RiskRoute: A Framework for Mitigating Network Outage Threats

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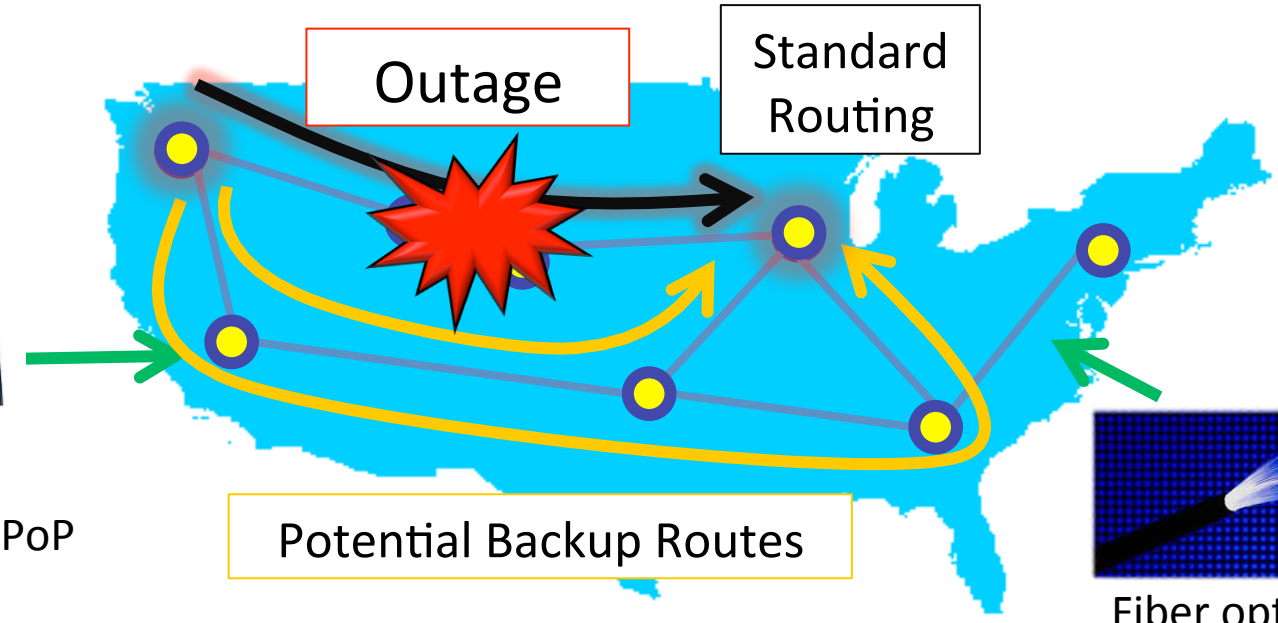
Problem Setup

Consider Internet physical infrastructure:

Physical Router or PoP



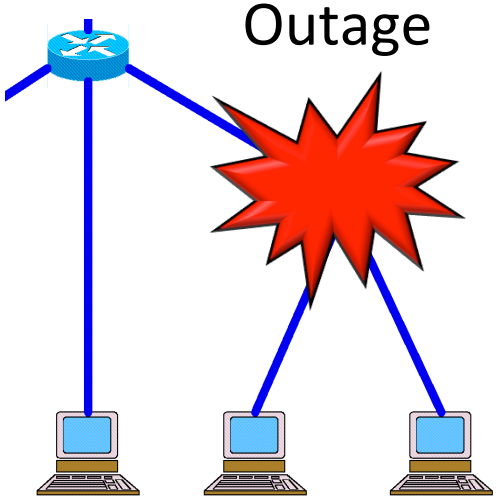
Fiber optics link

Goals :

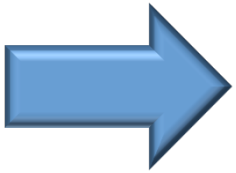
1. Can we automatically adjust Internet routing to avoid network outages *before they happen*?
2. Can we choose the best backup route?

Network Outage Causes

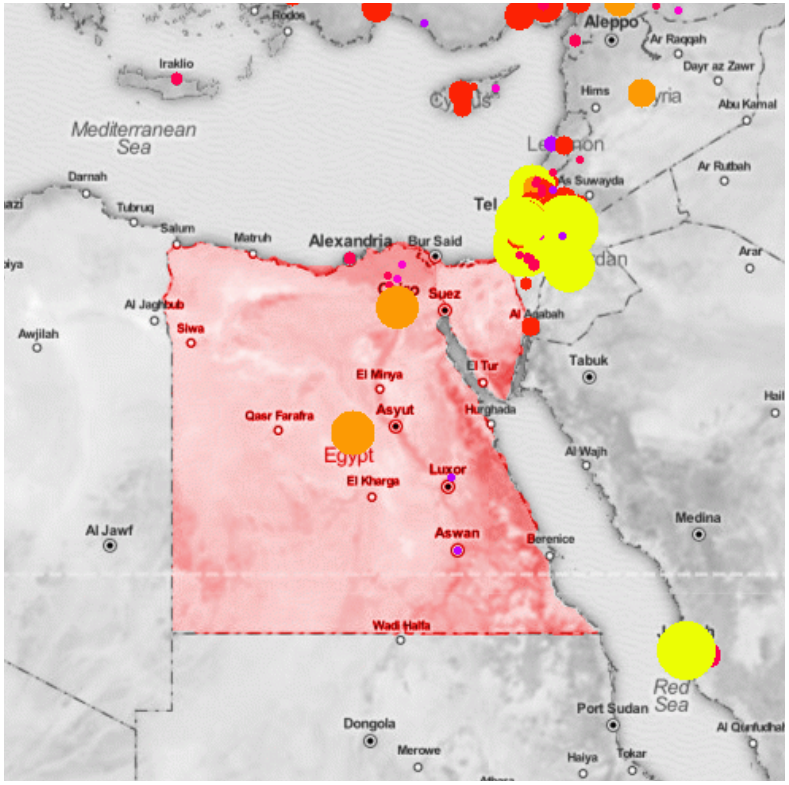
Outage



Why?



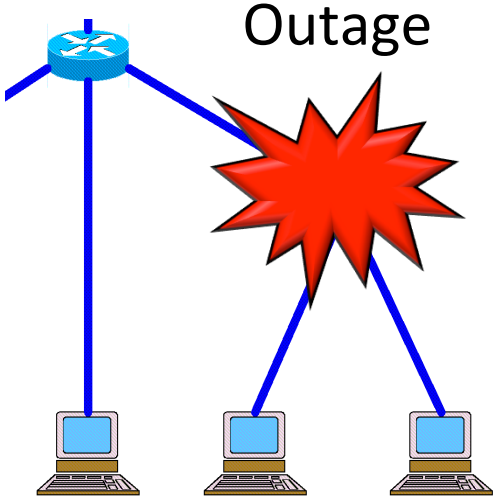
Censorship



http://www.caida.org

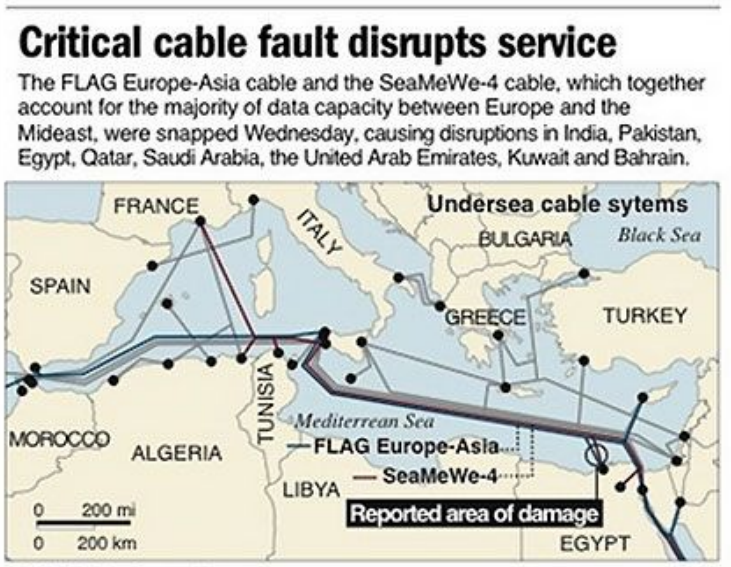
Network Outage Causes

Outage



Why?

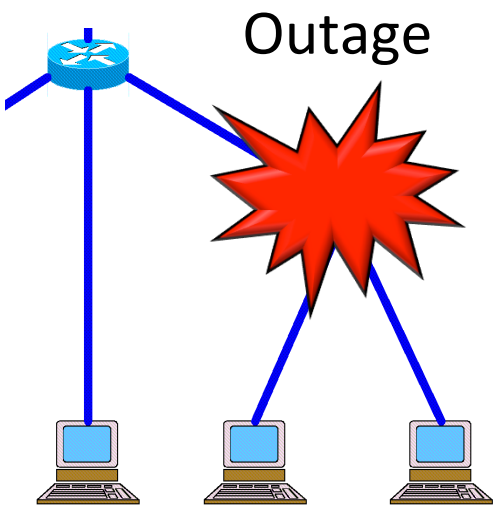
Accidents



http://www.ap.org/

Network Outage Causes

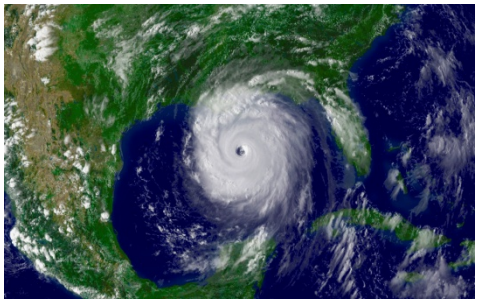
Our Focus: Natural Disaster Events



Why?

Thunderstorms

Tornados



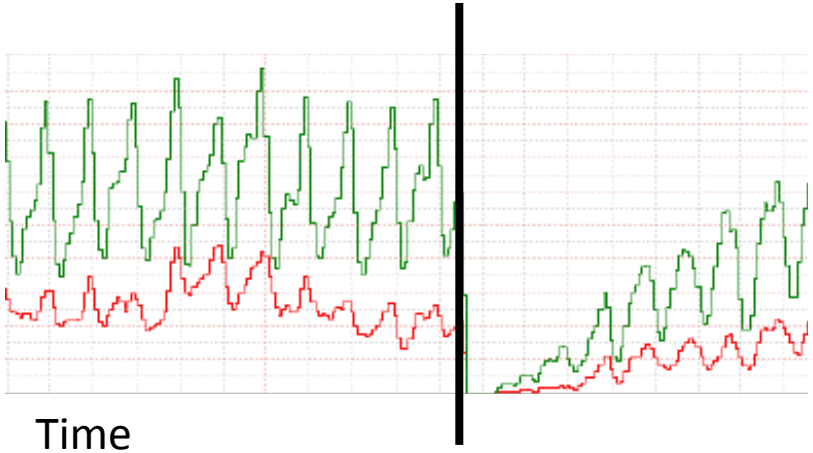
Hurricanes

http://www.noaa.gov/

Is the Internet fragile to Natural Disasters?

Large-Scale Disaster Events

Network Traffic



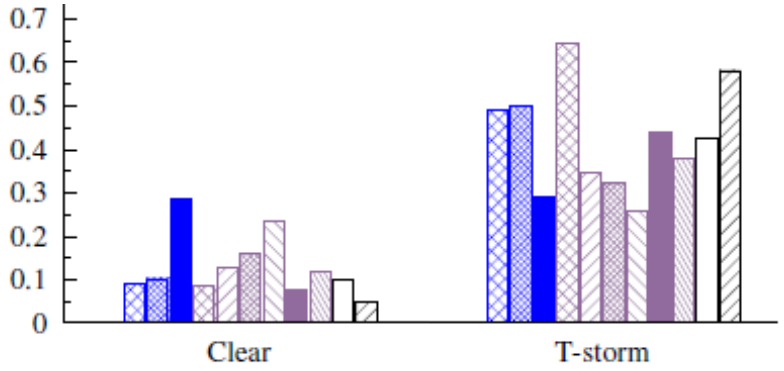
Time

March 11th 2011 Earthquake

Cho et. al., "The Japan Earthquake…", SWID 11

Small-Scale Disaster Events

End Host Up-Down Rate



Schulman and Spring, "Pingin in the Rain", IMC 11

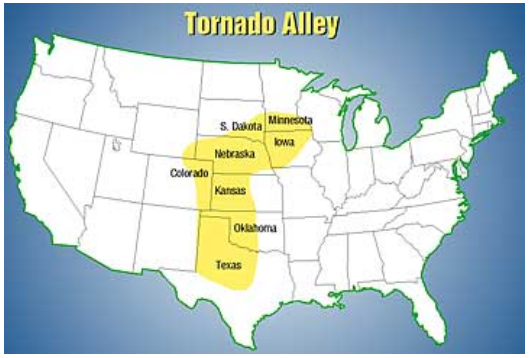
Network outages increase by 4x in storms.

Our Focus : Natural Disasters-Based Outages

In contrast to accidents and censorship, weather-related events ***follow predictable geographic and temporal patterns***.

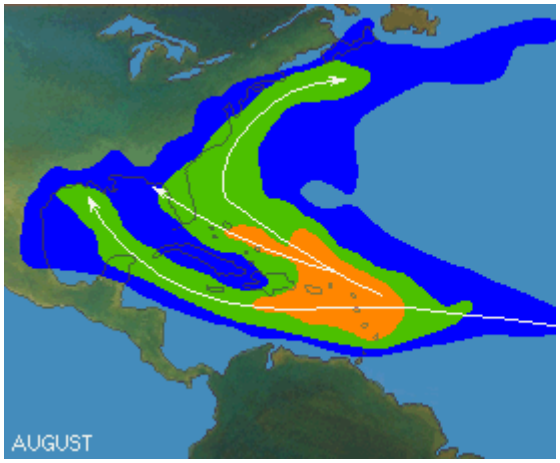
Known Occurrence Patterns

Earthquake Fault Lines



"Tornado Alley"

Predictable Trajectories via Forecasting



Hurricane Patterns

http://www.noaa.gov/

Current Routing Under Disasters

Does Internet routing currently take advantage of this predictability of natural disasters?

Answer: Sort of…


renesys | blog

Hurricane Sandy: Global Impacts

By Doug Madory on November 7, 2012 2:10 PM

In our recent posts about Hurricane Sandy, we analyzed the impacts of the super storm on Internet connectivity in the northeastern US. However, in addition to knocking out power and Internet connectivity in a significant part of the New York

http://www.renesys.com/blog/2012/11/sandys-global-impacts.shtml

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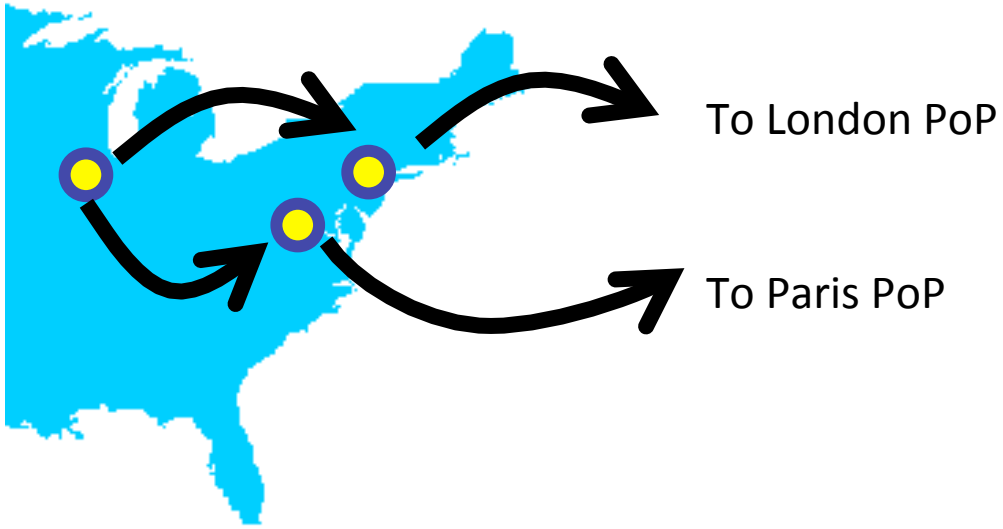
Level3 Network Topology



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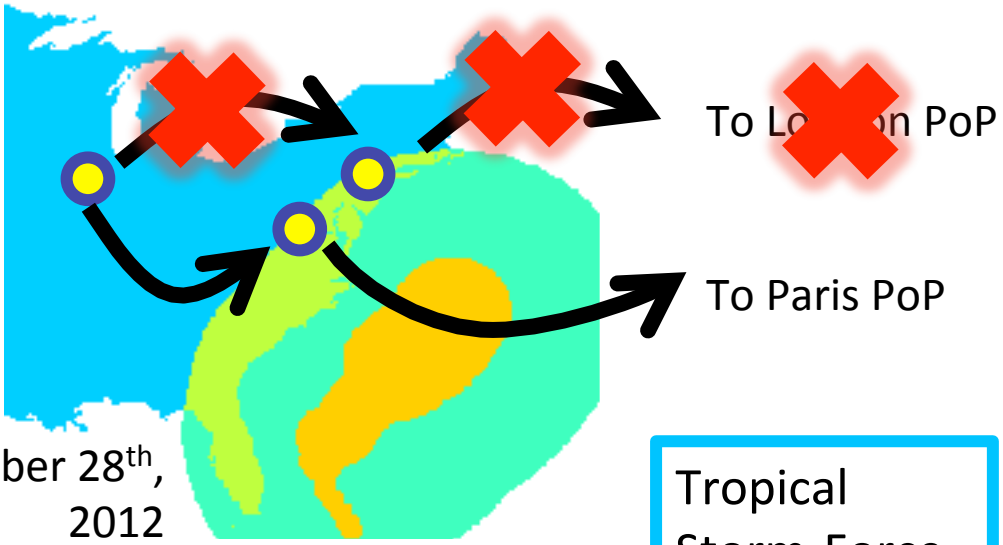
Manual Routing Change



11:00 PM October 28th, 2012

Weather Forecast Information:

Hurricane-Force Winds

Tropical Storm-Force Winds

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renesys | blog

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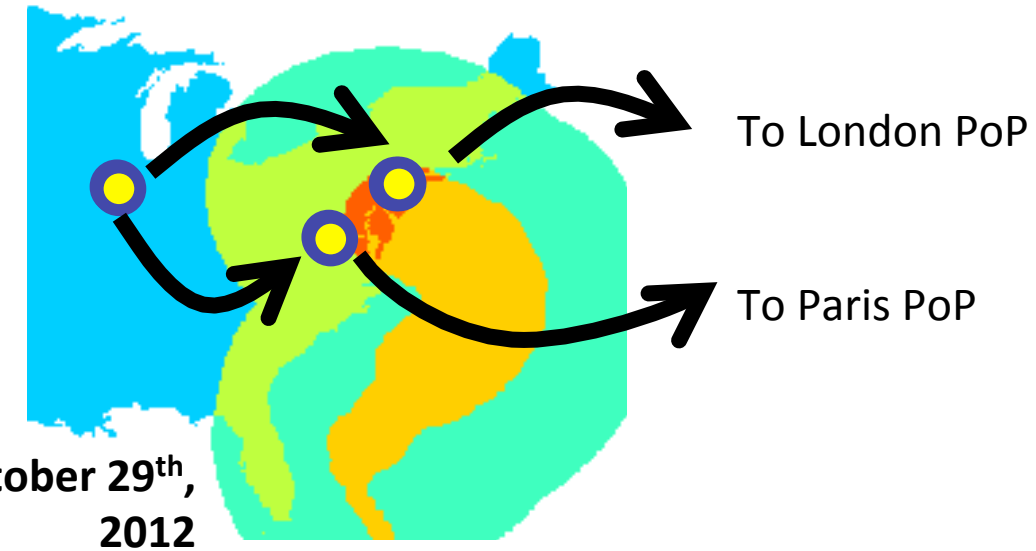


11:00 PM October 29th, 2012

Main Problem : Manual routing changes are too time-consuming and coarse-scale to be effective.

Talk Outline

Goal : Can we exploit the predictability of natural disasters to automatically adjust Internet routing?

- Bit-Risk Miles Metric
  - Assess sensitivity to network outages
- RiskRoute Framework
  - Real-time routing changes to minimize outage risk
- Experiments
  - Example routing changes on real world networks and historical disaster case studies
  - Robustness suggestions

Bit-Risk Miles Metric

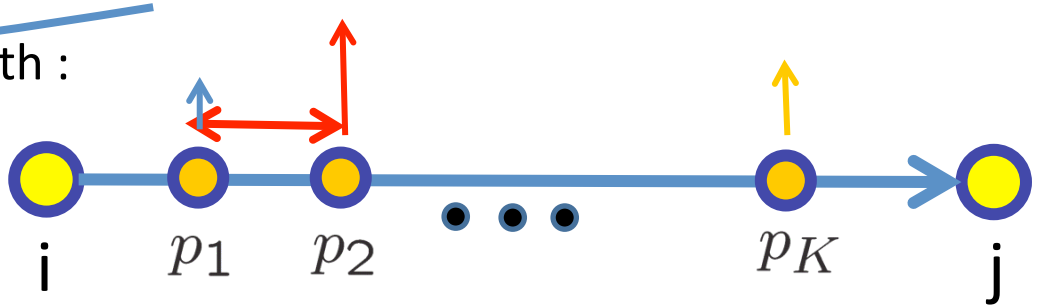
- The idea of bit-miles motivates the introduction of *bit-**risk** miles.*

# of Bits Sent + **Distance** + **Outage Risk** = Bit-Risk Miles

– Consider a routing path :

Bit Miles

$$\mathbf{p} = \{p_1, p_2, \ldots, p_K\}$$



– The bit-risk miles of the ro a fined as:

$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x, p_{x+} \; , \; h}(p_x) + \lambda_{f} \; ;) \right)$$

Bit Miles | Infrastructure Outage Risk

Bit-Risk Miles Metric

$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x,p_{x+1}} + \gamma_{i,j} \left(\lambda_h o_h(p_x) + \lambda_f o_f(p_x) \right) \right)$$

Bit Miles

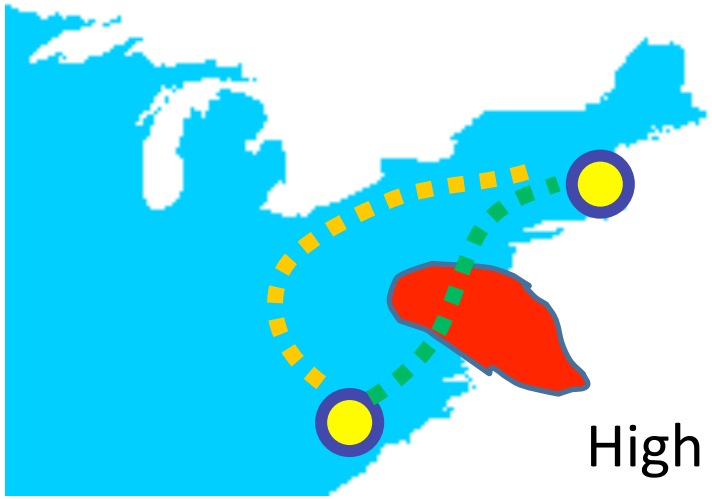
Infrastructure Outage Risk

- Quantifies the trade-offs of:

Short geographic routing paths with **high** outage risk

vs.

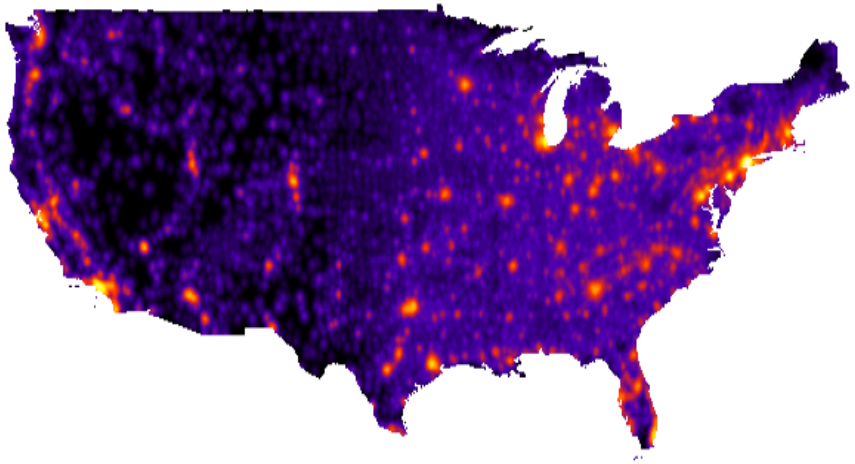
Long geographic routing paths with **low** outage risk



High Risk Area

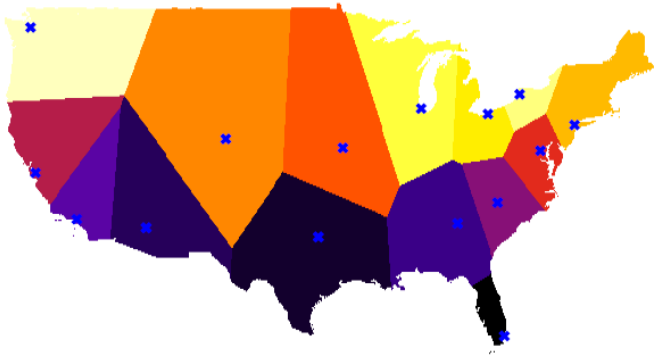
$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x, p_{x+1}} + \gamma_{i,j} \left(\lambda_h o_h(p_x) + \lambda_f o_f(p_x) \right) \right)$$

- What is the cost of an outage between the source and destination?
- In real-world networks, this can be monetary:
  - SLA violations
  - End user refunds
- To approximate this, we use the fraction of population affected:



United States Population Density (www.census.gov)

A nearest-neighbor partitioning aggregates population to PoP locations.



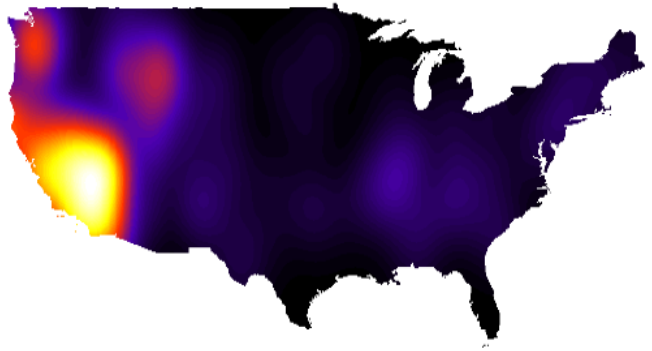
Teliasonera Network

$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x,p_{x+1}} + \gamma_{i,j} \left(\lambda_h o_h(p_x) + \lambda_f o_f(p_x) \right) \right)$$

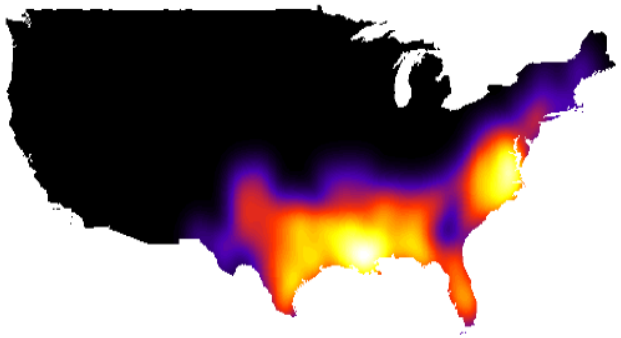
- What is historical outage probability at this PoP location?

Corpus of weather events from 1970 to 2010

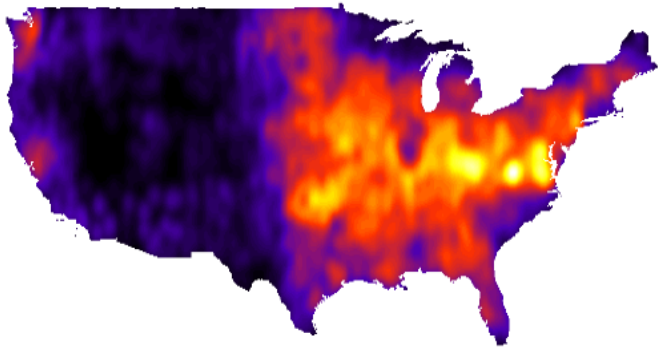
- 29,865 FEMA emergency declarations
- Over 145,000 NOAA severe weather events



2,267 Earthquake Occurrences



2,805 Hurricane Occurrences



20,623 Thunderstorm Occurrences

www.noaa.gov, www.fema.gov

$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x,p_{x+1}} + \gamma_{i,j} \left(\lambda_h o_h(p_x) + \lambda_f o_f(p_x) \right) \right)$$

- What is forecasted outage probability at this PoP location?

National Weather Service, National Hurricane Center (www.nhc.noaa.gov)

- Event Center
- Storm-specific Details
  - Radius of tropical-force winds
  - Radius of hurricane-force winds

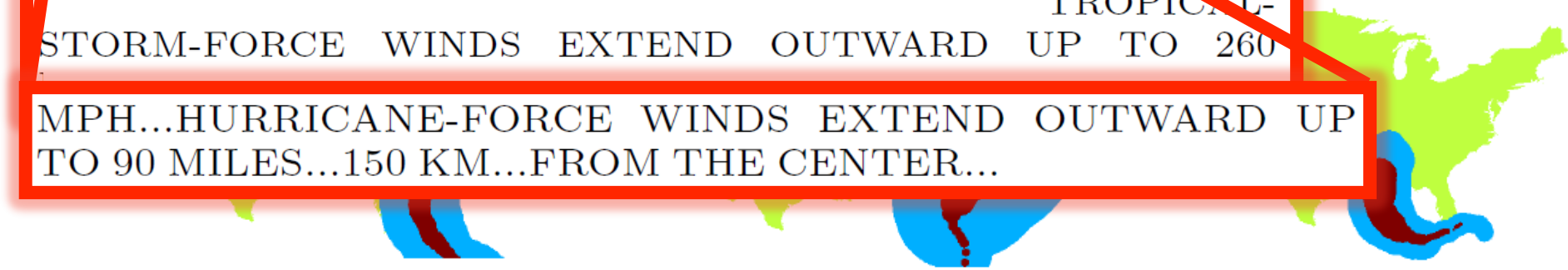
...THE CENTER OF HURRICANE IRENE WAS LOCATED NEAR LATITUDE 35.2 NORTH...LONGITUDE 76.4 WEST. IRENE IS MOVING TOWARD THE NORTHEAST NEAR 15 MPH...HURRICANE-FORCE WINDS EXTEND OUTWARD UP TO 90 MILES...150 KM...FROM THE CENTER...AND TROPICAL-STORM-FORCE WINDS EXTEND OUTWARD UP TO 260 MILES...415 KM...

HURRICANE IRENE INTERMEDIATE ADVISORY NUMBER 28A

LATITUDE 35.2 NORTH...LONGITUDE 76.4 WEST

800 AM EDT SAT AUG 27 2011

TROPICAL-STORM-FORCE WINDS EXTEND OUTWARD UP TO 260 MPH...HURRICANE-FORCE WINDS EXTEND OUTWARD UP TO 90 MILES...150 KM...FROM THE CENTER...



Hurricane Irene

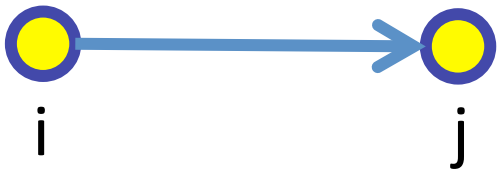
Hurricane Sandy

Hurricane Katrina

RiskRoute Methodology

How do we choose which backup path has the smallest bit-risk miles?

- Storing all the backup paths is combinatorial.
- Current Techniques: Storing only one backup path (e.g., Fast Reroute) is fragile to large-scale outages.
- RiskRoute Framework: Using shortest path techniques, continuously recalculate all paths with the smallest bit-risk miles:

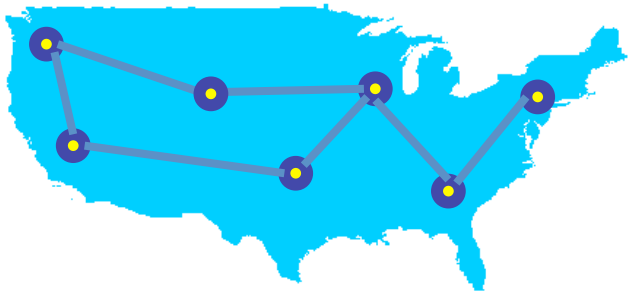


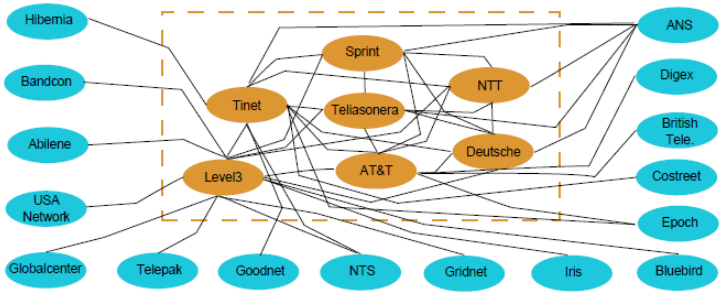
$$\mathbf{p}_{i,j}^{rr} = \arg \min_{\mathbf{p} \subset \mathbb{P}_{i,j}} r_{i,j}(\mathbf{p})$$

Bit-Risk Miles for route **p**

Experiment Datasets

- Real-World Network
  - 7 Tier-1 ISPs, 16 regional networks
- Intra-domain Routing
  - Routing inside a specified network
- Interdomain Routing
  - Routing between networks
- Performance Metrics:





1 **Risk Ratio** – The average reduction in bit-risk miles using RiskRoute compared with shortest path routing

$$r_r = 1 - \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{r\left(\mathbf{p}_{i,j}^{rr}\right)}{r\left(\mathbf{p}_{i,j}^{shortest}\right)}$$

2 **Distance Ratio** – The average increase in bit-miles using RiskRoute compared with shortest path routing

$$d_r = \frac{1}{N^2}\sum_{i=1}^{N}\sum_{j=1}^{N}\frac{d\left(\mathbf{p}_{i,j}^{rr}\right)}{d\left(\mathbf{p}_{i,j}^{shortest}\right)} - 1$$

Intradomain RiskRoute Results

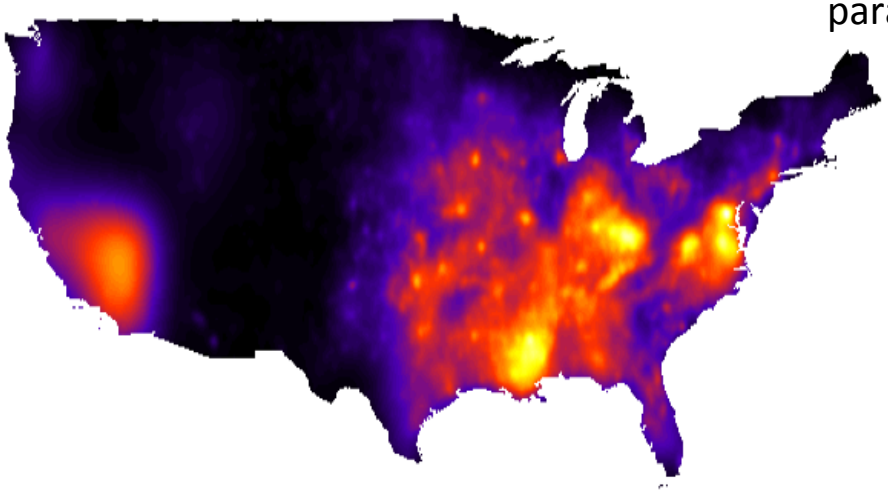
RiskRoute Path

Shortest Path

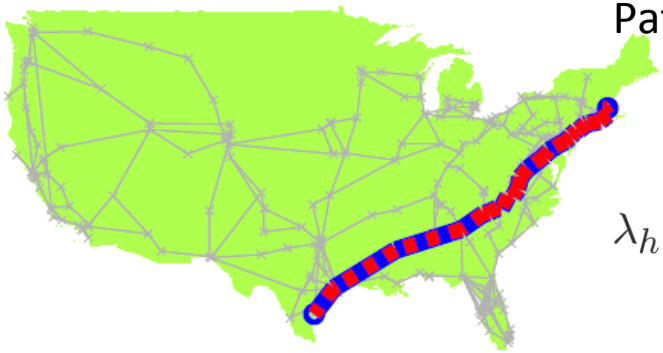
Historical Outage-Only Bit-Risk Miles metric:

$$r_{i,j}(\mathbf{p}) = \sum_{x=1}^{K} \left(d_{p_x,p_{x+1}} + \gamma_{i,j} \lambda_h o_h(p_x) \right)$$

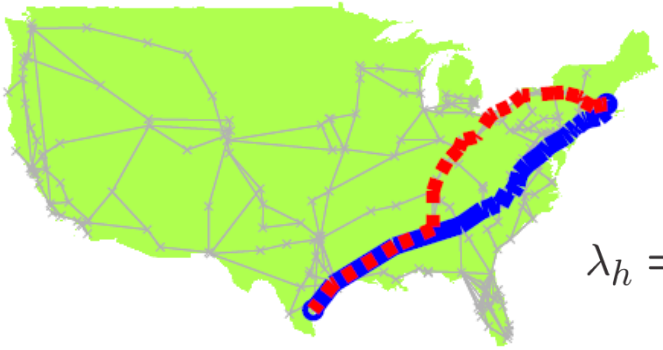
Tuning parameter



Historical Outage Probability



$\lambda_h = 10^3$



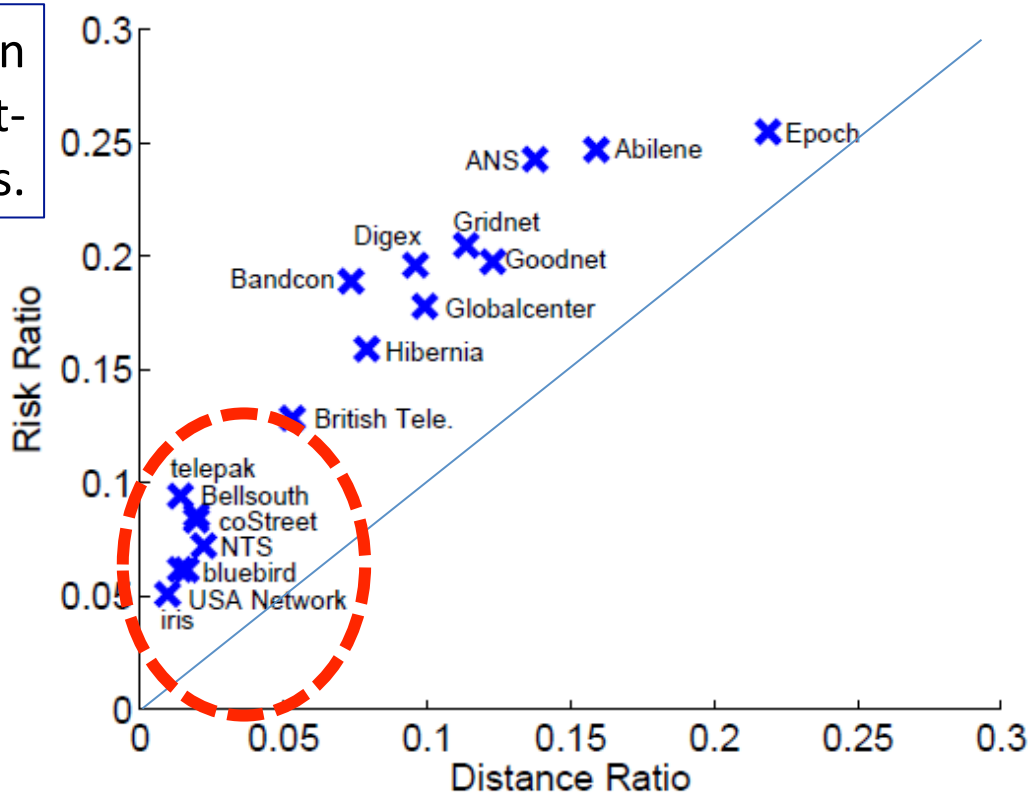
$\lambda_h = 10^4$

$\lambda_h = 10^5$

Intradomain RiskRoute Results

- What are the tradeoffs to using RiskRoute?

Average fraction reduction in bit-risk miles.



Average fraction increase in bit-miles.

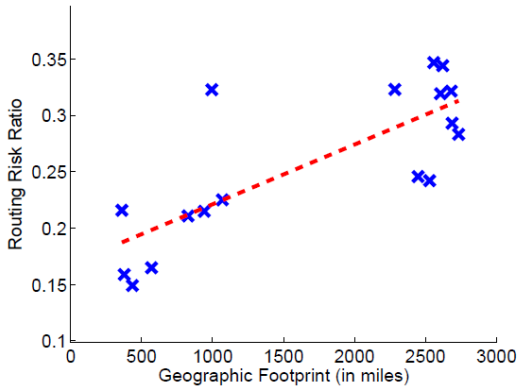
Intradomain RiskRoute Results

- What makes some networks more advantageous towards using RiskRoute?

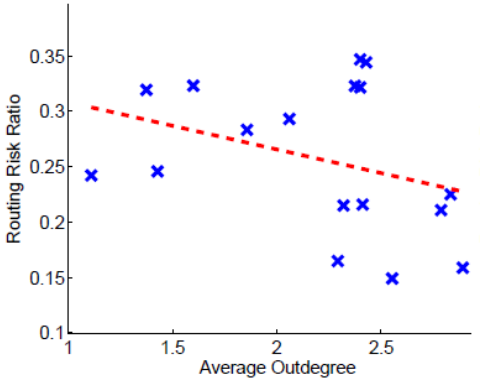
Reduction in Bit-Risk Miles (Risk Ratio)

Increase in Bit-Miles (Distance Ratio)

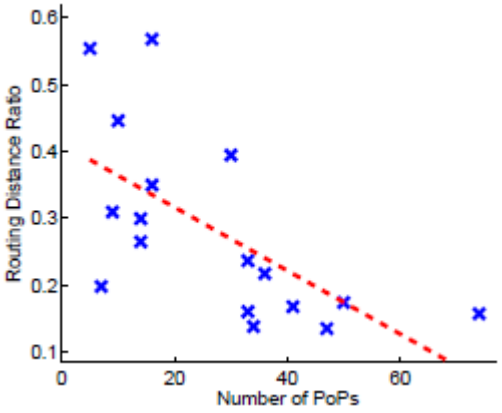
Geographic Footprint



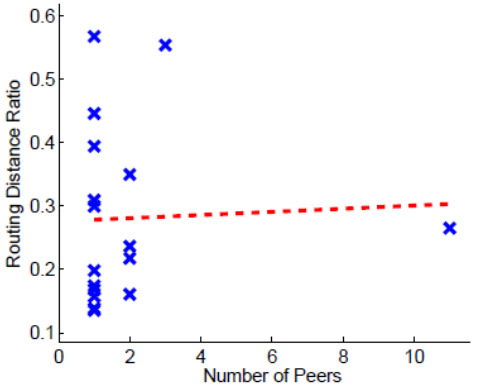
Aver. Router Outdegree



Number of PoPs



Number of Peers

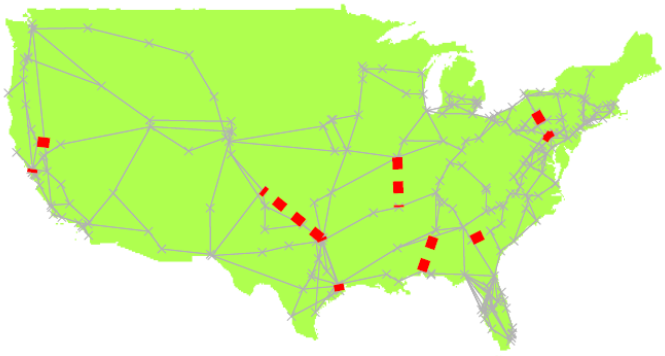


RiskRoute Robustness Analysis

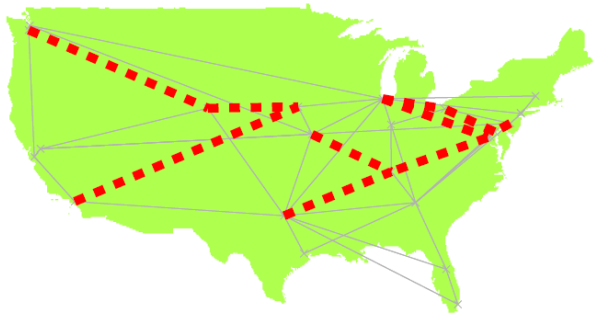
We find the best additional link such that the bit-risk miles is minimized.

$$\widehat{e} = \arg\min_{e \in \mathcal{E}^C} \sum_{i=1}^{N} \sum_{j=i+1}^{N} \min_{\mathbf{p} \subset \mathbb{P}_{i,j}} r_{i,j}(\mathbf{p})$$

Intradomain Results:

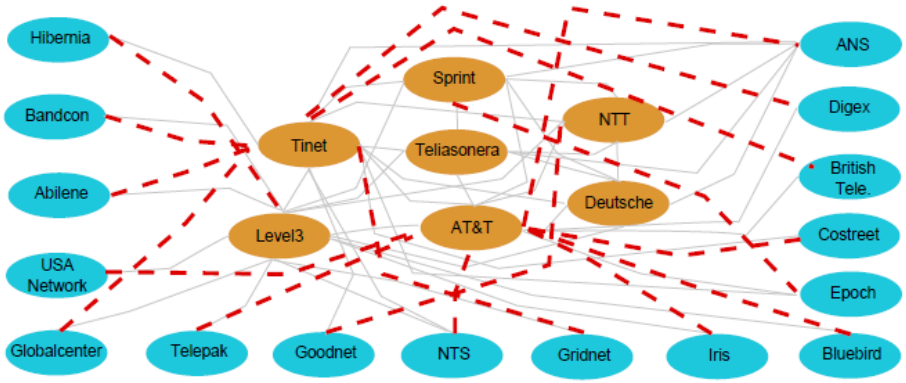


Level3 Network



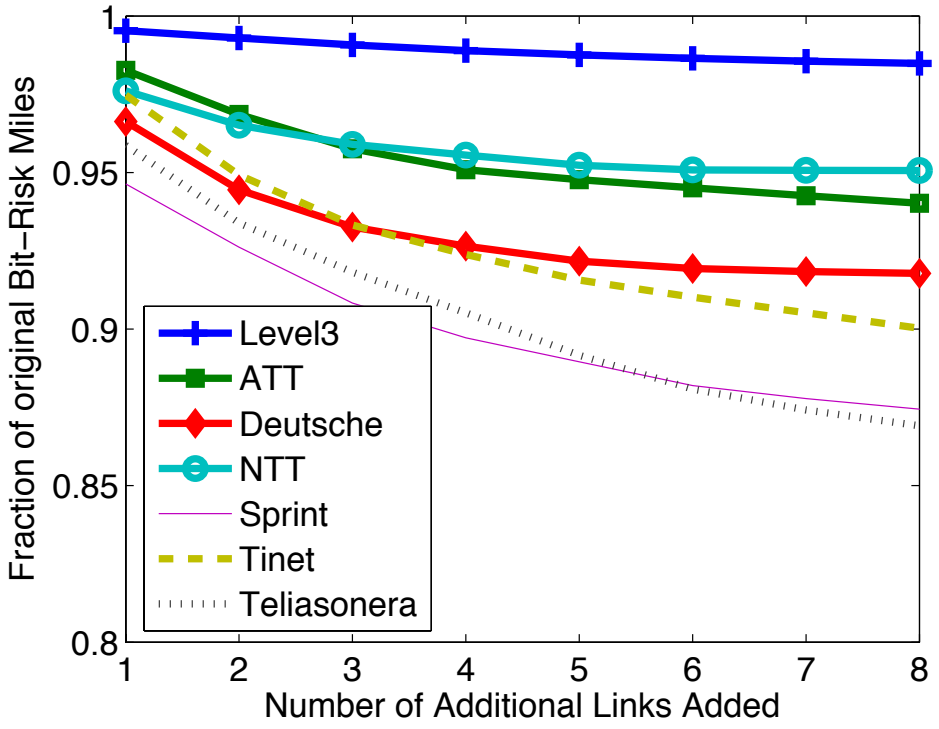
Sprint Network

Interdomain Results:

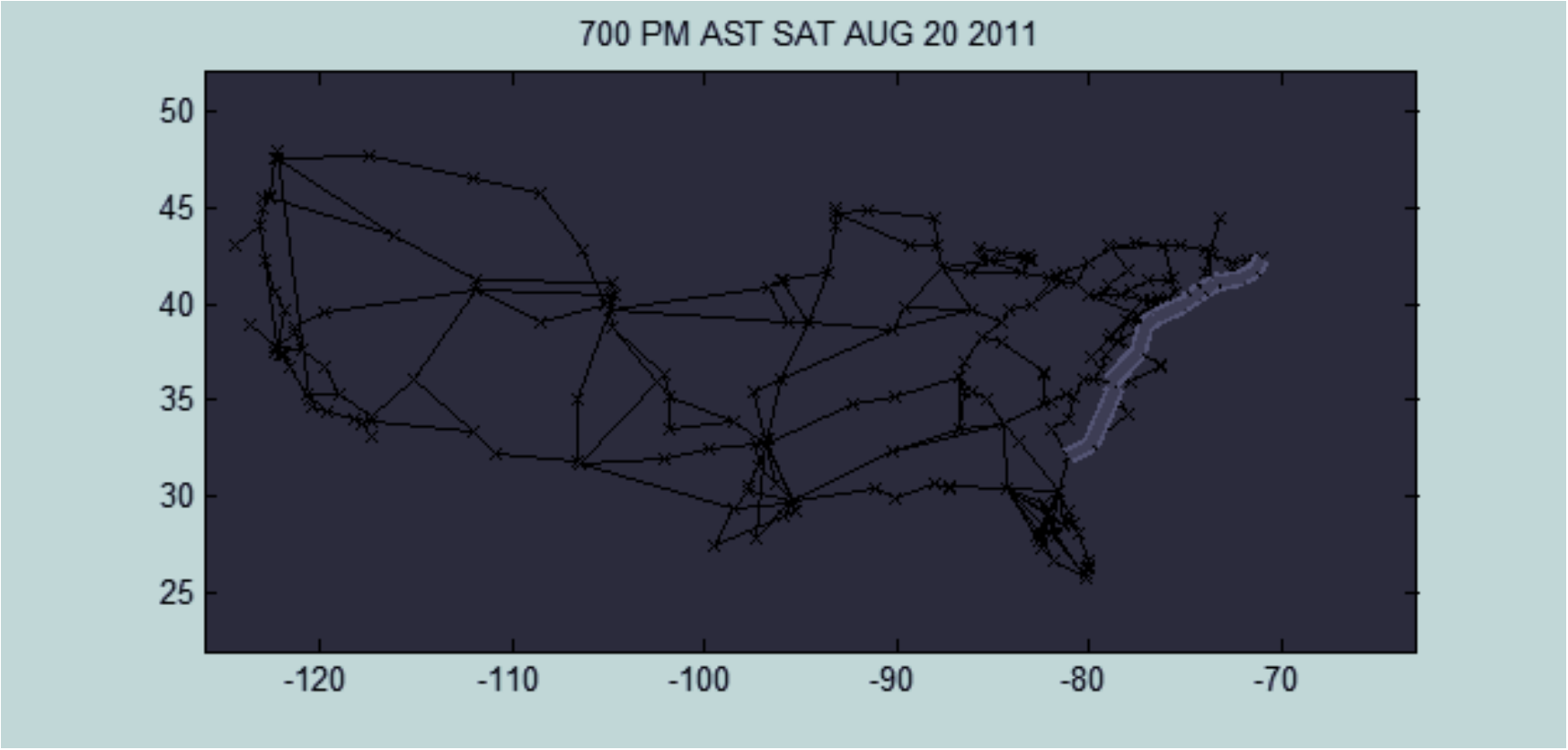


RiskRoute Robustness Analysis

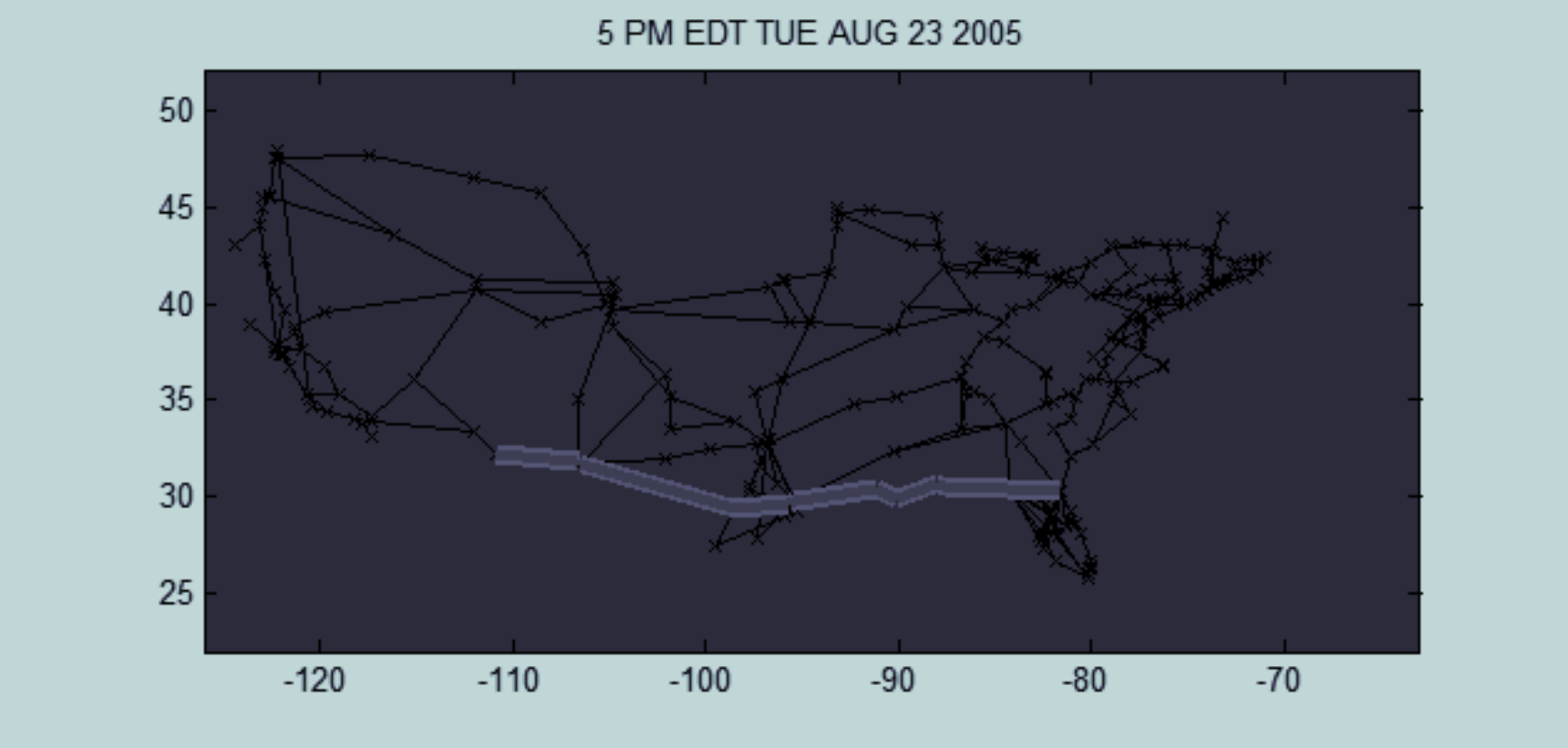
- Can all networks decrease risk via the new link infrastructure?



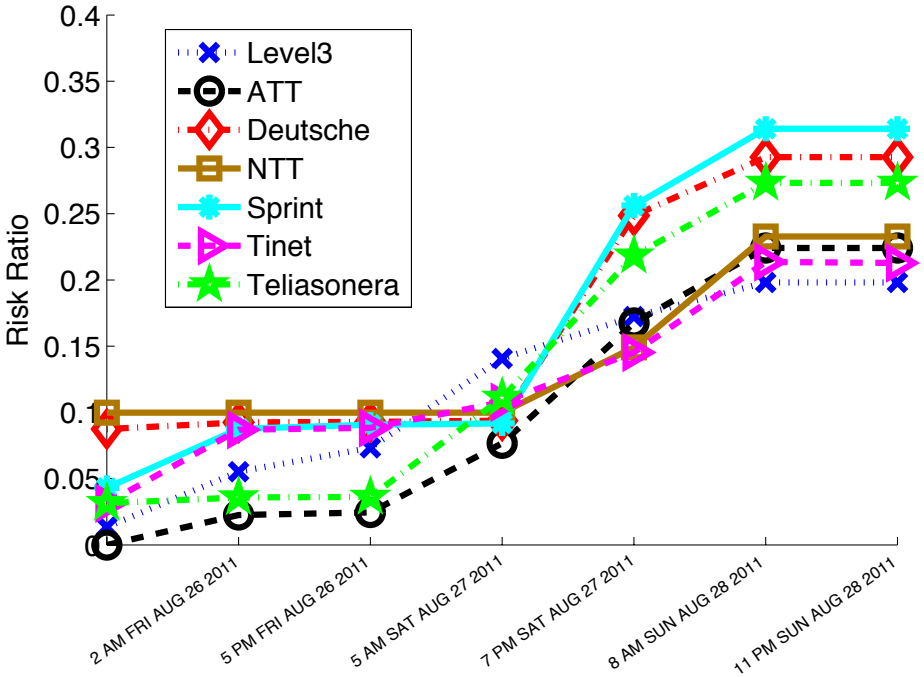
Hurricane Irene and the Level3 Network



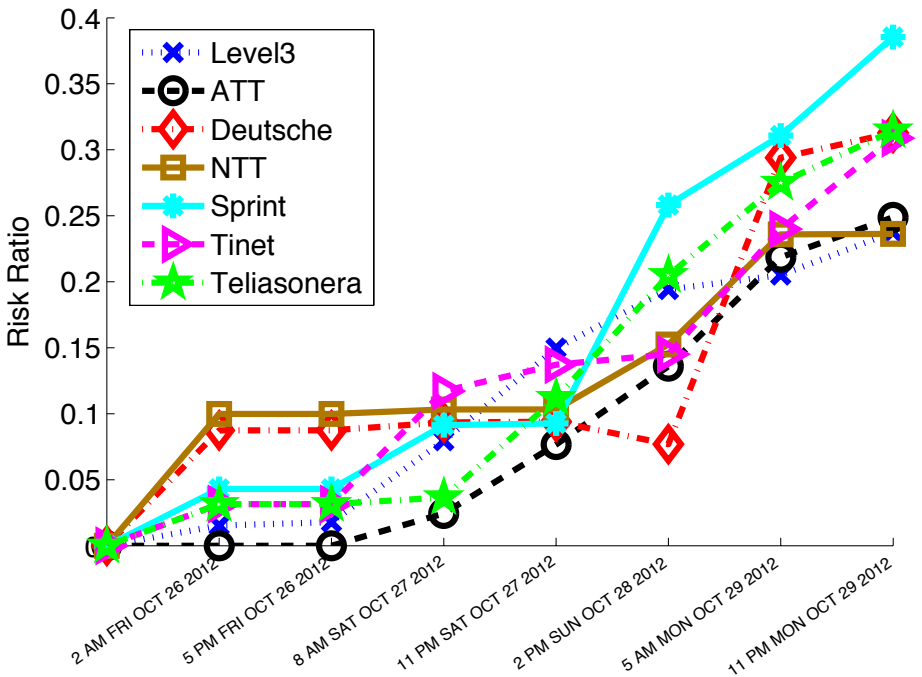
Hurricane Katrina and the Level3 Network



Tier-1 network case study



Hurricane Irene (Left)



Hurricane Sandy (Right)

Putting RiskRoute into Practice

- Intra-domain routing
  - OSPF or ISIS
  - link weights are composite of operational objectives and RiskRoute
- Inter-domain routing
  - Conjunction with proposed BGP “add paths” option
  - Can lead to new provider or peering relationships

Conclusions

- We presented ***RiskRoute***, a real-time routing framework for mitigating outage threats.
- We use a large corpus of network physical infrastructures, population data, historical disaster events, and weather forecast information.
- Our disaster case studies demonstrate how RiskRoute can incorporate weather forecast information to avoid outage risks.

Questions?