



## Traffic Engineering through Automated Optimization of Routing Metrics

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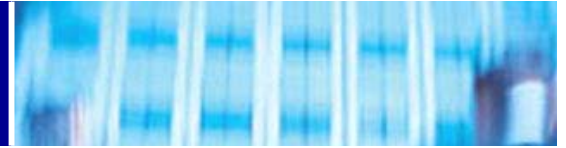
TERENA Networking Conference

June 7-10, 2004

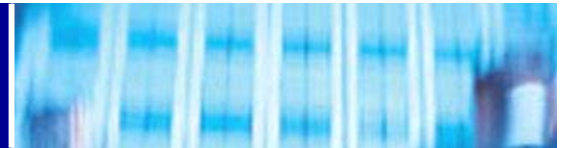
Rhodes, Greece



# Agenda



- IP Traffic Engineering
- Metric Optimization
- Traffic Matrix Estimation
- Results in 6 networks
- Case Study: Global Crossing backbone
- Summary



## **Manipulate Internal Routing**

- Prevent congestion
- Minimize maximum utilization
- Reduce network costs!

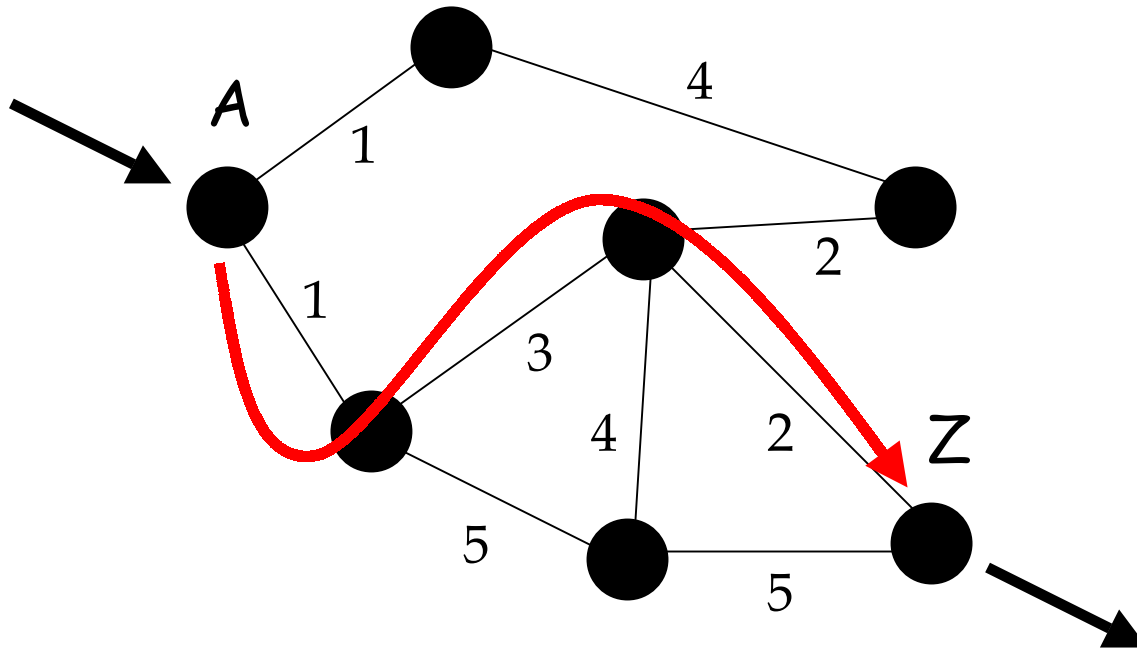
## **IGP Metric-based TE**

- Manual or Automated

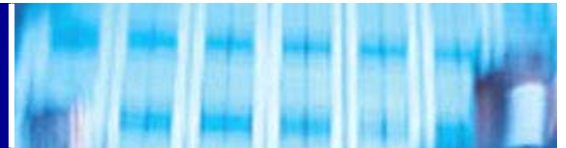
## **MPLS**

- Constraint-based routing, CSPF
- Explicit Paths
  - ↳ Primary + Secondary

# Shortest Path Routing (OSPF/ISIS)



- **Conventional IP routing uses pure destination-based forwarding**
- **Conventional IGP path computation is selected based upon a simple additive metric**
  - Bandwidth availability is not taken into account
- **Some links may be congested while others are underutilized**



## Automated calculation of IGP metrics to meet objectives (QoS)

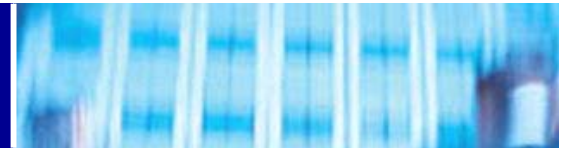
### Specify Optimization Objective

→ Minimize maximum worst-case link utilization

### Methodology

- Evaluate all failure scenarios
  - ↳ E.g. all single-link failures
- Use algorithm to calculate optimal metrics based on optimization objective
  - ↳ E.g. local search heuristic, linear programming, etc.
  - ↳ See references, [1] - [7]

# Minimize Maximum Utilization

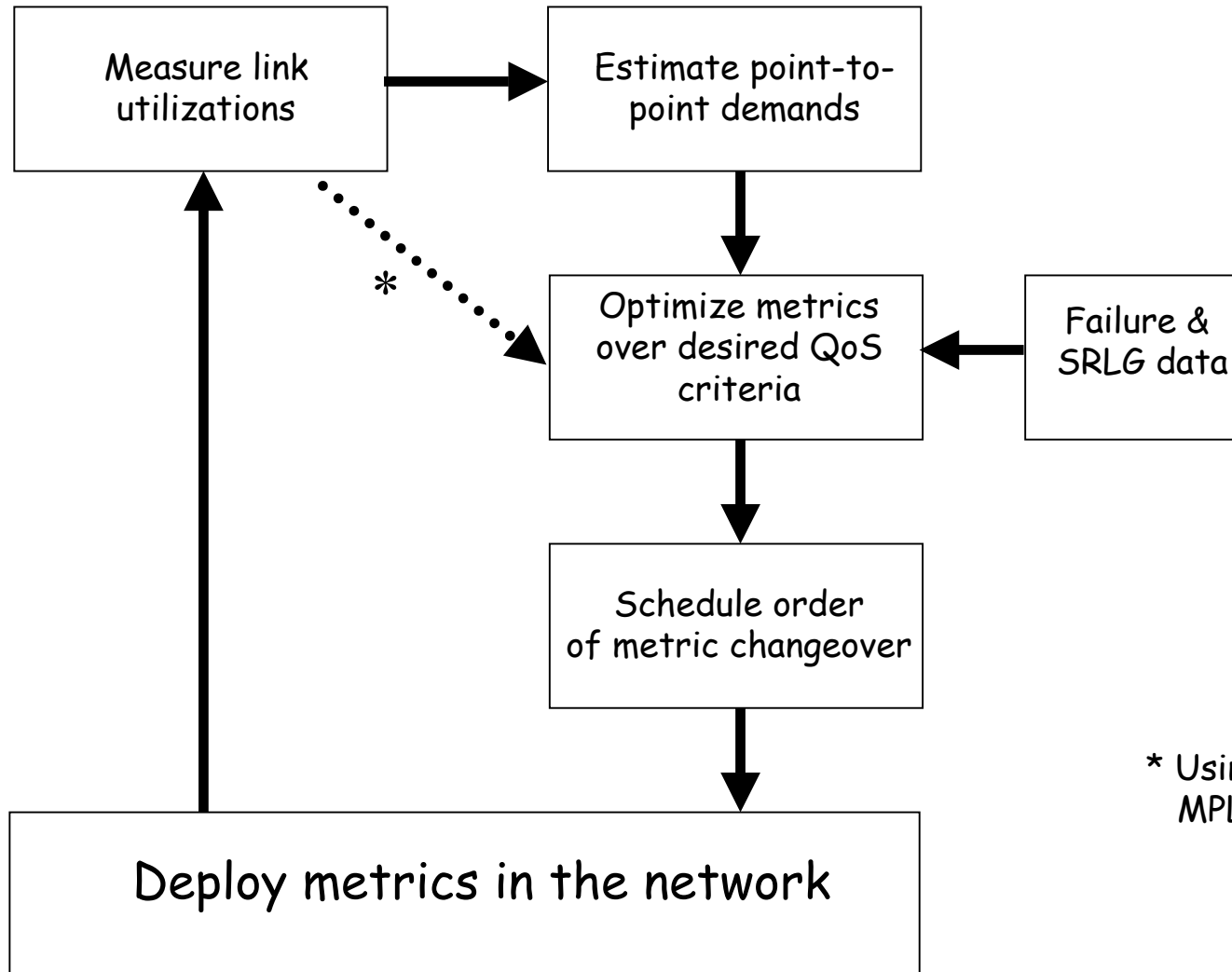
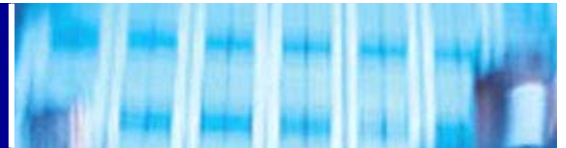


	<u>Link 1</u>	<u>Link 2</u>	<u>Link 3</u>	<u>Link 4</u>	...
<u>Failure 1</u>	-	84%	43%	59%	...
<u>Failure 2</u>	70%	-	90%	59%	...
<u>Failure 3</u>	51%	84%	-	67%	...
<u>Failure 4</u>	47%	91%	43%	-	...
...	...	...	...	...	...

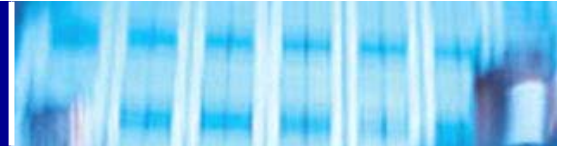
Maximum:        70%        91%        90%        67%        ...

Overall Maximum: 91%

# Metric-based TE Process



\* Using NetFlow or MPLS measurements



## Problem:

- Estimate point-to-point demands from measured link loads

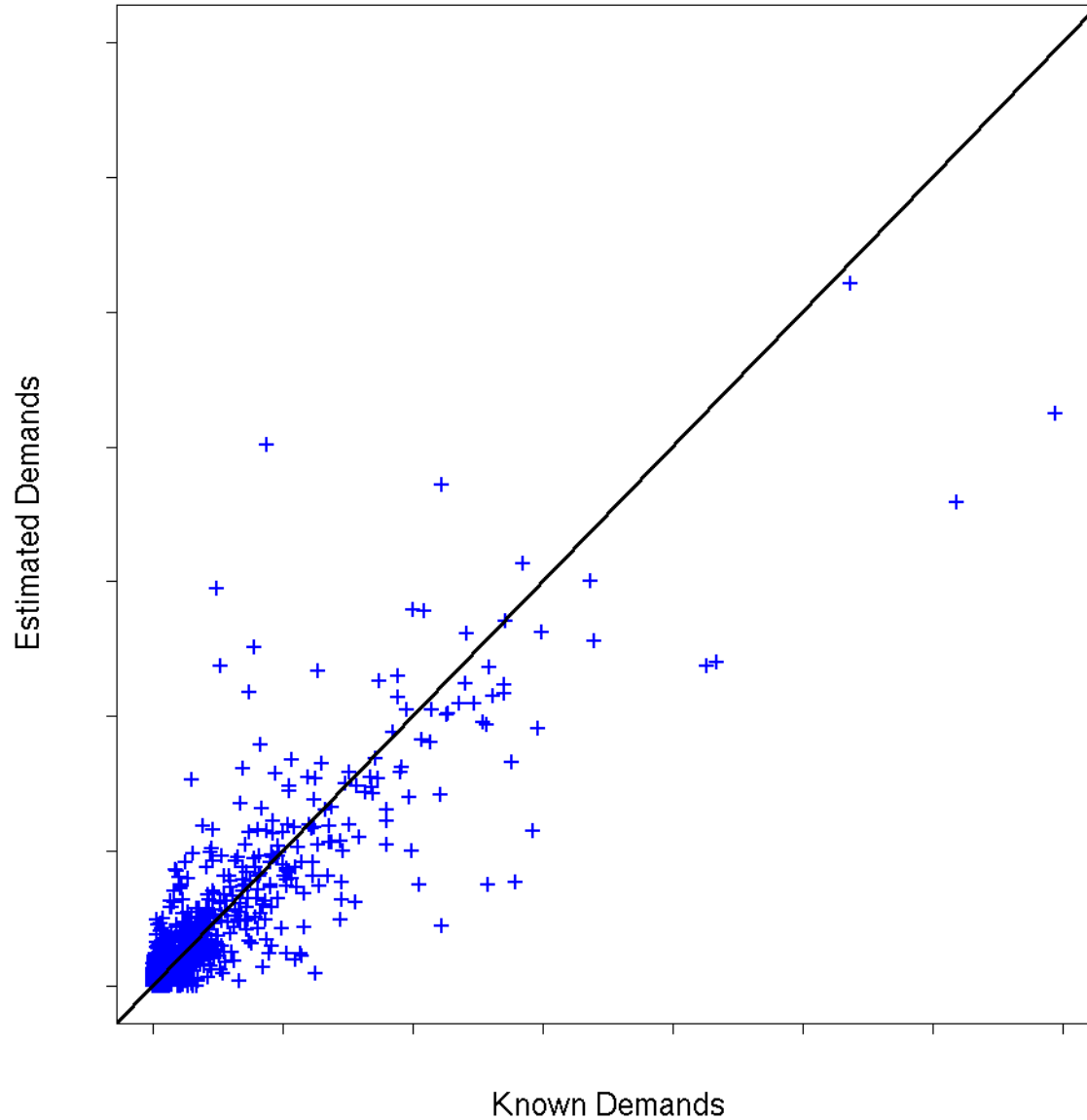
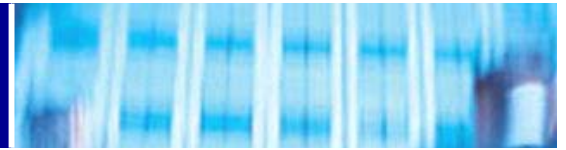
## Network Tomography

- Y. Vardi, 1996
- Similar to: Seismology, MRI scan, etc.
  - ↳ See references, [9] and [10]

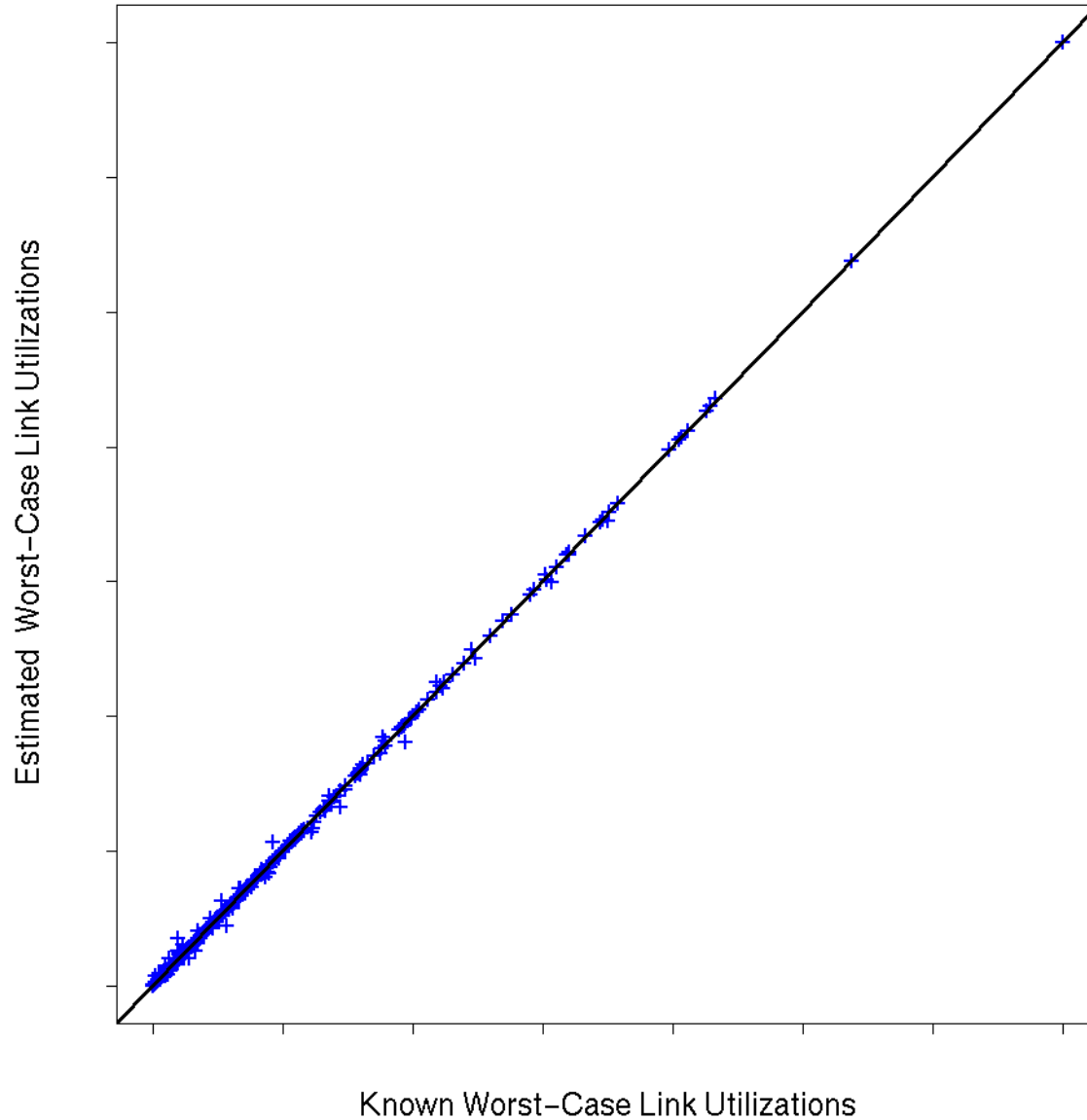
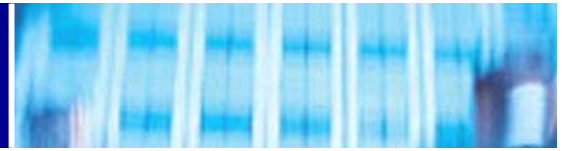
## Underdetermined system:

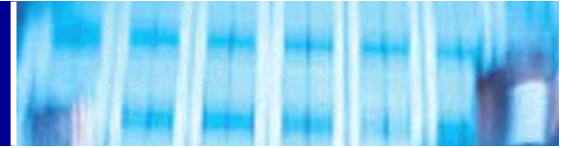
- $N$  nodes in the network
- $O(N)$  links utilizations (*known*)
- $O(N^2)$  demands (*unknown*)

# Real Network: Estimated Demands



# Estimated Link Utilizations!





## Individual demands

- Inaccurate estimates...

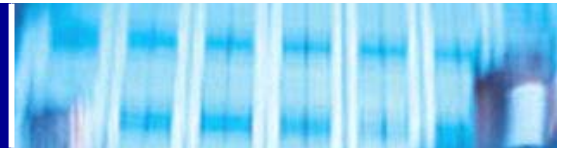
## Estimated worst-case link utilizations

- Accurate!

## Explanation

- Multiple demands on the same path indistinguishable, but their sum is known
- If these demands fail-over to the same alternative path, the resulting link utilizations will be correct

# Study: Six real networks



## Compare Efficiency

↳ Optimized Metrics versus



## Theoretical Optimal

→ multicommodity flow optimizations (no shortest-path limitation) [8]

## Metric Optimizations

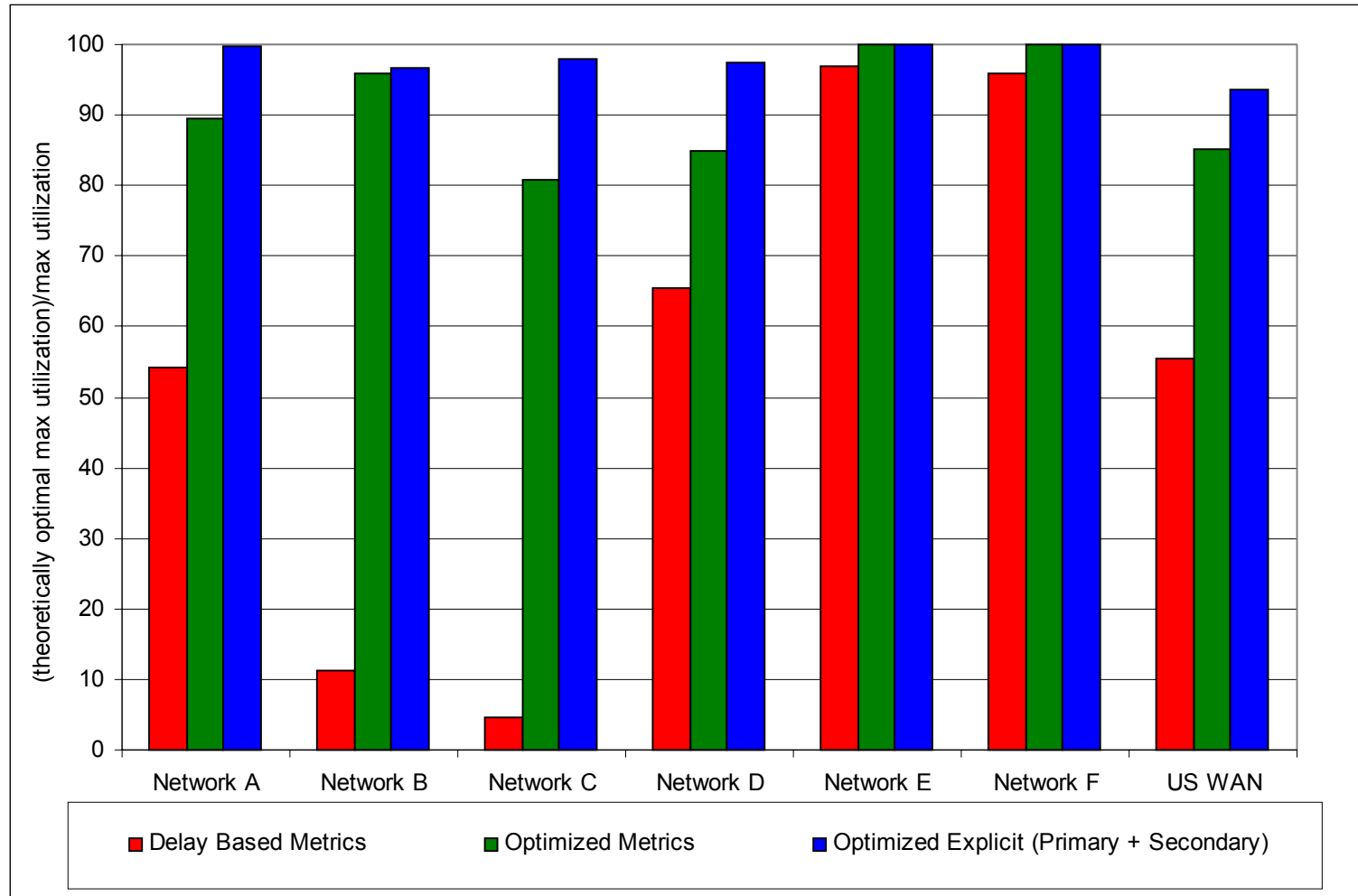
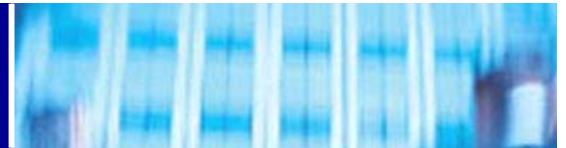
→ Objective: Minimize Maximum Utilization

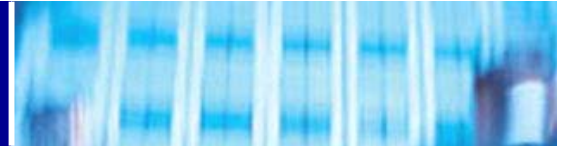
↳ Under all possible single-circuit failures

→ Inputs: Topology, Link Capacities, Demand Matrix

→ Outputs: Explicit Paths, or Link Metrics

# Results





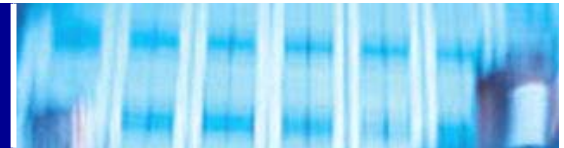
## **Can optimize SPF metrics within 80%-95% of maximum theoretical efficiency**

- Within uncertainty of demand forecasts
- Explicit routing around 90-95% of theoretical limit

## **Topology affects effectiveness Metric Optimization**

- Some are trivial, e.g.  $\langle 0 \rangle$
- Some are more difficult, like meshes

# Case Study: Global Crossing



## Global IP backbone

- Excluded Asia due to migration project

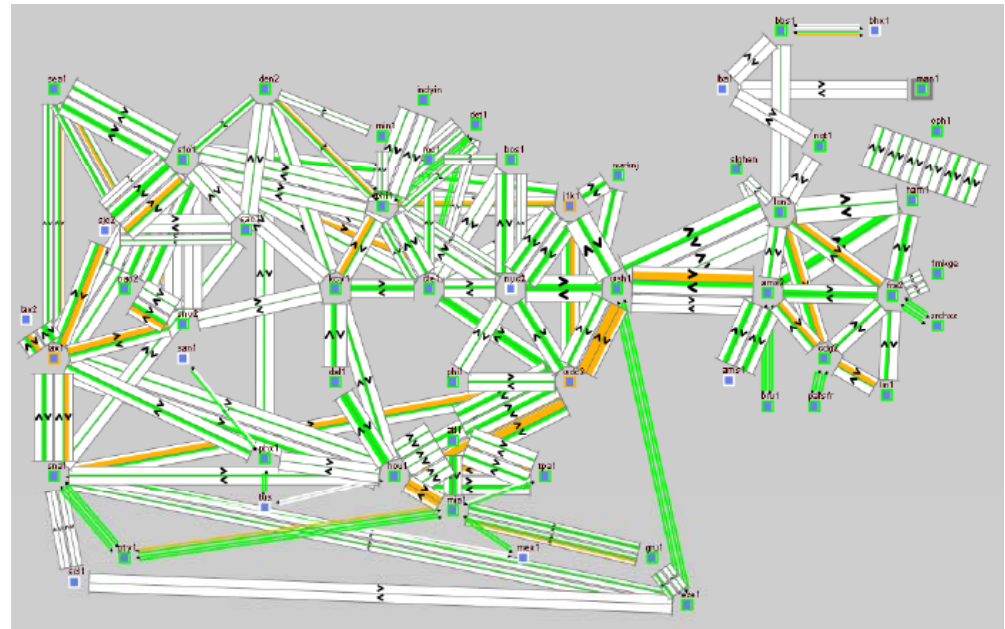
## MPLS TE (CSPF)

## Evaluate IGP Metric Optimization

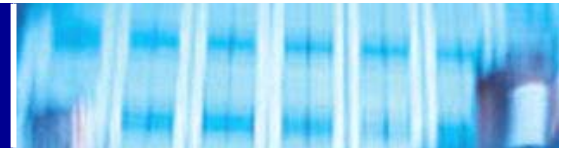
- Using 4000 demands, representing 98.5% of total peak traffic

## Topology:

- highly meshed



# Case Study: Global Crossing



## Comparison:

- Delay-based Metrics
- MPLS CSPF
- Optimized Metrics

## Normal Utilizations

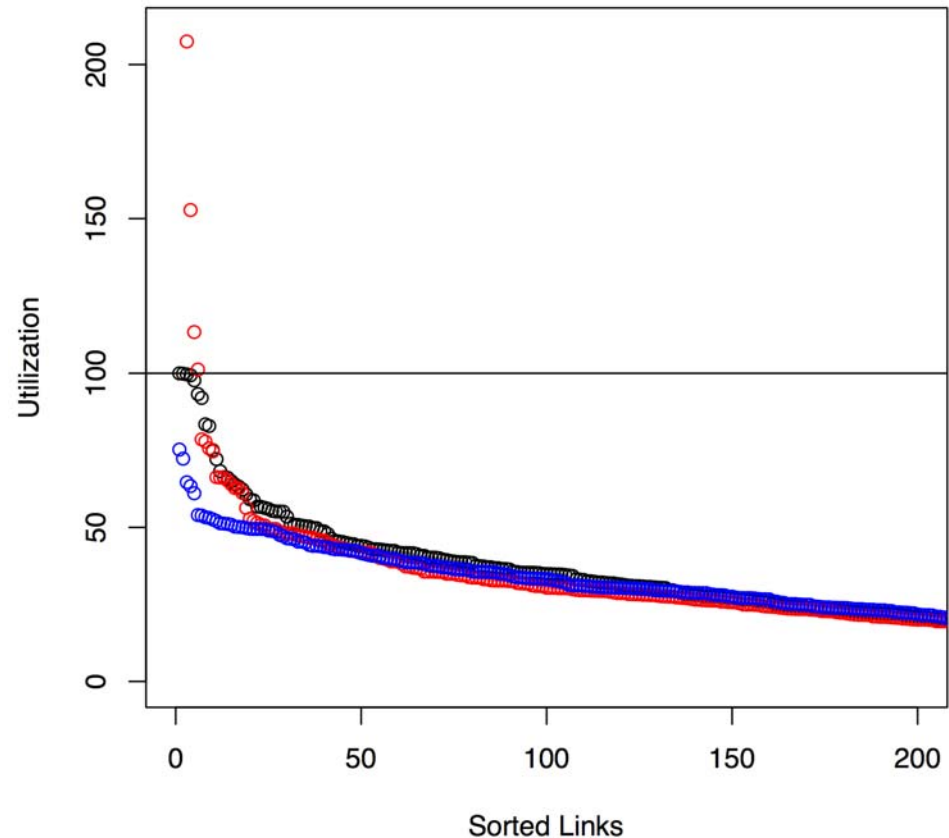
- no failures

## 200 highest utilized links in the network

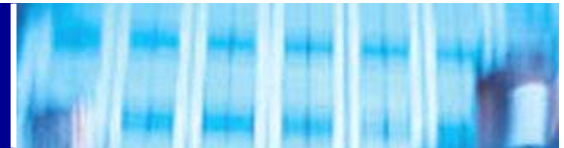
## Utilizations:

- Delay-based: **RED**
- CSPF: **BLACK**
- Optimized: **BLUE**

Non-Failure Utilizations



# Case Study: Global Crossing



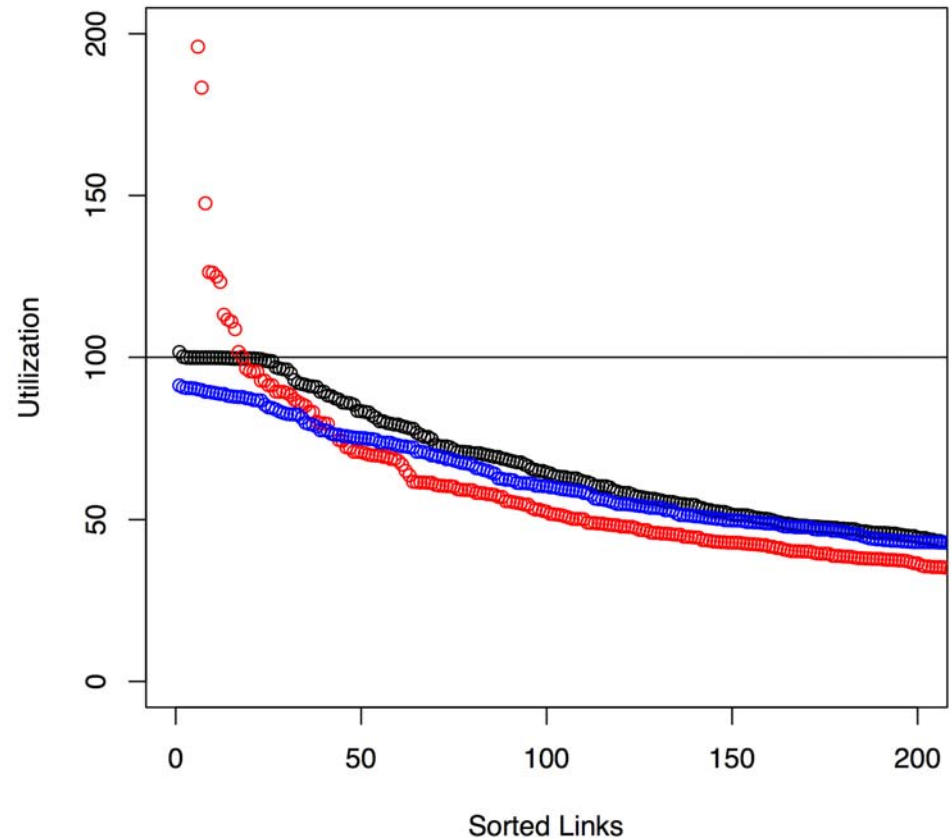
## Worst-Case Utilizations

- single-link failures
- core network
- 263 scenarios

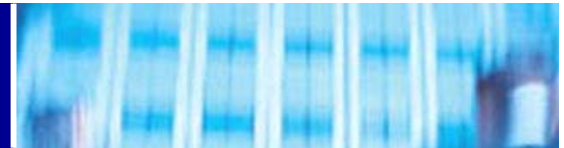
## Results:

- Delay-based metrics cause congestions
- CSPF fills links to 100%
- Metric Optimization achieves <90% worst-case utilizations

Worst-Case Utilizations for Single Link Failures



# Quantifying Congestion



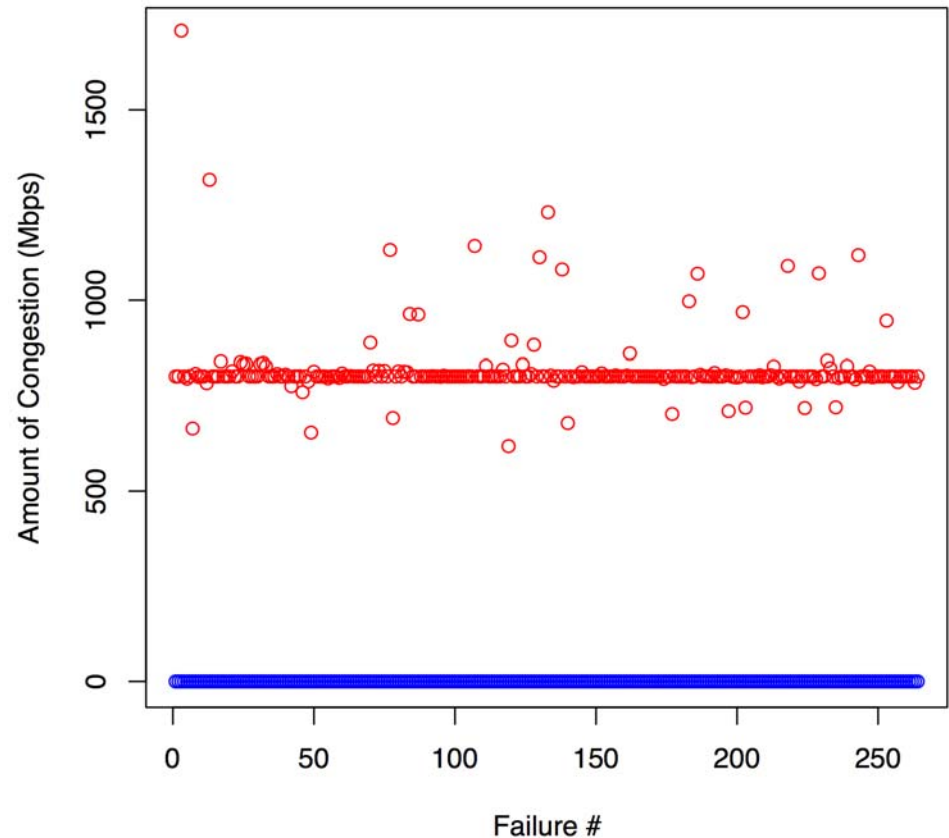
## Calculate “amount of congestion”:

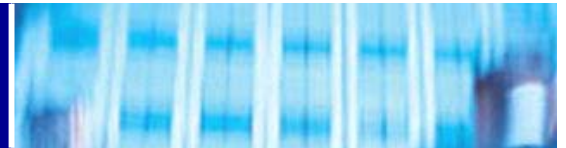
- $\sum ( (util-100)/100 * linkspeed )$   
     $\forall util > 100\%$

## Routing:

- Delay-based metrics: **RED**
- Optimized metrics: **BLUE**

**For no-failure, and all single-link failure scenarios (263)**





## **Optimized metrics can achieve 80%-95% of maximum theoretical efficiency**

- Close to optimal TE
- Results depend on topology

## **Optimized metrics can also be deployed in an MPLS network**

- LDP networks
- CSPF equals SPF when capacity is available

## **Traffic Matrix estimation techniques can be used to calculate point-to-point demands**

# Questions?

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Arash Afrakhteh: *arash @ cariden.com*

# References

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