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SHORT TERM SCIENTIFIC MISSION (STSM) – SCIENTIFIC REPORT

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

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STSM title: Optimization Algorithms for Improving the CDN Robustness to Link Cut Attacks
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PURPOSE OF THE STSM

The ceaseless growth of network traffic and the proliferation of services with strict performance requirements are propelling the growth and significance of the distributed cloud networking paradigm. A large portion of services use Content Delivery Networks (CDNs) to bring the content closer to the end users by replicating it across multiple, geographically diverse distributed data centres (DCs). On the other hand, the optical network infrastructure that underpins CDNs comes with a set of physical-layer vulnerabilities which can be exploited by malicious attackers to disrupt the aggregated upper-layer services. A relatively straightforward method of physical-layer attacks on the optical infrastructure is the targeted cutting of optical fibre links, which can cause wide-area disruption not only by severing the connectivity, but also by overloading the surviving network and degrading service performance.

Due to the instantiation of multiple content replicas at diverse locations, to which users can connect in an anycast manner, CDNs intrinsically support higher resiliency to failures. However, if the awareness of the underlying physical-layer vulnerabilities to targeted attacks is not taken into account during CDN planning, the network can still exhibit a great degree of vulnerability in spite of a high number of deployed replicas.

One of the essential problems in CDN planning is the replica placement problem (RPP). RPP can be solved with respect to multiple objectives and constraints. Minimization of the distance between the users and replicas is often prioritized by the operators in order to reduce communication latency and resource usage. Another operator concern refers to guaranteeing resiliency from failures and attacks. Network robustness must be high in order to avoid large-scale service disruption and the related losses. These and other CDN design criteria often incur trade-offs with one another and it is very difficult to address all of them by one single objective approach.

The purpose of this STSM is to investigate the impact of prioritizing the distance between the users and the content replicas as the guiding principle of RPP on the overall network robustness to targeted link cut attacks. To achieve a comprehensive evaluation of the trade-offs between distance minimization and robustness to link cut attacks, the aim is first to formulate and solve two optimization problems: (i) the k-best replica placement problem aimed at minimizing the average user-replica distance and (ii) the critical link set detection which allows us to identify the p most critical links whose cutting causes maximum disruption. Then, the aim is to develop a framework able to compute Pareto-optimal solutions that can be applied to real-world network topologies.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSM

For a given core optical network, we first considered the problem of selecting R nodes to host the replica of a particular content. The quality of a replica placement solution is determined as the average shortest path distance from every node to its closest replica. The objective of the k-best Replica Placement Problem (k-RPP) is to enumerate the best k solutions sorted in a non-decreasing order of their quality. The k replica placement solutions can be computed in k iterations. At iteration i, the ith solution is obtained by solving an Integer Linear Programming (ILP) model that takes into consideration all previous solutions. Once the set of k-best replica placements that minimize the user-to-replica distance for the given topology is found, we need to identify the worst-case link cut scenario and quantify the robustness of the obtained solutions.

The problem of identifying the worst-case link cut scenario that incurs the maximum damage in a CDN was formulated as ILP model, which we refer to as Critical Link Set Detection (CLSD). Then, the damage from a set of worst-case attacks with different extents was quantified in terms of mean content accessibility.

A custom-built Java-based tool was developed, using the CPLEX 12.6.3 callable library to solve all ILP models. For a given topology and values of k, R, pmin and pmax, the tool runs the k-best replica placements with R locations and stores, for each solution, the set of replica locations D and the average shortest-path user-to-replica distance. Then, for each replica placement solution, the tool solves the Critical Link Set Detection problem for p = pmin, …, pmax and computes the value of the the mean content accessibility. The computational tests run on two real-world network topologies showed that all ILP models are solved by CPLEX within a few seconds each, at most.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

We have conducted a set of simulations carried out on two publicly available reference networks: Germany50 topology (50 nodes and 88 bidirectional links) and Coronet Conus topology (75 nodes and 99 bidirectional links). To compute link lengths, we have considered that each link follows the shortest path over a sphere surface representing Earth.

For both topologies, we run the custom-built Java-based tool considering the following parameters. We considered the replica placement problem for R = 3, 4, 5, and 6 content replicas and compute the 500-best replica placement solutions. In all cases, the mean content accessibility was computed based on pmin = 2 (since both topologies are 2-connected, p = 1 does not disconnect any node) and pmax = 6, 9, and 12. Among all 500 replica placements of each case, we computed the Pareto-optimal solutions (i.e., the solutions representing different trade-offs between the average shortest path distance and mean content accessibility measure).

The simulations have shown that it is possible to improve the robustness to link cuts at the expense of small user-to-replica distance penalties. Moreover, the robustness improvement is more significant for topologies with smaller average node degree and when cuts involve a larger number of links. Concerning the average CPLEX runtime per solution of the k-RPP problem for the different numbers of replicas R, larger values of k increase the average runtime but the runtime growth becomes almost linear for values of k above 100. Moreover, the runtime evolution is similar for the different number of replicas and amount to around 1.5 seconds per solution (for Germany50) and 2.5 seconds per solution (for Coronet Conus) for k = 500. The average running time to solve the critical link set detection problem is less than 2 seconds (for Germany50) and 4 seconds (for Coronet Conus).

This work has been submitted to the 10th international Workshop on Resilient Networks Design and Modelling (RNDM), 2018.

FUTURE COLLABORATIONS

It is planned to keep the collaboration started in this STSM by the two teams and a new STSM is envisaged for the last quarter of 2018. Future collaboration includes the generalization of the work conducted so far to consider the throughput assessment of RPP solutions, the DC replica hosting costs and the dynamical move of replicas between DCs so as to react to ongoing link cut attacks. A journal extension of the current work is envisaged until the end of 2018.