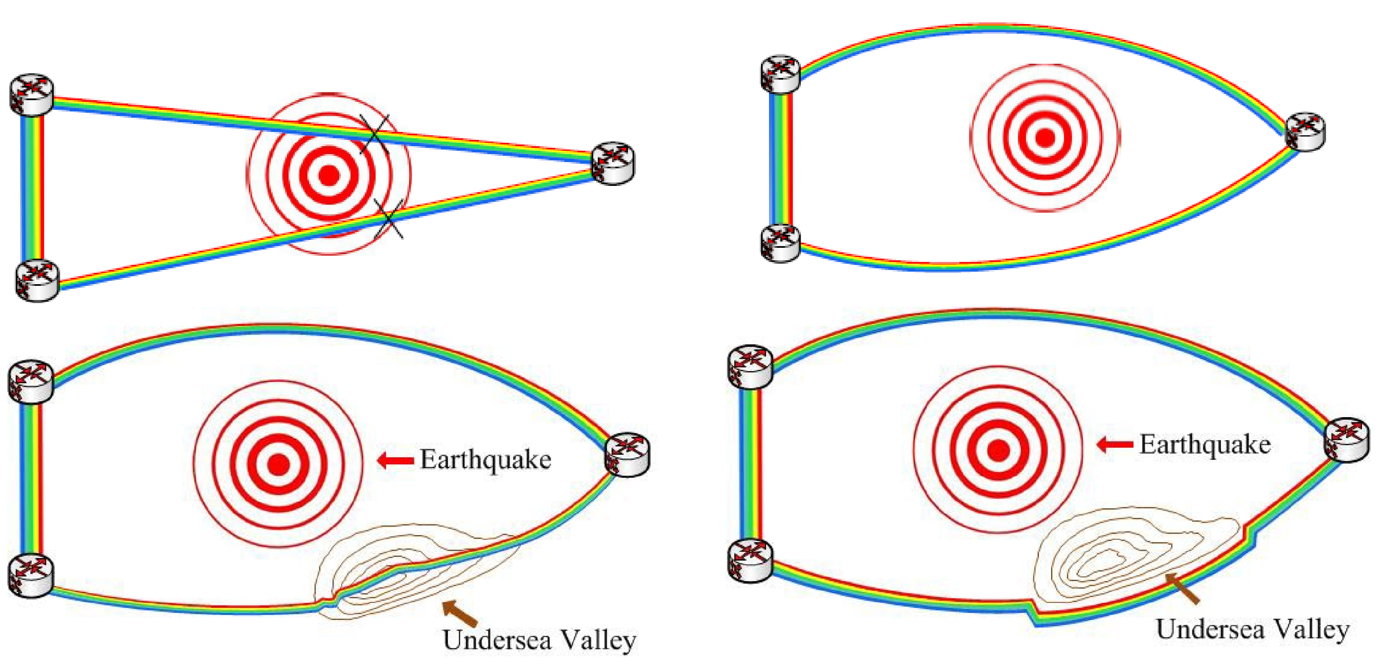

Fig. 4 Illustration of cost and risk tradeoff

Current practice

(a) MakaiPlan software for initial paths (credit: MakaiPlan)

(b) Manual approach to improve the path (credit: Pixabay)

(c) Send boat to investigate and keep improving the path (credit:COSL)

Fig. 5 Current practice of submarine cable path planning

- The initial path is not **optimal**;
- They do not consider the **earth's surface, various risks and restrictions**;
- They can not design a **system of multiple cables**;
- This method is **time and labor consuming**;
- The boat expedition of this method is **costly**.

Design considerations

- Landslides
- Currents
- Water depth
- Slope
- Sediment
- Earthquakes
- Volcanoes

Hydrogeological considerations

(credit: i.ytimg.com) (credit: Maritime goods) (credit: zdnet.com)

- Anchoring
- Fishing
- Existing cables/pipelines
- Prohibited areas
- Protected areas
- License requirements
- Curvature constraints

Anthropological considerations

(credit:industrytap.com) (credit: fs.com) (credit: great-barrier-reef.com)

Fig. 6 Design considerations

Model and methodology

Landform model

- Applied 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).

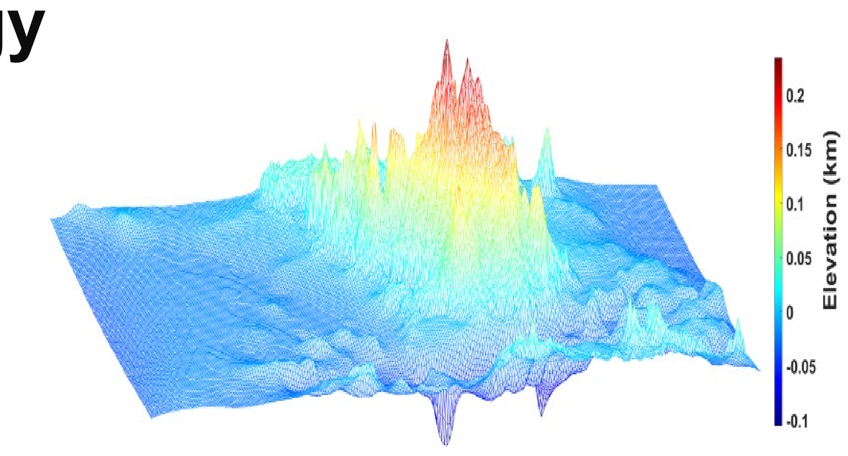

Fig. 7 Earth's surface model

Life-cycle cost model

- **Life-cycle cost**: the total cost over entire lifespan of a cable and it includes cost induced by various natural and human factors, namely **design considerations**. We use a weighted sum function to evaluate their budget effects.

$$C(X) = \sum_{m \in N} w_m c_m(X)$$

Fast Marching Method (FMM)

- The **FMM** offers the advantage of **not being restricted to grid points** at each step and ensures an optimal path on a given triangulated manifold.

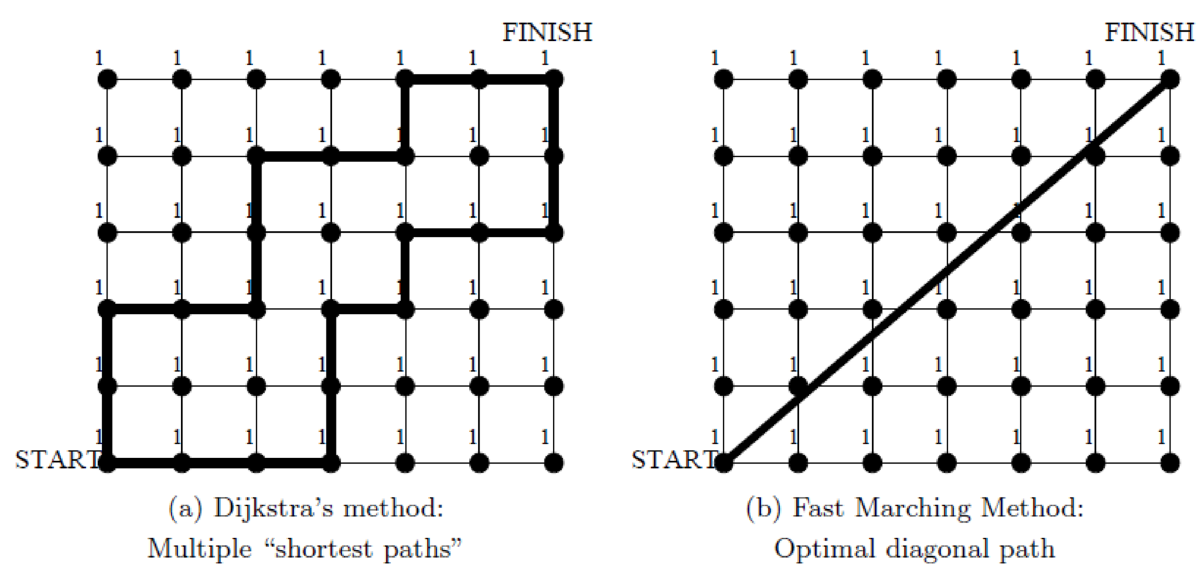

Fig. 8 The difference between Dijkstra's method and FMM (credit: Sethian 1999)

Point to point cable path planning

- We use **FMM** to find the least cost path between two points on earth.
- To address the computationally prohibitive challenges of high-resolution data and ultra-long-distance submarine cable design, we integrate **parallelization technique with FMM**.
- Our **Adaptive Parallel FMM (APFMM)** utilizes adaptive domain decomposition and dynamic multiresolution analysis.

Cable network system design

- To optimize a cable network, we design the network topology and position branching units (BUs) using **Steiner Minimum Tree** topology.
- **Latency requirements** and **bandwidth capacity demands** are also considered.

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