Resilience of Backbone Provider Networks

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I. MOTIVATION

- Modelling the Internet
  The Internet has evolved to today’s complex and heterogeneous critical infrastructure. Structurally, the Internet has hierarchy, composed of interconnected and tiered service provider networks. Furthermore, services are provided at different layers that makes the collective analysis of the Internet very difficult. The primary focus has been on the logical aspects of the topology, since tools have been developed to collect, measure, and analyse IP-layer properties of the Internet. On the other hand, physical topologies provide services for logical layers, and defining physical connectivity is a major research challenge.

- Understanding Challenges and Their Impact
  Understanding network behaviour under perturbations can improve today’s networks performance, as well as lead to a more resilient and survivable Future Internet. Network design and performance are currently based on the assumption that they are not affected by physical failures. Therefore, it is essential to have a thorough understanding of the network behaviour when exposed to challenges, such as component failures, attacks, large-scale disasters, and the effects of the mobile wireless communication environment.

- Network Design
  Networks are built by humans and are not completely resilient due to design flaws and cost constraints. The redundancy and diversity that increase resilience add to the cost of the network. Optimisation of the network design process while considering realistic constraints such as node deployment costs is nontrivial.

- Resilience Mechanisms
  Path diversification is a mechanism that can be used to select multiple paths between a node pair using a quantified path diversity measure to achieve maximum flow reliability. This mechanism allows Future Internetworking architectures to exploit the rich physical topologies to a far greater extent than is possible with shortest-path routing or equal-cost balancing.

II. RESEARCH GOALS

- Design cost-efficient networks that can withstand challenges in an optimal way
- Develop resilience mechanisms that enable networks to tolerate challenges, disasters, and attacks
- Understand the relation of the resilience and structural properties of interconnected and multi-tier networks
- Understand the evolution of networks through realistic modelling of networks

III. NETWORK ANALYSIS and DESIGN

- Physical Topologies and Visualisation
  Physical topologies are necessary to study the network resilience for geographically correlated failures. However, a lack of physical topology data makes the study of resilience properties problematic. We use a US long-haul fiber-optic routes map data to generate physical topologies. In this map US fiber-optic routes cross cities throughout the US and each ISP has a different coloured link to differentiate between other service providers. 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 using the Google Map API and JavaScript to visually present these maps. Unlike other visualisation tools, KU-TopView makes raw data conveniently available in the universal form of an adjacency matrix along with the node coordinates. Furthermore, we can overlay multiple topologies and obtain the combined adjacency matrices. The Rocketfuel-inferred Sprint logical topology on top of the Sprint physical topology is shown in Figure 1a. The overlaid Rocketfuel-inferred AT&T logical topology on top of the AT&T physical topology is shown in Figure 1b. The richly connected Level 3 topology is shown in Figure 1c.

- Path Diversity
  - Path: Any complete set of nodes and links in a graph that form a loop-free connection between a node pair.
  - Path diversity: Excluding the source and destination node pair, it is defined for a given path \( P_i \) with respect to original path \( P_0 \). The values range between 0 and 1, in which 1 represents complete diversity.
  - Effective Path Diversity (EPD): An aggregation of path diversities for a selected set of paths between a given node-pair \(( s, d)\). \( k_s \) is a measure of added diversity by multiple paths. Scale factor \( \lambda \) determines impact of \( k_s \) on EPD.
  - Total Graph Diversity (TGD): The total graph diversity is the average of the EPD values of all node pairs within that graph. This allows us to quantify the diversity that can be achieved for a particular topology, not just for a particular flow. For example a star or tree topology will always have a TGD of 0, while a ring topology will have a TGD of 0.6.

- Results
  - Performance Measures
    We measure the network’s aggregate performance in terms of TGD and aggregate packet delivery ratio (PDR).
  - Results
    We observe that most of the 17 topologies share similar characteristics in terms of the diversity available, although the absolute value of diversity that can be attained varies significantly. Selecting \( k \) most diverse paths between nodes in the AT&T and GÉANT2 graphs results in a strong increase in diversity for \( k < 4 \) with limited improvement for additional paths; however, the full-mesh and Level 3 graphs continue to show substantial improvement for \( k < 6 \). This emphasises the fact that basing a diversity metric on a particular number of diverse paths is highly topology dependent.

Figure 1. Topology Visualiser Examples

Figure 2. Path Diversity Example

Table 1. Network Characteristics

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IV. RESULTS and ANALYSIS

- • Geographic (distance and area) based diversity algorithm
- • Cross-validation with experimentation using the GpENI programmable Future Internet testbed

V. FUTURE WORK

- • Develop metric based synthetic topology generator
- • Geographic (distance and area) based diversity algorithm
- • Multi-level and multi-provider analysis

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