Resilience of Backbone Provider Networks

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***Abstract*—Network topology models have drawn tremendous interest from the research community. Traditionally, Internet modelling has been done at the AS or router level, in part because this information is most available from tomography and public databases such as Rocketfuel. We argue that *physical* topology analysis is important for a more complete understanding of Internet structure, particularly for insight into the resilience and survivability of infrastructure against attacks and natural disasters. However, complexity and lack of complete data sets has hindered accurate topology modelling. In this short paper, we show through a sample case that physical topologies have significantly different characteristics from traffic engineering and router-level overlays, and are important for analysis of geographically-correlated failures.**

***Keywords*-Internet topology, physical topologies, resilience, survivability**

I. Introduction and Motivation

The Global Internet is a complex, critical infrastructure and the research community has been analysing the topology of the Internet for over a decade. The primary focus has been on the logical aspects of the topology, since tools were developed to collect, measure, and analyse IP-layer properties of the Internet. Physical topologies provide services for logical layers, and defining physical connectivity is a major research challenge [1], [2]. Moreover, to study behaviour of the Internet under correlated geographic failure scenarios, physical topologies are *necessary* [3], [4].

Physical topologies provide the necessary connectivity, while logical topologies enable data communication between end systems. Resilience characteristics of the two topologies differ in part due to differences in the topological properties and in part due to different challenges networks face. For example, while a DDoS attack aims to consume network resources on an end host, the underlying physical infrastructure can be intact. Likewise, an earthquake might damage the physical infrastructure and if there is no geographical diversity built in the system this might cause the overlaid logical topology to become dysfunctional. We argue that resilience analysis of individual topologies (e.g. AS-level, IP-layer) alone is not enough and a collective analysis of networks is required to design resilient networks. Therefore, understanding the resilience characteristics of networks and further developing cost-efficient mechanisms to cope with network challenges of such complex systems is crucial.

While the physical topologies are crucial in understanding and modelling Internet, public data about physical topologies are limited. Two primary reasons that the service providers unwillingness to share the data are business competitiveness and security concerns. In this extended abstract, first we present our ongoing efforts towards making the physical topologies available. Next, we analyse network performance of a physical and logical topology against a correlated failure scenario using the ns-3 network simulator. Finally, we discuss our next steps towards developing resilient topologies.

II. Physical Topologies

Physical topologies are *necessary* to study the network resilience for geographically correlated failures [3], [4]. However, a lack of physical topology data hinders the study of resilience properties. We use the US *long-haul fiber-optic routes* map data to generate physical topologies [5]. In this map US fiber-optic routes cross cities throughout US and each ISP has a different colored link to differentiate between them. We project the cities to be physical node locations and connect them based on the map, which is sufficiently accurate for a national-scale map. We convert this visual data into machine understandable format by generating adjacency matrices for each individual ISP provider. We developed the KU-TopView (The University of Kansas Topology Viewer) visualiser, using the Google Map API and JavaScript to visually present these maps [6]. Unlike other visualisation tools, KU-TopView makes raw data available in the universal form of an adjacency matrix along with the node coordinates. The physical topology of a tier-1 ISP is shown in Figure 1.

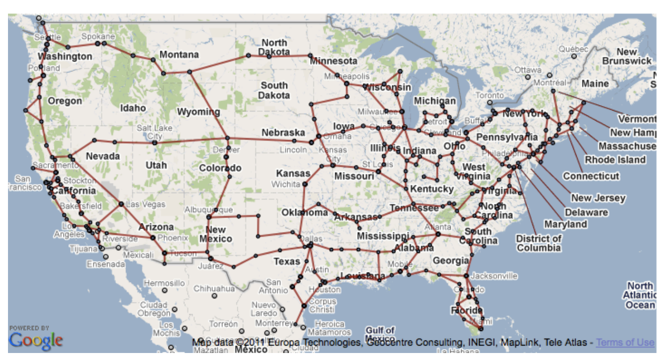

Fig. 1. Sprint physical topology

III. Performance Analysis

Given the size of the network and interactions among protocols, analysing complex topologies such as the Internet is non-trivial. On the other hand, simulations are powerful tools to analyse such complex interactions and we use the ns-3 [7] network simulator to study the performance of physical and logical topologies against correlated failures. We investigated performance of logical topologies under network challenges previously [3], [8]. To illustrate the importance of physical topologies, we demonstrate an area-based challenge scenario representative of a hurricane hitting south central US as shown in Figure 2. In this figure, we overlay the Rocketfuel-inferred [9], [10] Sprint logical topology on top of the Sprint physical topology using KU-TopView. In this illustrative challenge scenario a large-scale disaster with an increasing diameter impacts the south central US.

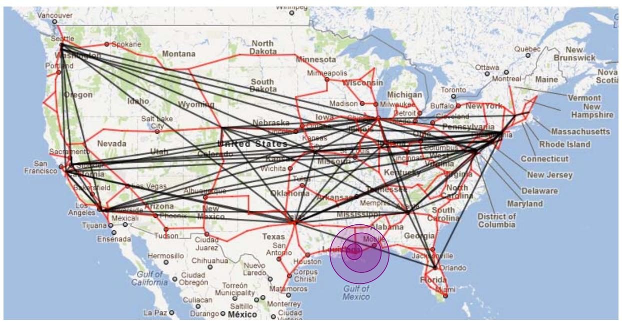

Fig. 2. Sample area-based challenge scenario

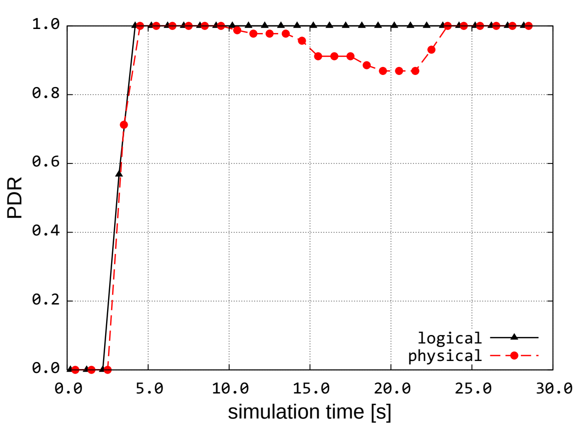

Fig. 3. South central US challenge PDR [3]

Network performance of physical and logical topologies when the south central US region is challenged is shown in Figure 3. The application traffic model in logical topology for our simulations is set to be CBR (constant bit rate) traffic between each pair of node. Since the physical topology consists of physical devices such as repeaters and ADMs (add-drop multiplexers) not all the nodes in a given physical topology will be a traffic generation source. To realistically match to a traffic-matrix, we use the Sprint MPLS PoP [11] nodes as traffic sources. Only one link in the logical topology is impacted throughout this challenge and due to geographic diversity built in this network, the PDR (packet delivery ratio) is 100%. On the other hand, the PDR of the physical topology drops to 98%, 91%, and 86%, respectively, as the challenge area covers more nodes and links. This demonstrates that it is imperative to study the impact of area-based challenges on the *physical* topologies [3], [4].

IV. Conclusions and Future Work

In this extended abstract, we discussed the necessity of physical topologies to realistically evaluate network resiliency. We argued that a collective topology information is needed to realistically evaluate resilience properties of networks. Furthermore, while geographic diversity is an essential mechanism to increase the resiliency of network, there is a trade-off between the increased level of resiliency and the cost of building such resilient systems. To design cost-efficient resilient topologies we plan to use KU-LocGen (Location and Cost-Constrained Network Topology Generator) [12], a synthetic topology generator, to investigate trade-offs between resiliency properties and cost of building such topologies.

Acknowledgments

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