Scientific Report: Short Term Scientific Mission - COST Action CA15127

David Hay

November 3, 2016

1 STSM Details

STSM title: Identifying Shared Risk Link Groups to Enhance the Resiliency of Communication Networks

STSM Applicant: Prof. David Hay, the Hebrew University at Jerusalem, Israel

Host: Prof. Janos Tapolcai, Budapest University of Technology and Economics, Hungary

Period: 20/10/2016–26/10/2016

Working group: WG1

2 Purpose of the STSM

Telecommunications networks, and in particular optical WDM networks, are vulnerable to large-scale failures in their physical infrastructure, resulting from physical attacks (such as an electromagnetic pulse attack) or natural disasters (such as solar flares, earthquakes, and floods). Such events happen at specific geographical locations and disrupt specific parts of the network.

The purpose of this STSM is to study how to identify the sets of links that can fail simultaneously under various failure models. Identifying these sets, commonly called "shared risk group links" (SRLGs), is the first step in enhancing the network against such failures (e.g., determining which set has the most significant effect, which link to shield against attacks, or where to add links to the network to enhance its resiliency). A key feature we plan to explore in this STSM is how to cope and define SRLGs that correspond to failures with probabilistic outcomes.

3 Description of the work carried out during the STSM

During the STSM, Prof. Hay gave two talks in the host institute describing his past recent activities. The first talk, given on the first day of the STSM, entitled *"The Vulnerability of Fiber Network and Power Network to Geographically Correlated Attacks"*, deals directly with the research topic of the STSM and was intended to put all researchers involved on the same page, let other researchers from the host institute engage in our activity, and transfer knowledge to students/researchers. The second talk, entitled *"OpenBox: A Software-Defined Framework for Developing, Deploying, and Managing Network Functions"*, describes recent work that was published in SIGCOMM 2016. While not directly related to "shared risk group links", it is certainly relates to resilience of future SDN network, where (some of) its network functions are implemented as software running on virtual machines.

Besides these talks, we have studied thoroughly the question of defining and identifying "shared risk group links" in a probabilistic environment. We have reviewed the literature on this subject, and figured out that most papers that deals with such scenarios, treat these SRLGs as a given input to their work. We,

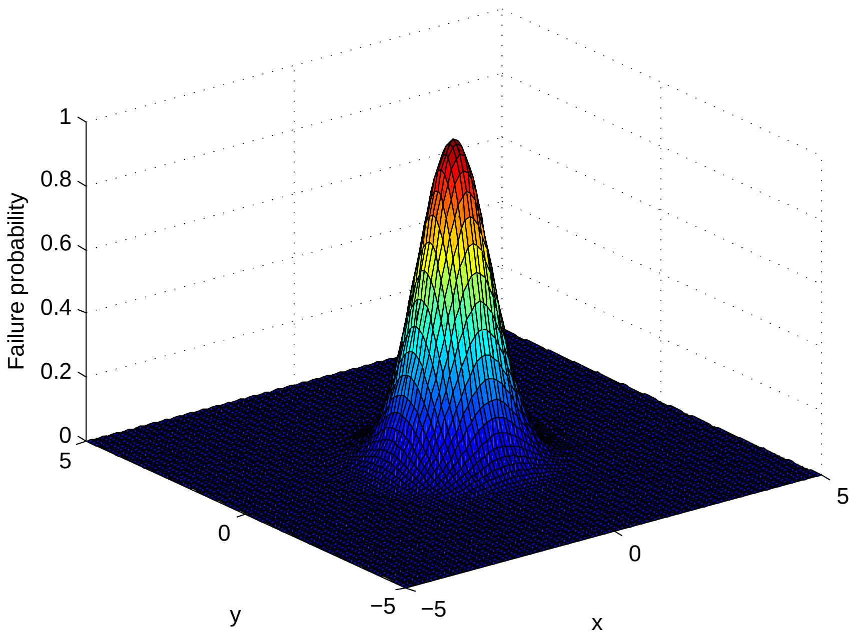

Figure 1: An example of spatial failure probability distribution that occurs in $(0, 0)$, where a component fails with a probability that corresponds to its distance from the failure epicenter.

on the other hand, are dealing with how to identify the SRLGs *efficiently* and represent them in the most *compact* way. The details of our definitions, as well as directions for solutions, are described in Section 4.

In addition, we had discussions with Prof. Gabor Retvari of the host institute about multipath routing, which is a crucial building block in making networks resilient to failures. The discussion mainly focused on recent results by Profs. Tapolcai and Retvari in this field, and how to extend them to multiple link failures, which typically occur in a geographically correlated settings.

4 Description of the main results obtained

Shared Risk Link Group (SRLG) is a failure the network is prepared for, which contains a set of links subject to a common risk of single failure. During planning a backbone network, the list of SRLGs must be defined very carefully, because leaving out one likely failure event will significantly degrade the observed reliability of the network. Regional failures are manifested at multiple locations of the network, which are physically close to each other.

In this visit, we have considered *probabilistic regional failures*, in which links are not surely to fail, but may fail only with a certain probability. We observe that the probabilistic nature of the failure event has two different aspects.

First, the location of the failure *epicenter* might be random and follow some spatial distribution over the plane. Examples of such distributions are the uniform distribution (e.g., solar flares which can happen anywhere with the same probability), distribution based on meteorological data/history (e.g., for weather-related failures like hurricanes or floods), distribution based on factors like population or proximity to strategic sites (e.g., for deliberate attacks in which network failures are collateral damage), etc. We denote the spatial probability density function (PDF) of the epicenter location by f, and assume it is given as an input.

The second given spatial PDF, denoted by p, deals with the probabilistic nature of the failure itself: . Physical failures rarely have a deterministic nature. The probability that a component is affected by the failure depends on various factors, such as the distance from the failures epicenter to the component, the topography of the surrounding area, the components specifications, and even its location within a building or a system. Figure 1 shows an example of such spatial PDF.

As SRLGs contain links, we need to define the failure probability of a link ℓ. Using the PDF p, we define $p_{xy}(\ell)$ as the probability ℓ fails, if the failure epicenter was in (x, y). Two link ℓ_1, ℓ_2 *may* fail together if there is a point (x', y') such that $p_{x'y'}(\ell_1) > 0$ and $p_{x'y'}(\ell_2) > 0$.[1]

Thus, we define the following optimization problem which will be the core of our research: Given the network topology graph $G = \langle V, E\rangle$ (embedded in the plane), PDFs f and p (as described before), the goal is to find the set $\mathcal{S} = \{S_1, S_2, \ldots, S_k\}$, where each set $S_i = \{e_{i1}, e_{i2}, \ldots, e_{i,m}\}$ is a set of links in E that may fail together[2]. The goal is find the smallest possible $\mathcal{S}$ (namely, to minimize k). We have shown that this can be done, and it derives from results in computational geometry. Our results also show that $\mathcal{S}$ induces a partition of the plane to contiguous faces, such that each $S_i \in \mathcal{S}$ corresponds to either one or more faces. We have also design an efficient algorithm that solve the problem and obtain $\mathcal{S}$ efficiently.

It is important to notice that in order to be able to use the set of probabilistic SRLGs, we need to define the failure probability of each $S_i \in \mathcal{S}$; as each S_i corresponds to a particular region in the plane, this failure probability is $f(S_i) = \iint_{S_i} f(x, y)dxdy$. Furthermore, we need to define the probability that a link $e \in S_i$ fails, given that the failure epicenter is in $p_{S_i}(e) = \Pr[e\text{fails} \mid \text{epicenter is in } S_i] = \iint_{S_i} p_{xy}(e)dxdy$. The overall failure probability of a specific link is therefore $\sum_{S_i \in \text{support}(e)} f(S_i)p_{S_i}(e)$. We note that both $f(S_i)$ and $p_{S_i}(e)$ can be computed using Monte-Carlo methods. We are now looking at more analytic methods (with some assumption on p and f).

It is important to note that our probabilistic SRLG representation can be used to compute connectivity, terminal reliability, expected number of failed components, and so on. However, it relies on a *given* epicenter distribution (the PDF f). A different line of research deals with finding the most vulnerable location of the network, which, in a sense, is about finding the most-damaging PDF f. Thus, our results are not applicable for these works. Moreover, it is important to notice that our compact SRLG representation attaches a single failure probability $p_{S_i}(e)$ to each link e within an SRLG S_i. Nevertheless, within S_i there might be points in which e fails with probability 1 and other points in which it fails with probability 0 (and, naturally, any value in between).

5 Future collaboration with the Host institution

Prof. Hay, Prof. Retvari, and Prof. Tapolcai intend to continue the fruitful collaboration established during this short visit. We plan to involve students from both groups in the research, as well as to apply for research grants together (e.g., through join European projects or bi-national funds if available).

Specifically, our next steps are as follows:

- Prove all results obtained so far.
- Try to refine the results (e.g., more efficient algorithms).
- Try to address open questions described in Section 4 (e.g., analytic methods for computing $f(S_i)$ and $p_{S_i}(e)$ in specific cases).
- Run simulations on real-life networks and compare with other (naive) probabilistic SRLG constructions available today.

[1] We note that for technical reasons, some distributions (e.g., Gaussian) require to bound this probability away from 0.

[2] More precisely, let support(e) $= \{S_i | e \in S_i\}$; support$(e_1) \cap$ support$(e_2) = \emptyset$ **if and only if** e_1 and e_2 cannot fail together.

6 Foreseen publications/articles resulting from the STSM

We believe the results obtained so far, upon completion, would result in a conference paper in either IFIP Networking, RNDM or DCRN. We are currently working on refining the results and extending their scope. If successful, we believe such a paper is suitable for venues like IEEE Infocom or ACM SIGMETRICS.