SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

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

Action number: CA15127
STSM title: Resilient communication services protecting end-user applications from disaster-based failures (RECODIS)
STSM start and end date: 01/07/2018 to 07/07/2018
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PURPOSE OF THE STSM

The purpose of this STSM is to jointly work on the robustness of network controllability.

The visit to the host has three main objectives. The first objective is to implement algorithms in the UdG simulator, for determining the minimum number of nodes Nc that should be controlled, such that the whole network can be driven, in finite time, to a desired state. The second one is to add algorithms to the UdG simulator, that quantify the impact of a variety of network attacks, on the minimum number of control (driver) nodes Nc. The third objective is the application of the algorithms mentioned above to a variety of real-world networks to see the impact of different attack strategies on the number of control nodes in these networks.

With the combination of theory (TU Delft) and the implementation in UdG simulator, the framework for the robustness evaluation and network protection of communication networks can be further improved, which can be steadily generalized to (either single or multi-layered) critical infrastructures.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

At the beginning of the STSMS, I gave a presentation of my recent work about the controllability of complex network and the robustness of controllability to the broadband communications and distributed systems group at the University of Girona. Professor José L. Marzo, Dr Eusebi Calle and other group members shared their ideas and suggestions which inspired me a lot. Based on my work, we had an in-depth discussion and decided the concrete task I need to finish during the STSMS.

The first work is to add a metric to measure the controllability of complex networks. In the previous version of the UdG simulator, metrics related to controllability were absent before this STSMS project. According to the theory of controllability in complex networks, a set of nodes need to be selected as the control (driver) nodes through which the whole network can be fully controlled. The minimum number of these control nodes, Nc, is a metric that can represent the controllability of complex networks. For a given network, the smaller the value of Nc is, the more controllable the network will be. The algorithm to calculate the minimum number of control nodes for a directed network is based on maximum matching. Since the programming language in UdG simulator is R, I used R language to implement the function to calculate Nc

for any directed networks. Specifically, a directed graph (network) will be transformed into a bipartite graph. And then by adopting maximum matching algorithm into the bipartite graph, the maximum number of matching will be found. Finally, the minimum number of control nodes equals to the number of nodes in the network minus the maximum number of matching. Besides, the IDs of these control nodes are also specified in order to find the location of these nodes for a certain network.

The second work is to implement critical link-based edge attack into the UdG simulator. From a perspective of controllability, a link is critical if the minimum number of control nodes increases after removing this link. In my previous work, I found that if we randomly remove critical links first and then remove other links, the increase of Nc will be more rapid when compared with randomly attacking all links. In addition, when attacking these critical links following the sequence of an ascending order of the sum of the out-degree of a link's start node and the in-degree of its end node, Nc will increase more rapidly. I implemented this critical link-based edge attack strategy along with other edge attack strategies into the UdG simulator in order to see the impact of a variety of network attacks on the minimum number of control (driver) nodes Nc.

The third work is to input real-life networks into the UdG simulator and get results of the increase of Nc under different attack strategies.

During the STSMS, I cooperated closely with Sergio Gómez to finish all work listed above.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Firstly, after inputting a directed network into the UdG simulator, we can open the "network visualizer" option and click the button of "compute analysis". After selecting "TUDelft controllers" it can display the minimum number of control nodes Nc as well as the locations of these control nodes in a visible way. Meanwhile, if we select "TUDelft critical links", the simulator can also display the number of critical links and their locations. The locations of these control nodes and critical links are intuitively depicted in the simulator which brings convenience to further analysis.

Secondly, our critical link-based attack strategies and the minimum number of control nodes Nc are added into the "Attack type" option and the "Metrics" option of the UdG simulator respectively. In this way, after selecting the network we want to analyse, setting the experiment parameters such as attack type, number of combination and number of attacked elements, and choosing "number of driver nodes" as the metric, we can get the value of Nc corresponding to different fraction of removed links under different edge attack strategies and use these data to compare and analyse the impact of these strategies on Nc.

FUTURE COLLABORATIONS (if applicable)

The host institution UdG and the home institution TUDelft have mutual interests in the area of network robustness which is a perfect match between applied expertise of UdG and the expertise in network theory of TUDelft. The cooperation prospect between these two institutions is broad and future collaborations will further advance the research on network robustness. For example, through collaborations, more strategies and metrics can be added into the UdG simulator in order to extend its function to satisfy research need for both institutions.