I. MOTIVATION

- Resilience of Telecommunication Network
With the increasing frequency of natural disasters and intentional attacks that challenge the telecommunication network, network vulnerability to cascading and regionally-correlated challenges is escalating. Given the high complexity and large traffic load of the optical networks, the correlated challenges have great damage to the network capacity. In this work, we propose a network vulnerability identification mechanism and study the different vulnerability scale using real-world optical network data. Based on the analysis of network characteristics, we propose one routing protocol GeoPath Diverse Routing Protocol (GeoDivRP), which considers geographical diversity of physical network topologies when making routing decisions and increases the routing protocol responsiveness. By enabling end points with multiple geographically diverse paths, GeoDivRP demonstrates better routing performance compared to Open Shortest Path First (OSPF) when the network is subject to area-based challenges. We further reduce its time complexity for calculating GeoPaths by introducing a heuristic algorithm, IWPS (iterative WayPoint Shortest Path).

II. CROSS-LAYER MECHANISM

- GeoDivRP: Protocol Stack
Our GeoDivRP fits in the protocol stack as shown in Figure 1. Knobs are used by higher layer to control the lower layer operation while dials are the mechanisms for lower layer to provide feedback for higher layers. The application layer passes service specification and threat model from network operators down to transport layer protocol ResTP. Upon receiving the requirement, ResTP demands GeoDivRP to calculate geodiverse paths that meet the requirement tuple \((k, d, \{h, t\})\), where \(k\) is the total number of geodiverse paths requested, \(d\) is the distance separation criteria, \([h, t]\) is the optimum path stretch and skew. ResTP then establishes different transport connections and uses different reliable modes to comply with the application premise by taking advantage of multiple geodiverse paths [P] provided by GeoDivRP.

III. VULNERABILITY ANALYSIS AND GEODIVERSE ROUTING PROTOCOL

- Vulnerability Identification Mechanism
The vulnerability identification mechanism starts by embedding the topology in the Euclidean plane based on each node geo-location and operates greedyly by scanning through the entire topology for possible vulnerable areas. It takes two input values from the user: the radius of the scanning circle and the degree that it forwards each step along longitude scale. The nodes fall into the circle in the Euclidean plane at any given degree step are defined as the challenged area set. When the challenged node set is exhausted in the longitude level of the topology, the model forwards along latitude scale for one step and repeats the above process. By applying this mechanism in optical fiber network, we are able to identify all the different scenarios for regional challenges. We calculate flow robustness of the network topology after each challenge node set has been challenged and removed from the topology, and it represents the different vulnerability level when the challenge happens in the location of the set. We plot the different flow-robustness values on the map in different color shades to demonstrate the relative importance of different areas in terms of geodiversity as shown in Figure 2.

- GeoPath Diversity Definition
As shown in Figure 3, node 0 is the source and node 2 is the destination. The shortest path consists node 0-1-2. GeoPath diversity \(D(P)\) is defined as the distance between any node member of the vector \(P\) and that of the shortest path. The green dotted line shows the path \(P_1\) and the diversity \(D(P_1)\) equals to 0. The black dotted line shows path \(P_2\) and its diversity \(D(P_2)\) is zero since \(P_2\) shares node 1 with the shortest path.

- GeoDivRP Routing Protocol using IWPS (Iterative WayPoint Shortest Path)
We implement the GeoDivRP routing protocol in ns-3 using the IWPS (Iterative WayPoint Shortest Path) heuristic. As shown in Figure 4, the IWPS heuristic calculates the geodiverse paths using the starting point of the geodiverse paths while converging, it calculates the geodiverse paths using the starting point of the geodiverse paths while converging. It looks twice at the shortest paths to find the node that is not a source and destination neighbor that are separated from the source and destination by \(d\), respectively, and the waypoint node separated by \(d + \delta\). The heuristic then executes Dijkstra’s algorithm twice to calculate shortest paths connecting the source node neighbor, waypoint node, and the destination node neighbor. We test our protocol in real-world physical topologies. Figure 5 shows the geodiverse paths calculated by GeoDivRP to bypass the challenge area represented by the red circle. The cites that fall in the circle are Omaha, NE and Kansas City, MO. The radius of the challenge area is 300 km. The solid lines show the paths calculated by GeoDivRP and the dotted lines represent the links failed caused by the challenge. By assuming the correct estimation of the challenge radius and position, we compare our protocol’s performance with standard OSPF in terms of PDR (packet delivery ratio) as well as delay.

IV. RESULTS AND ANALYSIS

- Performance Measures
The performance metrics for the evaluation are packet delivery ratio (PDR), and delay. We compare our protocol to Open Shortest Path First (OSPF) routing protocol, which is the default routing protocol in the Internet.

- Results
We present results with three challenges in Sprint physical network, the first in Kansas City, second in New York City, and third in Los Angeles. For the first challenge, the PDR of OSPF drops to 75 percent and it takes ten seconds to converge while the time for GeoDivRP is within one second and the PDR only drops two percent before it converges, as shown in Figure 6.

- Analysis on Real-World Topologies
We test our protocol in real-world physical topologies. Figure 5 shows the geodiverse paths calculated by GeoDivRP to bypass the challenge area represented by the red circle. The cites that fall in the circle are Omaha, NE and Kansas City, MO. The radius of the challenge area is 300 km. The solid lines show the paths calculated by GeoDivRP and the dotted lines represent the links failed caused by the challenge. By assuming the correct estimation of the challenge radius and position, we compare our protocol’s performance with standard OSPF in terms of PDR (packet delivery ratio) as well as delay.

V. PUBLICATIONS


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