The Minimum Cost D-Geodiverse Anycast Routing with Optimal Selection of Anycast Nodes

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Outline

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- Definition of D-geodiverse anycast routing
- The minimum cost D-geodiverse anycast problem
- Computational results
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Motivation

- Disaster based failures can seriously disrupt a telecommunications network, making its services unavailable.

- It is important not only to quickly recover the network in the disaster area (post-disaster problem) but also to minimize the disaster impact between network nodes outside the disaster area (pre-disaster problem).

- Improving the preparedness of telecommunication networks to disasters is becoming a key issue.

- To enhance the preparedness of networks to disasters, one approach is path geo-diversification:
  - to take into consideration the geographical diversity of the network topology when making routing decisions.
Motivation

- In anycast, network nodes are partitioned into two sets:
  - the source nodes
  - the anycast (destination) nodes

- The traffic of each source node is routed towards the anycast node providing the minimum cost routing path.

- Content Delivery Networking (CDN) - content replicated over multiple data centers (DCs) and users retrieve content from the closest DC.

- Software Defined Networking (SDN) - control plane separated from the data plane and based on a set of physically distributed SDN controllers; switches query the closest (primary) controller for routing decisions.
Definition of D-geodiverse anycast routing

- Consider a given geographical network $G=(N,A)$ and a distance parameter $D$.

- A **D-geodiverse anycast routing** solution guarantees for each source node that:
  - there are two routing paths,
  - each one towards a different anycast node, such that
  - the geographical distance between the two paths is at least $D$.

- A disaster with a coverage diameter below $D$ (involving neither the source node nor its entire set of links):
  - cannot affect both paths simultaneously,
  - thus, enhancing the network robustness to natural disasters.
Definition of D-geodiverse anycast routing

Source node: 1
Anycast nodes: 3, 5 and 8

Assume: $D_1 < D_2 < D_3$

If $D < D_1$
• all solutions are feasible

If $D > D_3$
• none of these solutions is feasible
  • either another set of anycast nodes can provide a feasible solution
  • or node 1 must be a anycast node
Minimum cost D-geodiverse anycast problem

- The selection of the anycast nodes has an impact both on the feasibility and cost of a D-geodiverse anycast routing solution.

- Given:
  - a geographical network $G=(N,A)$ with a routing cost $c_{ij}$ associated to each arc $(i,j) \in A$
  - a geographical distance parameter $D$
  - a number of anycast nodes $R$

The minimum cost D-geodiverse anycast problem (MCD-GAP) aims to select a set of $R$ anycast nodes that obtain a minimum cost routing solution.
Minimum cost D-geodiverse anycast problem

- MCD-GAP is modelled and solved by Integer Linear Programming (ILP).

- Pre-processing:
  - Based on the geographical information of the network, we compute $\delta(a, b)$ as the shortest distance between any point of link $a$ and any point of link $b$.
  - Then, for each node $s \in N$, we compute the set of link pairs $P_s$ whose minimum distance between them is lower than $D$.
  - Special care is taken for link pairs sharing the source node $s \in N$ as two of such links must exist whatever $D$ is defined (details in paper).
Minimum cost D-geodiverse anycast problem

Then, MCD-GAP is formulation as an ILP model guaranteeing that for each node $s \in N$:

- if $s$ is not an anycast node, at most one of each pair of links $P_s$ is in the two routing paths from $s$ to two different anycast nodes
- if $s$ is an anycast node, no routing paths need to exist in the solution starting from $s$

The objective function is the sum of the costs of all pairs of paths from each source node

We mitigate the symmetry problem with a variable elimination rule (details in paper)
Minimum cost D-geodiverse anycast problem with vulnerability regions

- MCD-GAP assumes that a disaster can happen at any region of the network
- In practice, the probability of natural hazards is not uniform in the geographical area of a given network
- Network operators might want to tailor the network robustness to the different hazard types and regions, which are referred as vulnerability regions
- Moreover, the network operator might consider different geographical parameters $D$ for each vulnerability region, depending on its hazard type
Minimum cost D-geodiverse anycast problem with vulnerability regions
Minimum cost D-geodiverse anycast problem with vulnerability regions

- Consider:
  - a set of $V$ vulnerability regions and
  - a distance $D_v$ associated to each region $v = 1 \ldots V$

- The aim is that each pair of paths is:
  - node disjoint outside regions and
  - $D_v$-geodiverse inside vulnerability region $v = 1 \ldots V$

- A pair of links is in set $P_s$ only if both links belong to a region $v$ and if their minimum distance is lower than $D_v$

- If a pair of links belongs to different regions, the largest value $D_v$ among all involved regions is used
Computational results

- Germany50: 50 nodes, 88 links, average node degree 3.52 (http://sndlib.zib.de)
- Germany seismic hazard map from: M. Müller et al., CEDIM Risk Explorer – a map server solution in the project Risk Map Germany, Natural Hazards and Earth System Sciences, vol. 6, pp. 711-720, 2006
Computational results

- CORONET CONUS: 75 nodes, 99 links, average node degree 2.64 (http://monarchna.com/topology.html)
- USA natural hazard risk map from: http://alertsystmsgroup.com/earthquake-early-warning/informative-maps
Computational results

**Germany 50 results without vulnerability regions**

- The cost decreases with higher number of anycast nodes $R$
- For the same $R$, cost increases with larger geographical distances $D$
- The minimum required number of anycast nodes $R$ increases with larger values of $D$
Computational results

**Germany 50 results with and without vulnerability regions**

- For the pairs of values $D$ and $R$ such that both cases are feasible, there are cost gains in considering vulnerability regions
  - These cost gains are higher for higher values of $D$
- The minimum $R$ is lower when vulnerability regions are considered
  - This reduction is higher for higher values of $D
Computational results

**CORONET CONUS results without vulnerability regions**

- The cost decreases with higher number of anycast nodes $R$
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Computational results

**CORONET CONUS results with and without vulnerability regions**

- For the pairs of values $D$ and $R$ such that both cases are feasible, there are cost gains in considering vulnerability regions.
  - These cost gains are higher for higher values of $D$.
- The minimum $R$ is lower when vulnerability regions are considered.
  - This reduction is higher for higher values of $D$.
Computational results

Anycast nodes of CORONET CONUS for $D = 120$ Km and $R = 14$ anycast nodes

(a) Cost = 223008

(b) Cost = 126362

• Anycast nodes are mainly selected on the network parts with closer nodes and shorter links in the whole network (a) or only inside the vulnerability regions (b).

• With vulnerability regions, anycast nodes are selected more uniformly throughout the network obtaining in this way an huge cost reduction of 43.3%.
Computational results

**Germany 50 running times**

- CPLEX runtime without (a-b) and with (c) survivability regions
- Instances with larger values of D are harder to be solved
- Without vulnerability regions, the instances are harder to be solved than with vulnerability regions
- The worst runtime becomes 1030 seconds for D = 80 Km and almost 20500 seconds (around 5 hours and 40 minutes) for D = 100 Km
Computational results

**CORONET CONUS running times**

- CPLEX runtime without (a) and with (b) survivability regions
- These instances are much easier to solve than the Germany50 ones
- Recall that the average node degree of CORONET CONUS is much lower than the one of Germany50
- So, the number of paths between pairs of nodes is smaller which, in turn, makes the problems easier to solve
Conclusions

- We have exploited path geodiversity in anycast communications to enhance the network robustness against natural disasters.
- We have defined and solved the minimum cost D-geodiverse anycast routing problem with optimal selection of anycast nodes.
- We have extended it to consider the existence of vulnerability regions.
- We have presented computational results based on two well-known network topologies using real information of their hazard regions.
Conclusions

- We were able to compute the optimal solutions for all cases of interest.
- The results showed that, in general, improving the robustness to natural disasters:
  - increases the routing costs and
  - requires a higher minimum number of anycast nodes.
- A careful characterization of the vulnerability regions allows the operator to achieve:
  - either improved robustness with the same cost and number of anycast nodes
  - or reduced number of anycast nodes and routing costs for the same robustness
Thank you for your attention!

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