I. MOTIVATION

- 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 Internetwork. 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. Furthermore, intelligent attacks with an adaptive scheme can cause the most damage. Recognition of network disruptions and their causes is crucial for planning and designing networks. We cannot thoroughly study the effects of challenges in live networks without impacting users. Textbooks are useful, but do not provide the scope and scale necessary to understand the resilience of large, complex networks, although progress is being made in this direction. Simulations arguably provide the best compromise between tractability and realism to study challenges, however this is nontrivial.

- 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 locations and deployment costs is nontrivial.

- Modelling the Internet
  The Internet has evolved to today’s complex and heterogeneous critical infrastructure. Structurally, the Internet has hierarchy, composed of 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 were 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. Multiscale modelling and simulation of the Internet, while enabling the multiple layers is promising. Moreover, to study the behaviour of the Internet under correlated geographic failure scenarios, physical topologies are necessary. Understanding the fundamental resilient structure below can help design upper layers to self-organise based on resilience needs.

II. RESEARCH GOALS

- Design a Challenge Simulation Module to evaluate the impact of disruptions on networks
- Model malicious challenges, non-malicious challenges, and correlated failures that spatially and temporally evolve
- Design cost-efficient networks that can withstand challenges in an optimal fashion
- Understand the evolution of networks through realistic modelling of networks

III. NETWORK ANALYSIS and DESIGN

- Challenge Simulation Module
  The KU Challenge Simulation Module (KU-CSM) provides a cost-effective methodology to evaluate challenges. We utilise ns-3 network simulator as the main component of our framework and KU-CSM consists of four distinct steps: challenge specification, network topology, ns-3 C++ code, simulation and post-processing, shown in Figure 1.

- Challenge Modelling
  Non-malicious challenges: The number of nodes or links subject to random failure are shut down for the duration of the challenge.
  Malicious attacks: The critical nodes or links (degree of connectivity of nodes and betweenness of nodes and links) are shut down for the duration of the challenge period.
  Large-scale disasters: We model area-based challenges as an n-sided polygon with vertices located at a particular set of geographic coordinates or a circle centered at specified coordinates with radius r. The simulation framework then determines the nodes and links that are encompassed by the polygon or circle, and disables them during the challenge interval. We also implement dynamic area-based challenges, in which the challenge area can evolve in shape over time: expand or contract, rotate, and move on a trajectory during the simulation.
  Wireless challenges: To simulate challenges in the wireless domain, we have created a new ns-3 propagation loss model that includes a mobility model parameter and range of influence. We implement a jammer module that sends high power signals with high data rate frames.
  Adaptive challenges: Challenges can be adaptive based on repetition. For example an attacker can target highest degree nodes adaptively in a repetitive manner.

- Physical Topologies and Visualisation
  Physical topologies are necessary to study the network resilience for geographically correlated failures. However, a lack of physical topology data hinders the study of resilience properties. We use US long-haul fiber-optic routes map data to generate physical topologies. 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 nodes, and locations and connect them based on the map, which is sufficiently accurate for a national-scale map. We converted this visual data into machine understandable format by generating adjacency matrices. We developed the KU-TopView visualiser, using the Google Map API and JavaScript to visually present these maps. 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 3.

- Evolution of Networks
  Connectivity pattern of links define a topology. In the logical topologies, the nodes are connected in a mesh-like structure, in which average degree of the nodes is higher than the physical topologies. The logical connectivity depends on realistic constraints such as the number of ports available on the routers. Moreover, networks evolve to increased resilience state after proper refinements can be performed. Our preliminary observation using physical topologies is that the links follow close correlation between the roads and railways. Figure 4 shows the relationship of the Sprint physical fiber topology to railway mainlines and Interstate freeways in the US.

IV. RESULTS and ANALYSIS

- Performance Measures
  We measure the network’s aggregate performance under challenges in terms of aggregate packet delivery ratio (PDR).

- Results
  Given the size of the network and interactions among protocols, analysing complex topologies such as the Internet is non-trivial. 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 5. In this figure, we overlay the Rocketfuel-inferred 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.

V. FUTURE WORK

- Evaluate adaptive challenges and remediation mechanisms
  - Wireless and heterogeneous network performance
  - Cross-validation with experimentation using the GpENI programmable Future Internet testbed

Acknowledgements: This project is supported in part by the National Science Foundation GENI, FIND, and EU FIRE Programs

March 2012