COST
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

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

Action number: CA15127
STSM title: Extending Carrier Network Topologies to be more Resilient Against Large Scale Natural Disasters (WG1)
STSM start and end date: 03/03/2018 to 10/03/2018
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PURPOSE OF THE STSM/

Several recent studies shed light on the vulnerability of networks against failures of multiple equipment in a physical region, which is a result of a disaster, such as earthquakes, hurricanes, tsunamis, tornadoes, etc. These type of failures are called regional failures, which are simultaneous failures of nodes/links located in specific geographic areas.

The focus of the STSM was on the problem how to extend the network with new links such that it can survive regional failures.

There are several techniques to extend a network topology

(1) purchase existing dark, shared fiber assets,
(2) shield existing fibers, or
(3) install new fibre-optic cables.

For (1) there is still a substantial number of dark fibers that can be purchased to reduce the vulnerability of the network against regional failures. The route of these cables are given, and it is binary decision to utilize in the network. For (2) shielding critical links (e.g. strengthening cables) is also a common approach, for example it is possible to upgrade or cover the vulnerable components to resist electromagnetic pulse attacks, dig areal fibre-optic cables underground, reinforce undersea cables against shark bites, etc.

Finally, for (3) new cables can be installed, which has a cost per its length, which greatly depends on the location. For example cutting a meter of a very narrow channel into the pavement costs significantly more than installing a meter of undersea cable.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The work has been conducted in define an optimization problem, which we believe well captures the underlying practical problem, and at the same time leads to an interesting theoretical solution.

The network is modeled as an undirected connected geometric graph *G=(V,E)* with *n* nodes and *m* edges. The nodes of the graph are embedded as points in the Euclidean plane, and for each edge the route of the physical fibre is also given. Typically the route of the physical fibre is defined as a polygonal chain specified by a sequence of points in the plane called its corner points, where the first and last points are at the terminal node of the edge. The curve itself consists of the line segments connecting the consecutive corner points. Later in the paper we will generalize polygonal chain and allow connecting the consecutive corner points by circular arcs, besides line segments.

The **disk failure model with fix radius** will be adapted, which overestimates the area of a disaster such that all network elements that intersect the interior of a circle *c* of radius *r* are failed, and all other network elements are untouched. We will refer to circular disks simply as disks.

Def. 1: A circular disk failure *c* hits an edge *e* if the polygonal chain of the edge *e* intersects the interior of disk *c*. Similarly node *v* is hit by failure *c* if it is in the interior of *c*. Let E_c (and V_c) denote the set of edges (and nodes, resp.) hit by a disk *c*.

Before we define the vulnerability metric of the input network topology, let us specify the failure events we consider to be protected

Def. 2: A network survives a circular disk failure *c* if the graph $G_c=(V \setminus V_c, E \setminus E_c)$ is connected. The center of *c* is called dangerous point.

The above definition is straightforward if the failures are limited to circular disks. Nevertheless, we argue this definition is also relevant in more realistic scenarios, where not every edges and nodes are destroyed interior to the disk. The intuition is that nodes physically close to the disaster will tolerate network outages, however, nodes that are far must have connectivity between each other. In other words, we are not dealing with the problem of providing internet in a catastrophic region, but our goal is to ensure that nodes far enough from the disaster does not suffer loss of internet connectivity.

In the network extension problem first we will focus on (3) and assume the cost of installing a new optical cable is uniform at each location. With this simplification we can better understand the problem, and helps to design heuristic algorithm for the general problem where all three type of network extensions are allowed.

Finally, based on Def. 2 we can set our goal to find the minimum cost network topology extension such that the resulted network survives a single circular disk failure of radius *r* at any location.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

- We have define an optimization problem, which well captures the underlying practical problem, and at the same time leads to an interesting theoretical solution.
- Solved several small networks, and provided a rough outline of the possible algorithms and techniques.

FUTURE COLLABORATIONS (if applicable)

The work conducted on this STSM was the first step of the joint collaboration. In the next months, the collaboration will continue in the development, implementation, analysis and evaluation of the methods and strategies defined during the STSM.

The plans are to submit a conference paper to IEEE Infocom 2018 and, then, a journal paper. This joint work is to be included on the RECODIS book.