OA3101 Group Project

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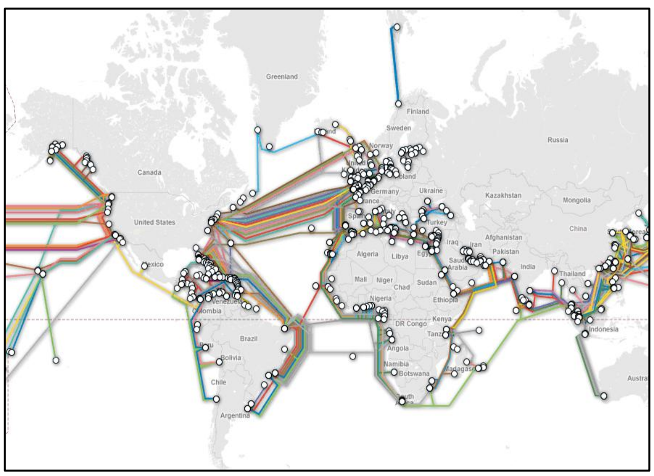
Undersea Cable Network

Background:

The undersea cable network is the infrastructure component that makes modern global internet and international telephone communications possible. The cables, which are owned by both private and public companies, consist of high speed, high capacity fiber optic data cables that provide bandwidth to telecommunications providers. This network of cables connects land masses across the globe and has been a major factor in the globalization phenomenon experienced over the last twenty years. As the network became the backbone of international commerce and communication, it correspondingly became a potential vulnerability to world stability and a possible target for terrorism.

Regardless of whether cables are severed due to natural disasters, accidental disruptions or terrorist attack, the threat to the undersea cable network is real. According to the BBC, maintainers experience an average of one severed cable per year. In 2008, three cables were severed in the waters off Alexandria Egypt when a ship dragged its anchor across the sea floor. In January 2010, the catastrophic earthquake in Haiti disrupted the single undersea cable connecting it to the rest of the world and in March 2012, a ship severed cables off east Africa, severely disrupting communications there. These disruptions decrease network capacity and force providers to seek alternate modes of communication.



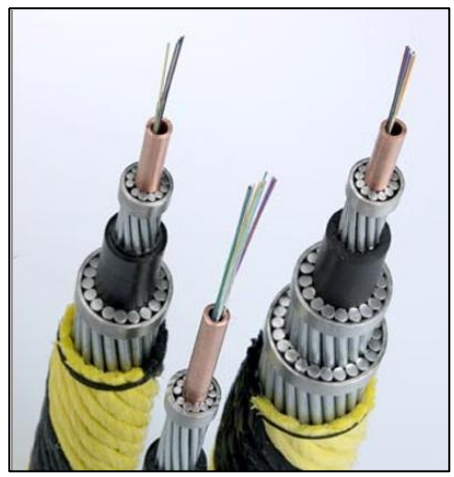


Figure 1a. The global undersea cable network stretches across all the world's oceans.
Figure 1b. A cut-away, cross-section view of a cable.

Scope and Problem Statement:

As an initial, small scale assessment of the entire network, this analysis examines the interconnectivity and resiliency of the Caribbean Islands. Many of these islands are U.S. territories and represent a national interest. Connectivity between the United States and the islands not only directly affects those who live on the islands, but also U.S. businesses located on the islands, as well as U.S. citizens who vacation there. This analysis explores the nature of the network in two different contexts. The first aspect of the analysis is the structure and resiliency of the network with regards to the islands strictly interested in connectivity to the mainland United States. The second aspect of the analysis is the structure and resiliency of the networks with regards to all of the islands being connected with each other. The intent of the analysis is to treat all islands as equals, regardless of population or industry located on the island. The measure of effectiveness used to judge the resiliency of the network is the number of islands that are disconnected due to severed cables.

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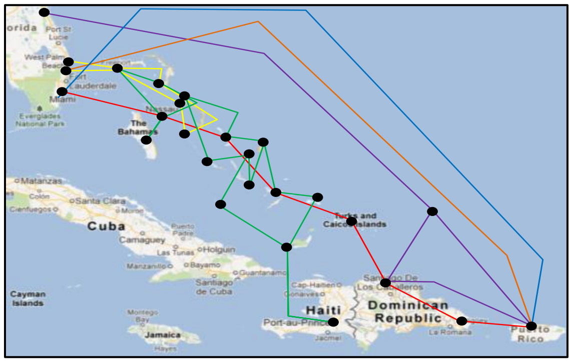

Figure 2. Caribbean cable network consisting of 6 high capacity data cables lines.

Model of Network:

There are six different undersea cables owned by various companies that connect the Caribbean islands and Florida. This analysis combines those six cables into a single network to represent all possible paths for a signal to pass between the land masses. The nodes of this network consist of each island connection point, along with two additional nodes representing mainland Florida and mainland Peurto Rico, both of which have four connection points. The edges in the network are simply the stretches of cable between connection points and are undirected to allow two way flow of information. This model only incorporates the undersea network and does not factor in other forms of communication, such as satilite signals.

There two major assumptions that are present in the model. The first major assumption is that there is no limit on capacity for the cables. The basis for this assumption is that current data flow is far below maximum capacity. When a cable is laid on the sea floor, it has many individual fibers within it. Currently, only a small percentage of these fibers are actually hooked into the network and considered “lit”. When demand rises above the current capacity, the “unlit” portion of the cables can be tapped. This justifies the assumption. The second major assumption is that re-routing data flow due to interdicted cables has no penalty. This assumption is drawn from the speed at which the data travels through the cable and the short distances to be covered resulting in no perceived difference to the end user in the re-routing of their data.

A muli-commodity flow linear program was used to model the network. For the first scenario of examining individual islands connectivity with mainland Florida, each island node was given a supply of -1 for its own data and the Florida node was given a demand of 1 for each of the island nodes’ data. For the second scenario of inter-island connectivity, each island node was given a supply of -21 for its own data and also a demand of 1 for every other island node’s data. Each island was given equal supplies an demands since the analysis sought to treat each island equally. The capacities on all the arcs was set at 1000, so as not to impede any flow. This was the first major assumption of the model. The cost associated with each arc was a unit of 1, which counts the number of arcs traveled and drives the data towards an efficient path. Time was not modeled as a cost, which was the second major assumption of the model.

The model was implemented in GAMS with optimal interdictions taking place to test the worst case scenario resiliency of the network under the two scenarios.

Analysis:

For the first scenario of island to mainland connectivity, the illustrations of optimal attacks are displayed in Figure 3, starting with one well placed attack that disconnects one island and progressing through six optimal attacks that disconnect the entire network. As shown in Figure 4, four optimal attacks are enough to disconnect a significant proportion of the island nodes. A scenario of three or four optimally placed attacks is not expected to occur via a randomly occurring natural event. However, strategically placed attacks such as this are plausible under a terrorist devised plot.

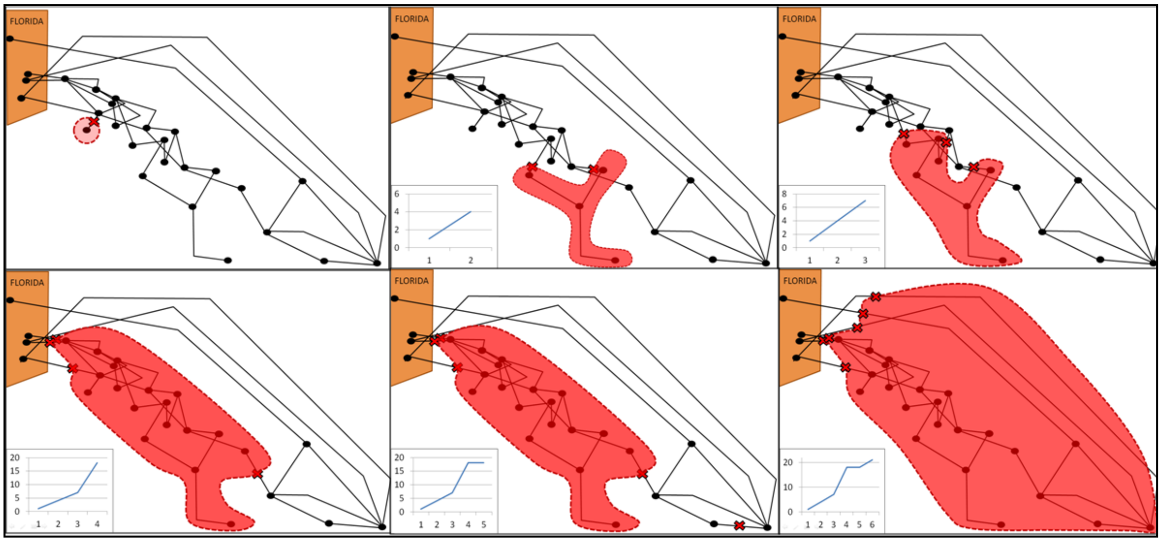

Figure 3. Caribbean cable network performance under optimal attacks. Disconnected islands indicated by shaded portion.

When inter-island connectivity was similarly modeled, it was shown that optimal attacks occur on the exact same arcs. The attacks show a nested solution for the optimal arcs to attack centered on the group of islands with the most limited access to the entire network. Specifically, there are two islands that are susceptible to single arc attacks. In an attempt to make every island resilient to a single attack, a second model was created with those two vulnerable islands connected to their nearest neighbor. This made the entire network resilient against a single attack and changed the solution for two attacks to another area of the graph. However, beyond two attacks the exact same nested solution emerged for the enhanced network.

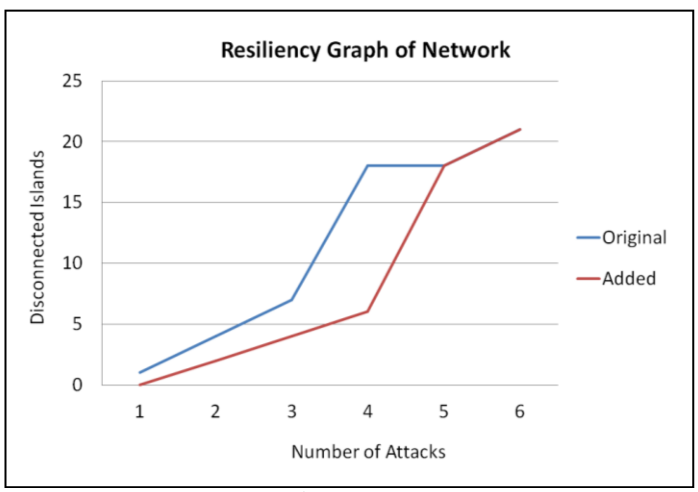

Figure 4. Resiliency graph of the Caribbean undersea cable network.

Summary:

The Caribbean island network is robust against a random event cable disconnection. It is recommended that a redundant cable be added for the two islands with one cable connection in order to prevent natural disruptions as seen during the 2010 catastrophic earthquake in Haiti. Based on this analysis and the excess capacity already in existence, it would not be worthwhile to lay more cables from Florida through all the islands only for the sake of resiliency. If there is an economic advantage for more cable to be laid however, this will only improve network resiliency.

This study could be expanded by examining other regions of the globe, including satellite communications with delays and cost penalties, or by placing weights on islands based on strategic value.