Best Practices in Network Planning and Traffic Engineering

RIPE 61, Rome

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Outline

- Objective / Intro [CF]
- Traffic Matrix [CF]
  - pmacct [PL]
- Network Planning [TT]
- Optimization/Traffic Engineering [TT]
- Planning for LFA FRR [CF]
- IP/Optical Integration [CF]
- A final example [TT]
- Conclusion & References

Introduction & Objective

Objective

- SLA enforcement
  - expressed as loss, latency and jitter availability targets
- How is SLA monitored
  - PoP to PoP active probes
  - Per-link or per-class drops
- How to enforce
  - **Ensure that capacity exceeds demands frequently enough to achieve availability targets**
  - Highlight: catastrophic events (multiple non-SRLG failures) may lead to “planned” congestion. The planner decided not to plan enough capacity for this event as the cost of such a solution outweights the penality. A notion of probability and risk assessment is fundamental to efficient capacity planning.

Basic Capacity Planning

- Input
  - Topology
  - Routing Policy
  - QoS policy per link
  - Per-Class Traffic Matrix
- Output
  - Is Per-class Per-link OPF < a target threshold (e.g. 85%)?

    OPF: over-provisioning factor = load/capacity
- If yes
  then be happy
  else either modify inputs
  or the target output threshold
  or accept the violation

Topology

- Base topology is simple to collect
  - ISIS/OSPF LS Database
- Needs to generate all the “failure” what-if scenari
  - all the Link failures (simple)
  - all the Node failures (simple)
  - all the Srlg failures (complex)

    Shared fate on roadm, fiber, duct, bridge, building, city

    More details later

Routing Policy – Primary Paths

- ISIS/OSPF
  - Simple: Dijkstra based on link costs
- Dynamic MPLS-TE
  - Complex because non-deterministic
- Static MPLS-TE
  - Simple: the planning tool computes the route of each TE LSP

    It is “simple” from a planning viewpoint at the expense of much less flexibility (higher opex and less resiliency). There is no free lunch.

Routing Policy – Backup Paths

- ISIS/OSPF – Routing Convergence
  - Simple: Dijkstra based on link costs
- ISIS/OSPF - LFA FRR
  - Complex: the availability of a backup depends on the topology and the prefix, some level of non-determinism may exist when LFA tie-break does not select a unique solution
- Dynamic MPLS-TE – Routing Convergence
  - Complex because non-deterministic
- Dynamic MPLS-TE – MPLS TE FRR via a dynamic backup tunnel
  - Complex because the backup LSP route may not be deterministic
- Dynamic MPLS-TE – MPLS TE FRR via a static backup tunnel
  - Moderate: the planning tool computes the backup LSP route but which primary LSP's are on the primary interface may be non-deterministic
- Static MPLS-TE – MPLS TE FRR via static backup tunnel
  - Simple: the planning tool computes the route of each TE LSP (primary and backup) (reminder… there is a trade-off to this simplicity.

QoS policy per-link

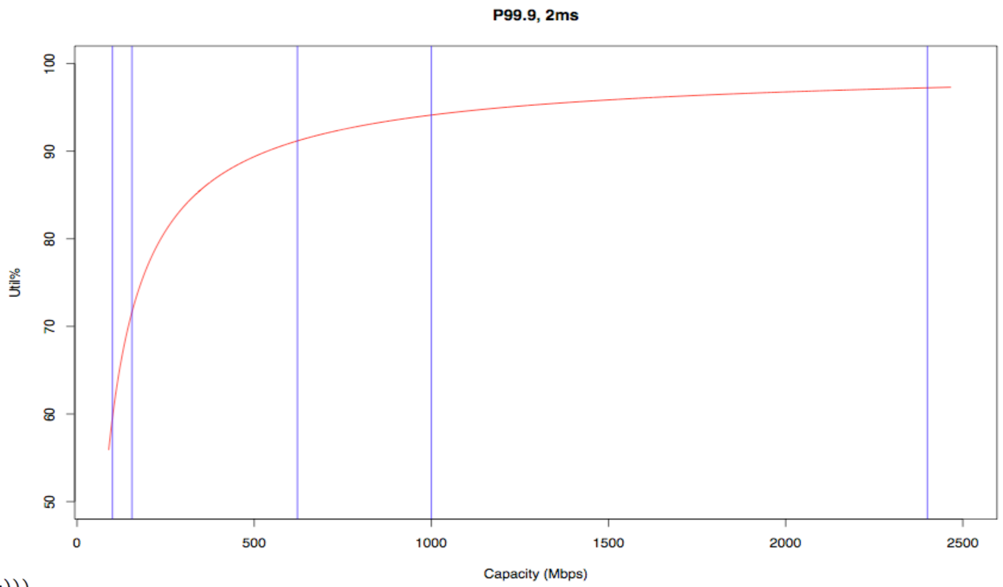
- Very simple because
  - the BW allocation policy is the same on all links
  - it very rarely changes
  - it very rarely is customized on a per link basis for tactical goal

Over-Provision Factor

- Area of research
- Common agreement that [80-90%] should be ok when underlying capacity is >10Gbps
  - with some implicit assumptions on traffic being a large mix of independent flows

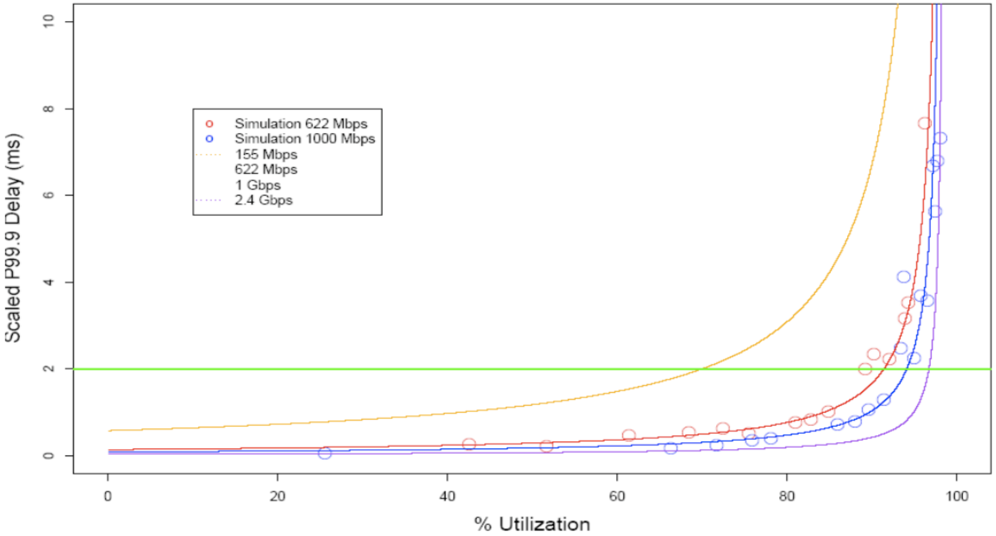
Over-Provision Factor – Research

- Bandwidth Estimation for Best-Effort Internet Traffic
  - Jin Cao, William S. Cleveland, and Don X. Sun
  - [Cao 2004]
- Data:
  - BELL, AIX, MFN, NZIX
- Best-Effort Delay Formula:



$$\mathrm{logit}_2(u) = o + (o_c + o_{\tau\delta}) \log_2(c) + o_{\tau\delta} \log_2(\gamma_b \delta) + o_\omega(-\log_2(-\log_2(\omega))).$$

- Similar queueing simulation results [Telkamp 2003/2009]:



Digression – Why QoS helps

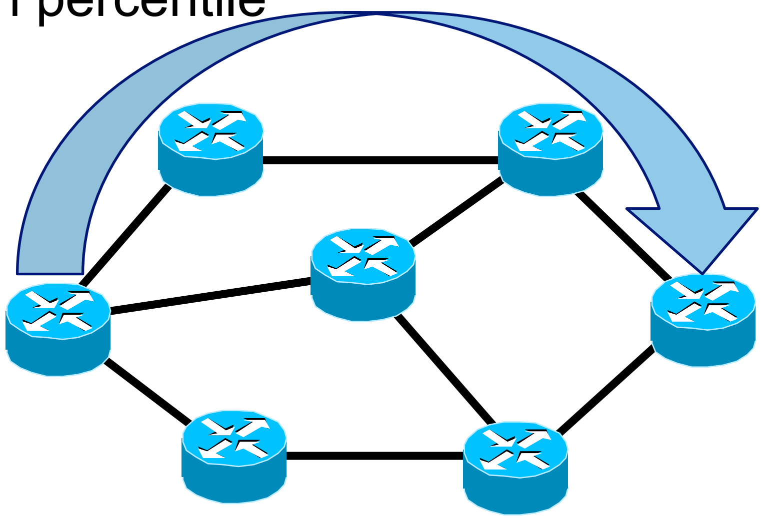
- Link = 10Gbps, Load 1 is 2Gbps, Load 2 is 6Gbps
- Class1 gets 90%, Class2 gets 10%, work-conservative scheduler
- Over-Provisioning Factor (Class1) = 2/9 = 22% <<<< 85% (no risk!)
- OPF (Class2) = 6/8 = 75% and actually even worse if Class1 gets more loaded then expected. Much closer to the 85% target and hence much more risky!
- But fine because the availability target for Class2 is much looser than Class1 (eg. 99% vs 99.999%)

- QoS allows to create excellent OPF for the Tightest-SLA classes at the expense of the loosed-SLA classes.
- More details in [Filsfils and Evans 2005] and in [Deploy QoS]

Traffic Matrix

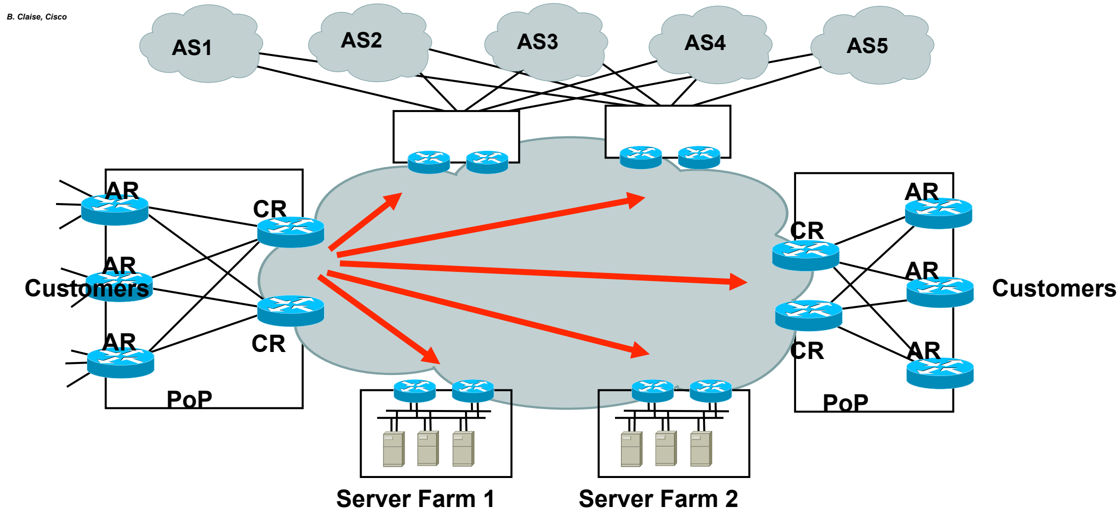
Traffic Demand Matrix

- Traffic demands define the amount of data transmitted between each pair of network nodes
  - Typically per Class
  - Typically peak traffic or a very high percentile
  - Measured, estimated or deduced



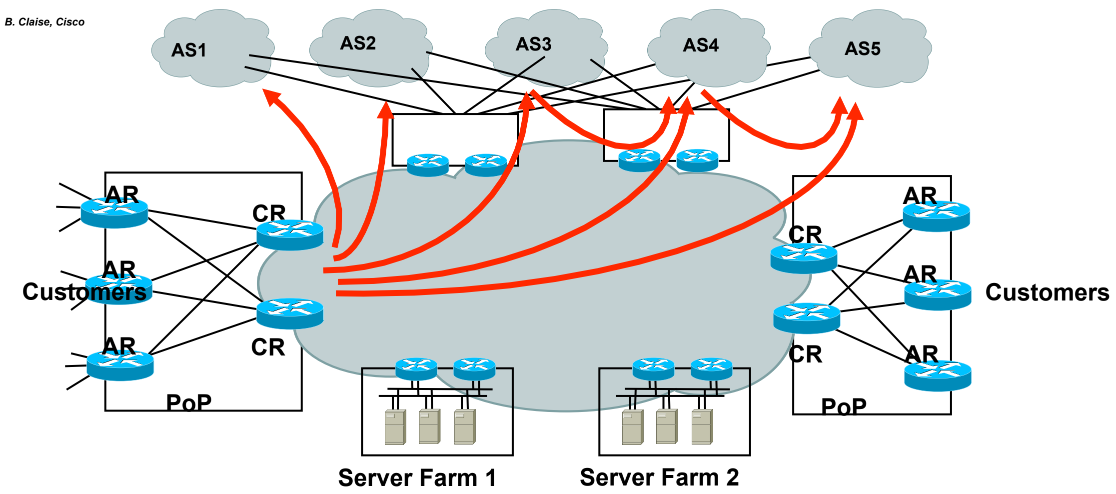
Internal Traffic Matrix

- POP to POP, AR-to-AR or CR-to-CR



External Traffic Matrix

- Router (AR or CR) to External AS or External AS to External AS (for transit providers)
- Useful for analyzing the impact of external failures on the core network
- Peer-AS sufficient for capacity planning and resilience analysis, See RIPE presentation on peering planning [Telkamp 2006]



Internal Traffic Matrix Collection

- LDP MIB
  - miss per-class information
- TE mesh
  - miss per-class information (except if multiple meshes for each class, very rare today)
  - opex implication of operating a TE mesh

Internal Traffic Matrix Collection

- Netflow v9
  - aggregated (BGP nhop, Class)
  - My 0,02 euro, the best option

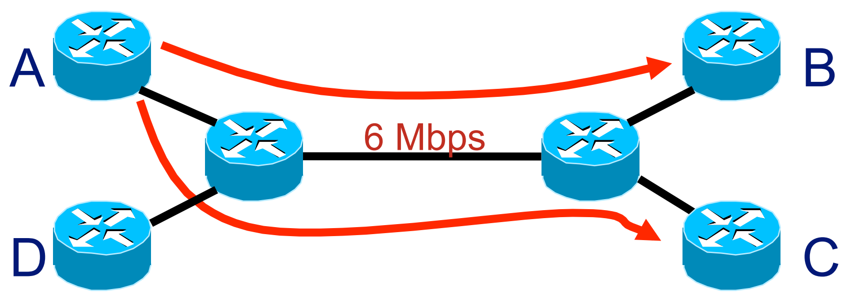
    Netflow analysis is needed for many other reasons (security, peering strategy, traffic knowledge)

    CoS ready

    Simple extension to compute External Traffic Matrix

Demand Estimation

- Goal: Derive Traffic Matrix (TM) from easy to measure variables
- Problem: Estimate point-to-point demands from measured link loads
- Underdetermined system:
  - N nodes in the network
  - O(N) links utilizations (known)
  - O(N2) demands (unknown)
  - Must add additional assumptions (information)
- Many algorithms exist:
  - Gravity model
  - Iterative Proportional Fitting (Kruithof's Projection)
  - … etc
- Estimation background: network tomography, tomogravity*, etc.
  - Similar to: Seismology, MRI scan, etc.
  - [Vardi 1996]
  - * [Zhang et al, 2004]



y: link utilizations

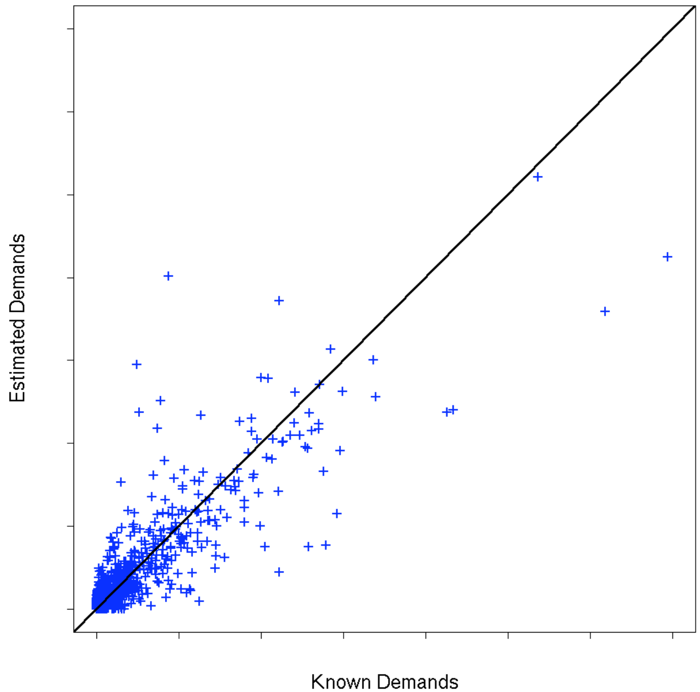
A: routing matrix

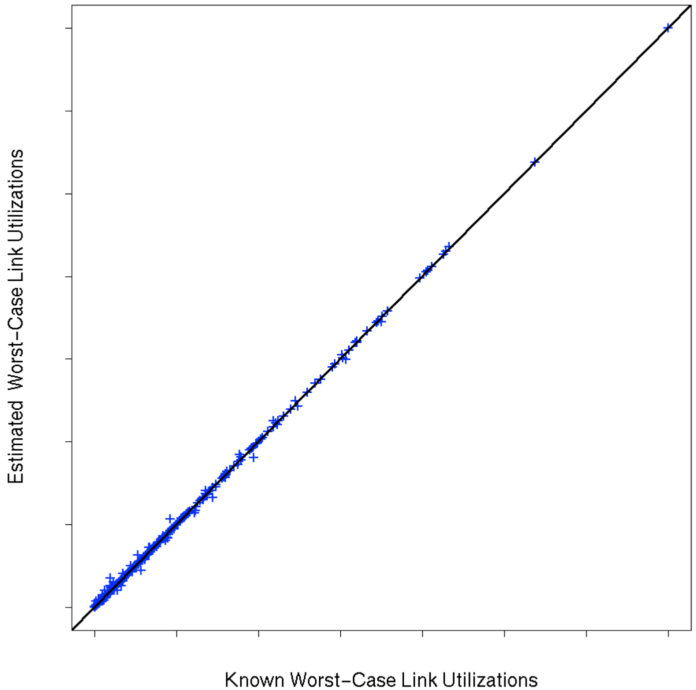
x: point-to-point demands

Solve: <u>y = Ax</u> -> In this example: <u>6 = AB + AC</u>

Calculate the **most likely** Traffic Matrix

Demand Estimation Results



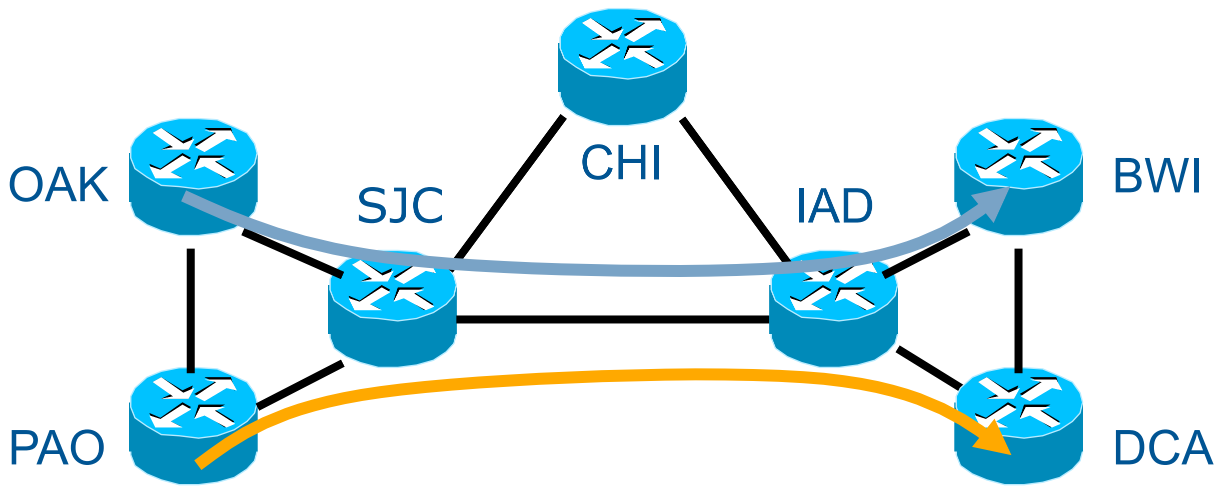


- Individual demand estimates can be inaccurate
- Using demand estimates in failure case analysis is accurate

See also [Zhang et al, 2004]: "How to Compute Accurate Traffic Matrices for Your Network in Seconds"

Results show similar accuracy for AT&T IP backbone (AS 7018)

Estimation Paradox Explained



- Hard to tell apart elements
  - OAK->BWI, OAK->DCA, PAO->BWI, PAO->DCA, similar routings
- Are likely to shift as a group under failure or IP TE
  - e.g., above all shift together to route via CHI under SJC-IAD failure

Forecasted Traffic Matrix

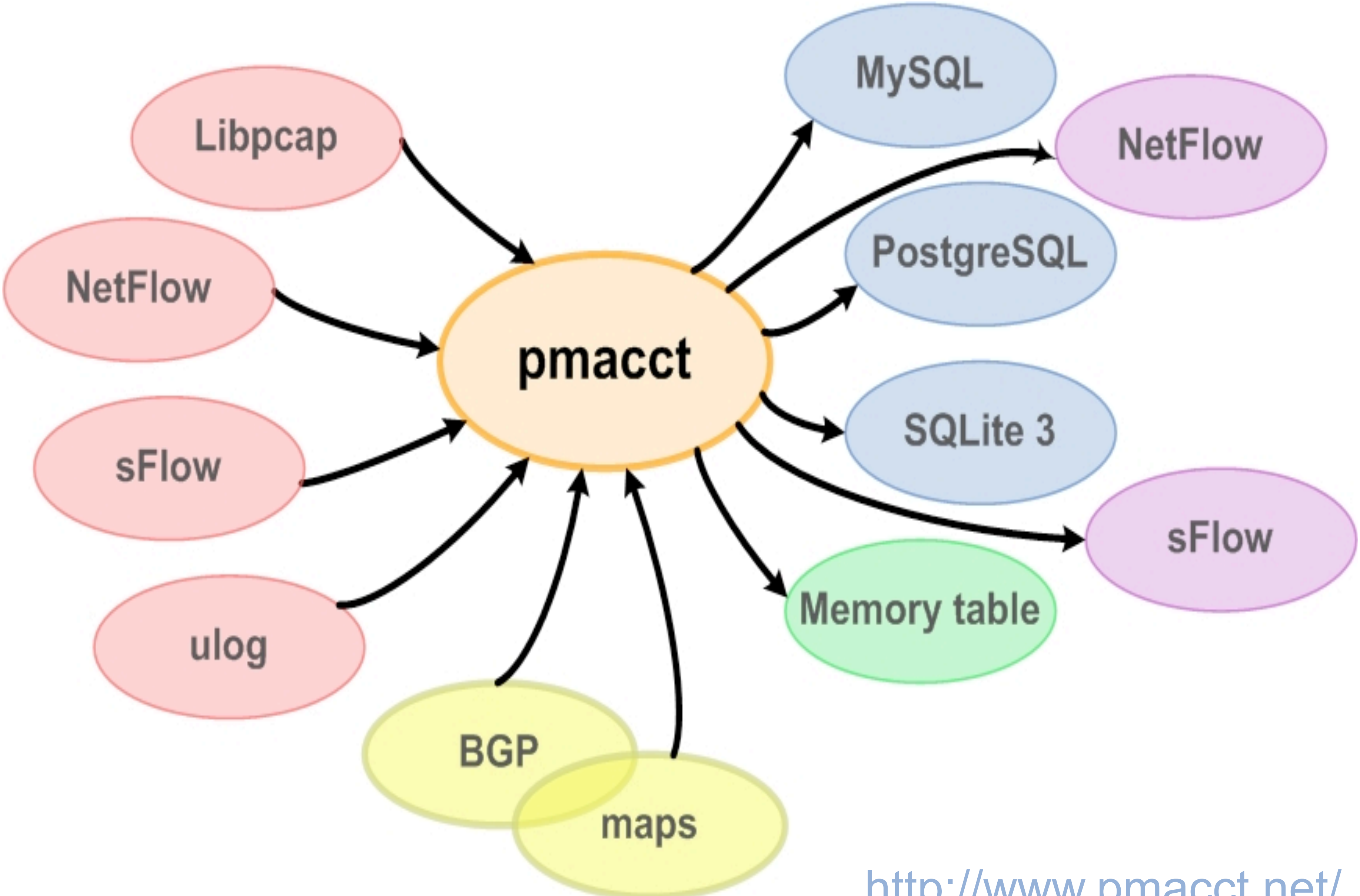
- DWDM provisioning has been slow up to now
  - this will change, see later
- Capacity Planning needs to anticipate growth to add bandwidth ahead of time
  - the slow DWDM provisioning is one of the key reasons why some IP/MPLS networks look “not hot” enough
- Typical forecast is based on compound growth
- Highlight: planning is based on the forecasted TM based on a set of collected TM’s

Regressed Measurements

- Interface counters remain the most reliable and relevant statistics
- Collect LSP, Netflow, etc. stats as convenient
  - Can afford partial coverage
    (e.g., one or two big PoPs)
  - more sparse sampling
    (1:10000 or 1:50000 instead of 1:500 or 1:1000)
  - less frequent measurements
    (hourly instead of by the minute)
- Use regression (or similar method) to find TM that conforms primarily to interface stats but is guided by NetFlow, LSP stats, etc.

pmacct

pmacct is open-source, free, GPL'ed software



http://www.pmacct.net/

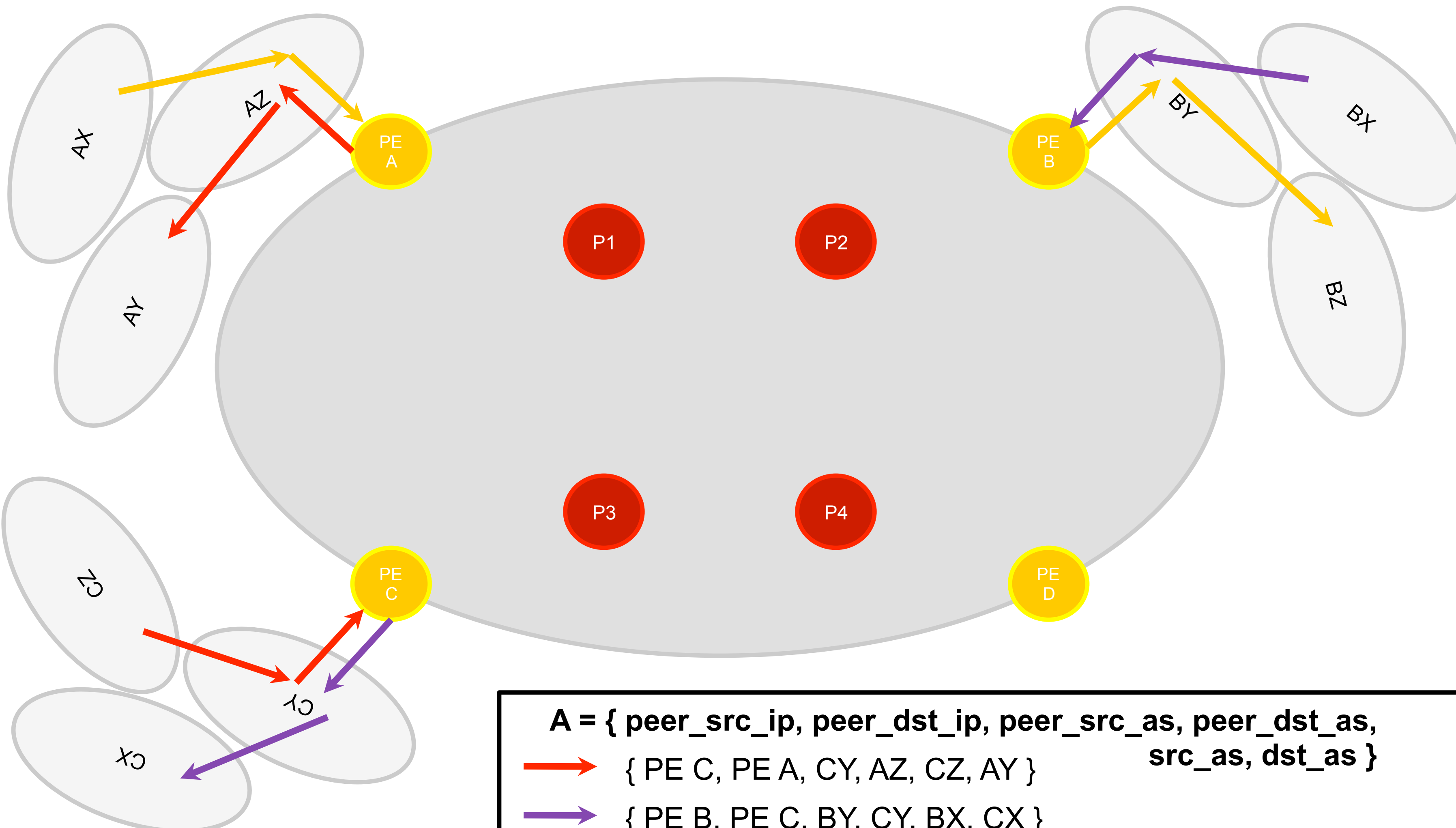
The BGP peer who came from NetFlow (and sFlow)

- pmacct introduces a Quagga-based BGP daemon
  - Implemented as a parallel thread within the collector
  - Maintains per-peer BGP RIBs
- Why BGP at the collector?
  - Telemetry reports on forwarding-plane
  - Telemetry should not move control-plane information over and over
- Basic idea: join routing and telemetry data:
  - Telemetry agent address == BGP source address/RID

Telemetry export models for capacity planning and TE

- PE routers: ingress-only at edge interfaces + BGP:
  - Traffic matrix for end-to-end view of traffic patterns
  - Borders (customers, peers and transits) profiling
  - Coupled with IGP information to simulate and plan failures (**strategic solution**)
- P, PE routers: ingress-only at core interfaces:
  - Traffic matrices for local view of traffic patterns
  - No routing information required
  - **Tactical solution** (the problem has already occurred)

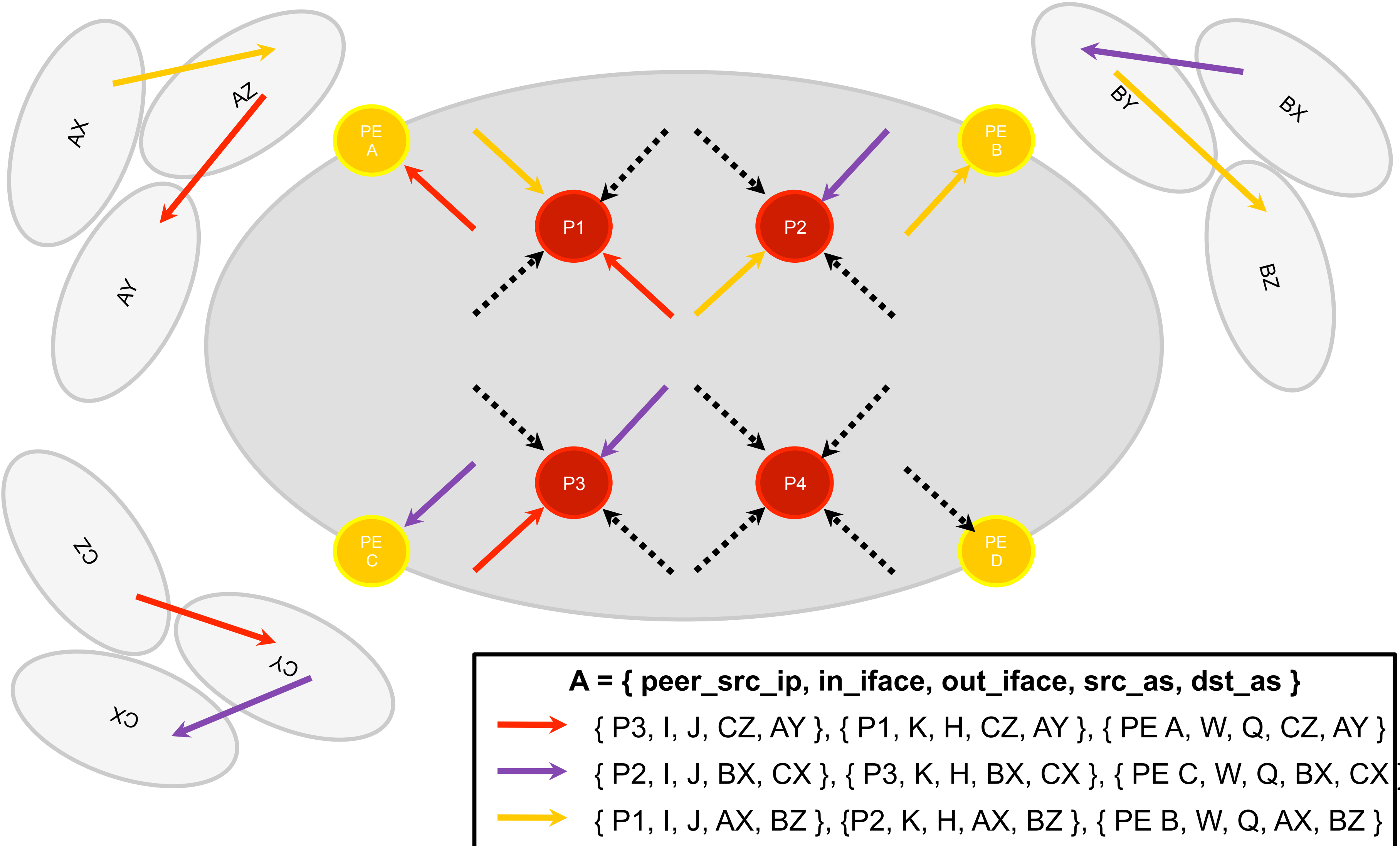
PE routers: telemetry ingress-only at edge interfaces + BGP illustrated



A = { peer_src_ip, peer_dst_ip, peer_src_as, peer_dst_as, src_as, dst_as }

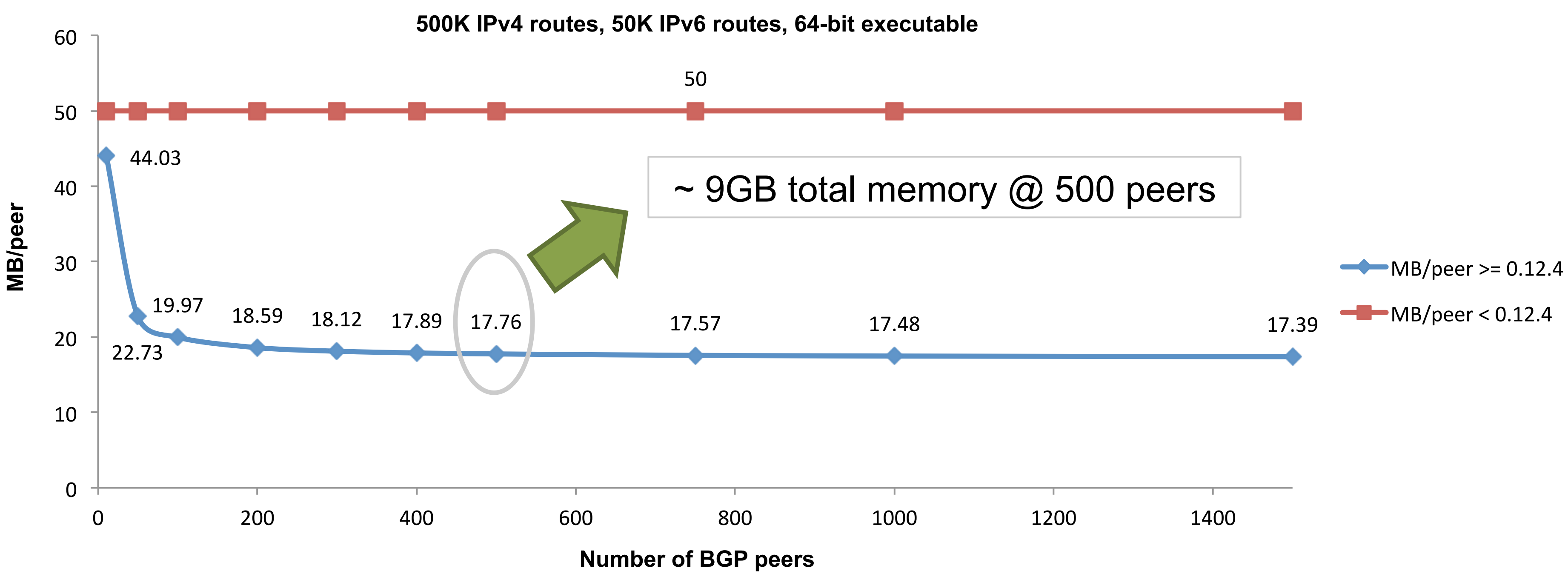
- { PE C, PE A, CY, AZ, CZ, AY }
- { PE B, PE C, BY, CY, BX, CX }
- { PE A, PE B, AZ, BY, AX, BZ }

P, PE routers: telemetry ingress-only at core interfaces illustrated



Scalability: BGP peering

- The collector BGP peers with all PEs
- Determine memory footprint (below in MB/peer)

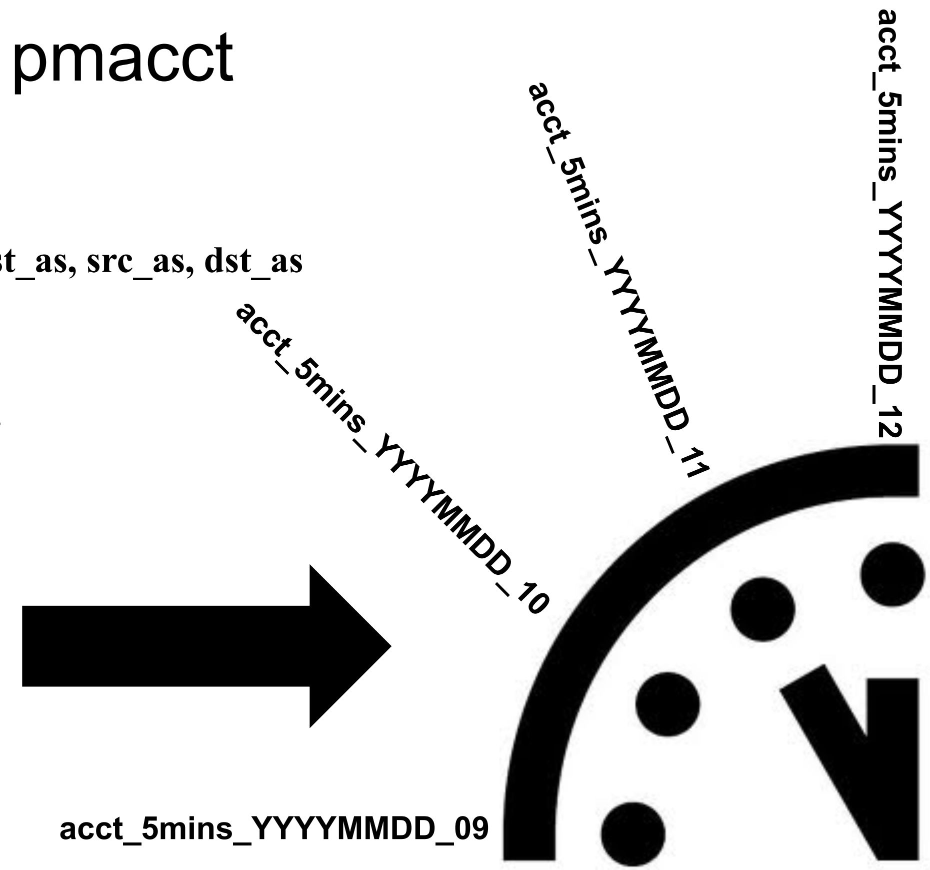


Scalability: aggregation and temporal grouping

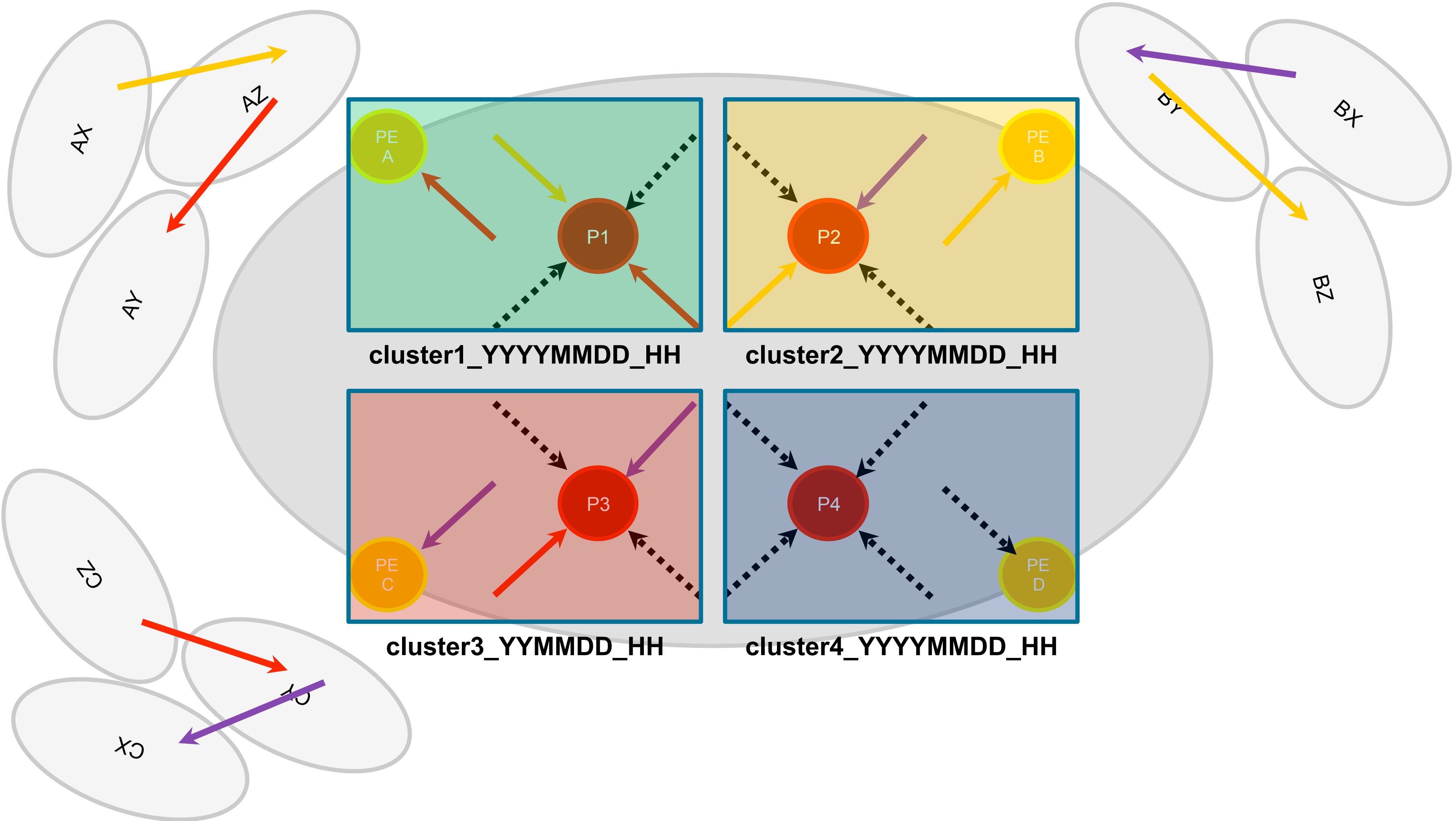
– Flexible spatial and temporal aggregation is:
  - Essential element to large-scale sustainability
  - Original idea underlying pmacct

```
xacctd.conf:
…
aggregate: peer_src_ip, peer_dst_ip, peer_src_as, peer_dst_as, src_as, dst_as
sql_history: 5m
```

```
acct_5mins_%Y%m%d_%H (
  id int(4) unsigned NOT NULL AUTO_INCREMENT,
  as_src int(4) unsigned NOT NULL,
  as_dst int(4) unsigned NOT NULL,
  peer_as_src int(4) unsigned NOT NULL,
  peer_as_dst int(4) unsigned NOT NULL,
  peer_ip_src char(15) NOT NULL,
  peer_ip_dst char(15) NOT NULL,
  packets int(10) unsigned NOT NULL,
  bytes bigint(20) unsigned NOT NULL,
  stamp_inserted datetime NOT NULL,
  stamp_updated datetime DEFAULT NULL,
  [ … ] );
```



Scalability: spatial grouping



Still on scalability

- A single collector might not fit it all:
  - Memory: can’t store all BGP full routing tables
  - CPU: can’t cope with the pace of telemetry export
  - Divide-et-impera approach is valid:
    - Assign routing elements (telemetry and BGP) to collectors
    - Assign collectors to RDBMSs; or cluster the RDBMS.
- Matrices can get big, but can be reduced:
  - Keep smaller routers out of the equation
  - Filter out specific services/customers on dense routers
  - Focus on relevant traffic direction (ie. upstream if CDN, downstream if ISP)
  - Increase sampling rate

Downloading traffic matrices

– Strategic CP/TE solution traffic matrix:

```
SELECT peer_ip_src, peer_ip_dst, peer_as_src, peer_as_dst, bytes,
stamp_inserted

FROM <table>

WHERE stamp_inserted = < today | last hour | last 5 mins >

[ GROUP BY … ];
```

– Tactical CP/TE solution traffic matrix k (1 <= k <= N, N = # observed interfaces):

```
SELECT peer_ip_src, iface_in, iface_out, as_src, as_dst, bytes,
stamp_inserted

FROM <table>

WHERE peer_ip_src = < Pi | PEj > AND

    iface_in = k AND

     stamp_inserted = < today | last hour | last 5 mins >

[ GROUP BY … ];
```

Further information

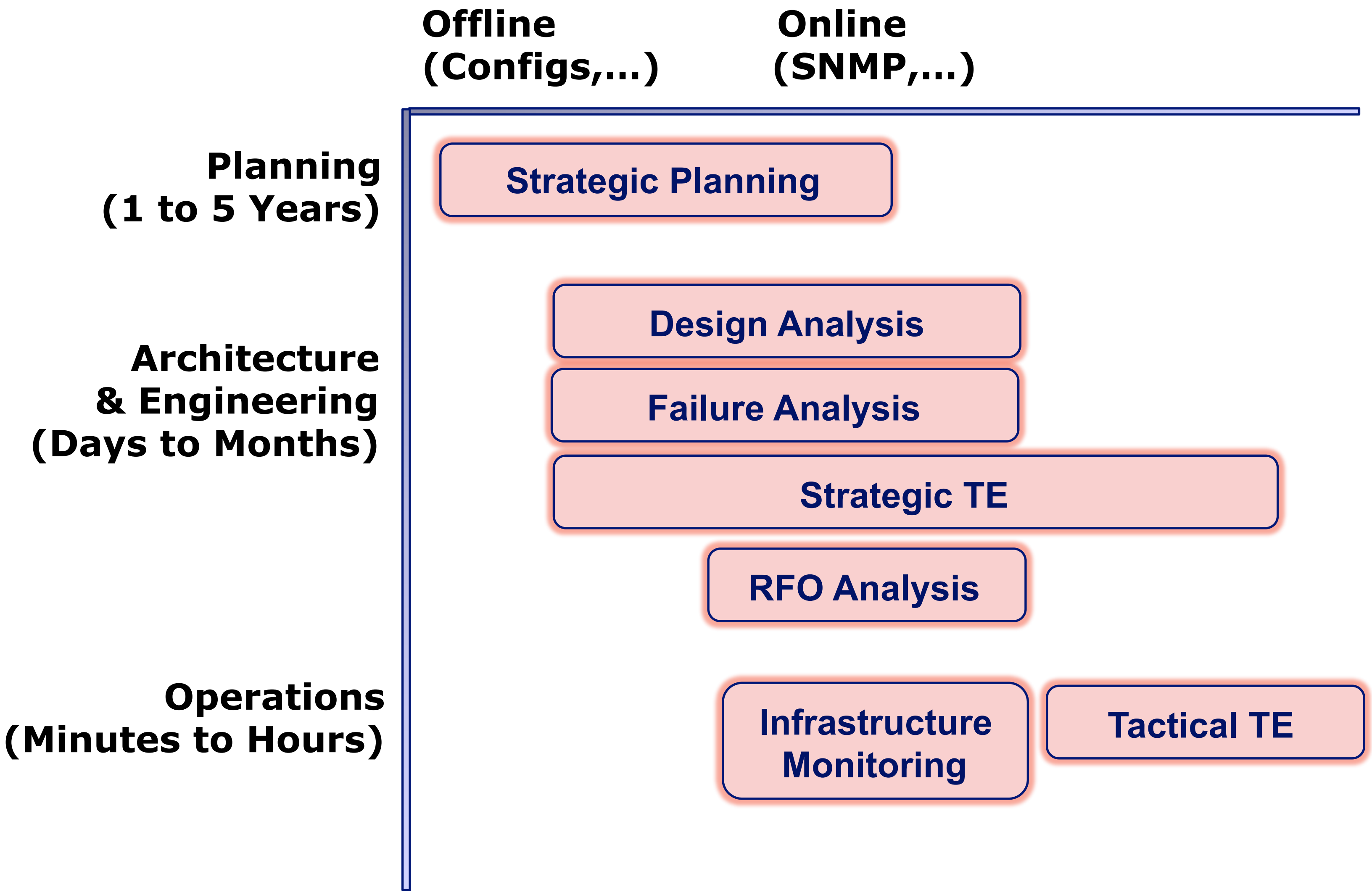
– http://www.pmacct.net/lucente_pmacct_uknof14.pdf
  - AS-PATH radius, Communities filter, asymmetric routing
  - Entities on the provider IP address space
  - Auto-discovery and automation

– http://www.pmacct.net/building_traffic_matrices_n49.pdf
  http://www.pmacct.net/pmacct_peering_epf5.pdf
  - Building traffic matrices to support peering decisions

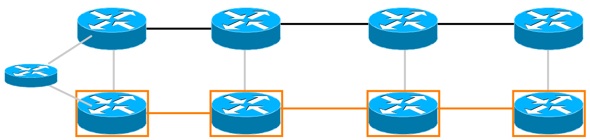
– http://wiki.pmacct.net/OfficialExamples
  - Quick-start guide to setup a NetFlow/sFlow+BGP collector instance, implementation notes, etc.

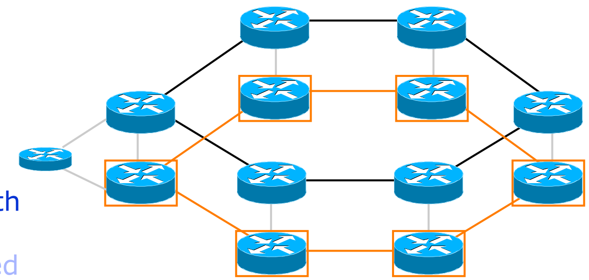
Network Planning

Comprehensive Traffic Management



Common & Wasteful (Core Topologies)



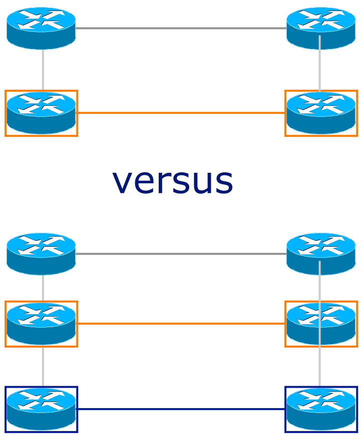


Blue is one physical path
Orange is another path
Edge is dually connected

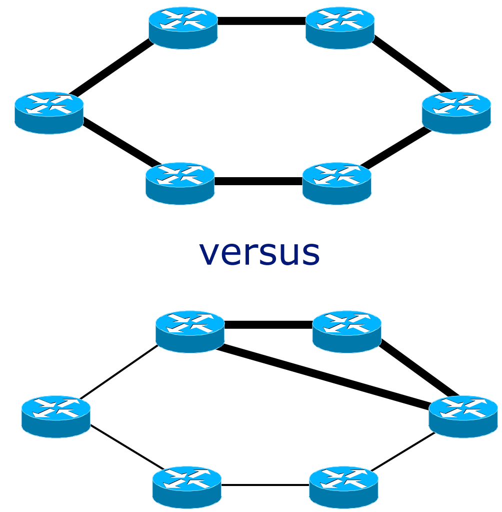
- Link capacity at each ladder section set as twice traffic in that section
- 1:1 protection: 50% of infrastructure for backup

- Ring is upgraded en masse even if one side empty
- Hard to add a city to the core, bypasses (express links) avoided because of complexity
- 1:1. And some infrastructure lightly used

N:1 Savings



- **1:1 Protection**
  $100 carrying capacity requires $200 expenditure
- **2:1**
  $100 carrying capacity requires $150 expenditure
- 15%-20% in practice
- E.g. national backbone costing $100M (capex+opex) saves $15M-$20M



- Instead of upgrading all elements upgrade the bottleneck
- Put in express route in bottleneck region
- 10%-20% savings are common

N:1 Costs

- Physical diversity not present/cheap
  - However, usually present at high traffic points (e.g., no diversity in far away provinces but yes in capital regions)
- Engineering/architecture considerations
  - E.g., how effectively balance traffic
- Planning considerations

  → Subject of this talk

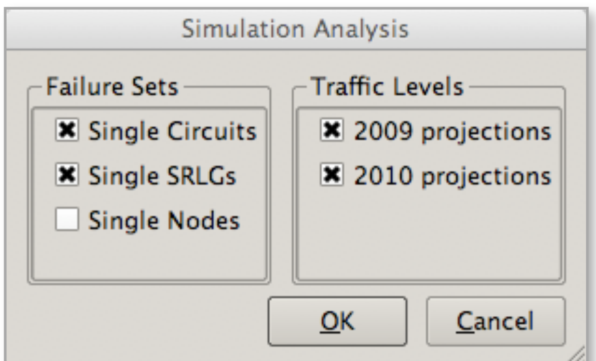
Planning Methodologies

- Monitoring per link statistics doesn't cut it
- Planning needs to be topology aware
- Failure modes should be considered
- Blurs old boundaries between planning, engineering and operations

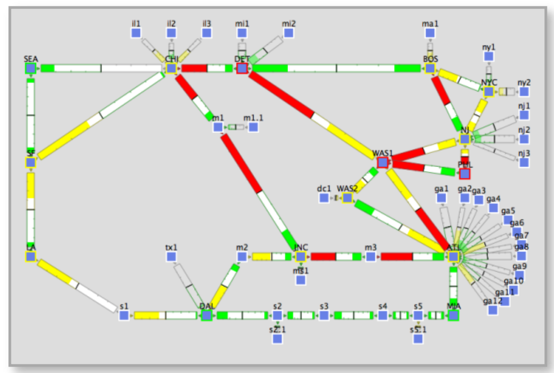
Failure Planning

Scenario: Planning receives traffic projections, wants to determine what buildout is necessary

Simulate using external traffic projections



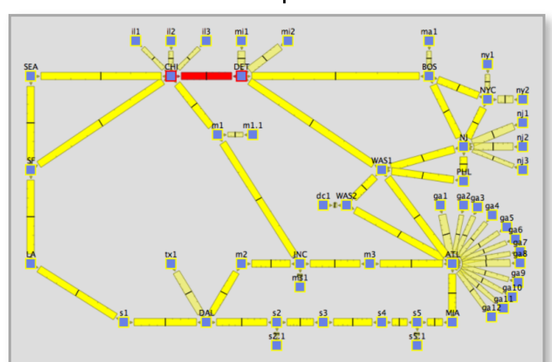
Worst case view



Potential congestion under failure in **RED**

Perform topology What-If analysis

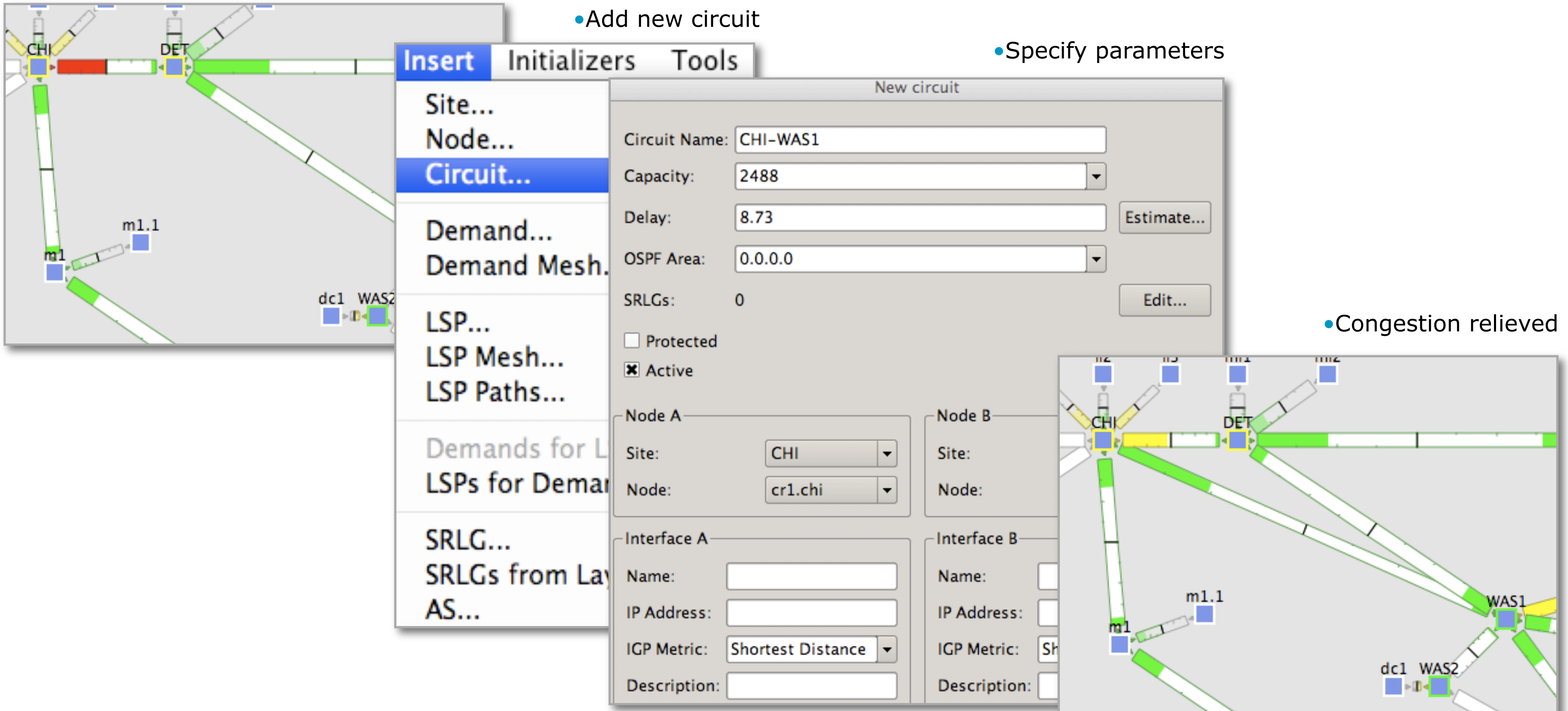
Failure impact view



Failure that can cause congestion in **RED**

Topology What-If Analysis

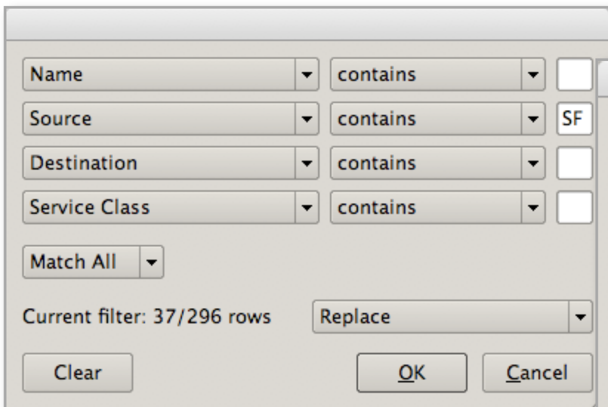
Scenario: Congestion between CHI and DET



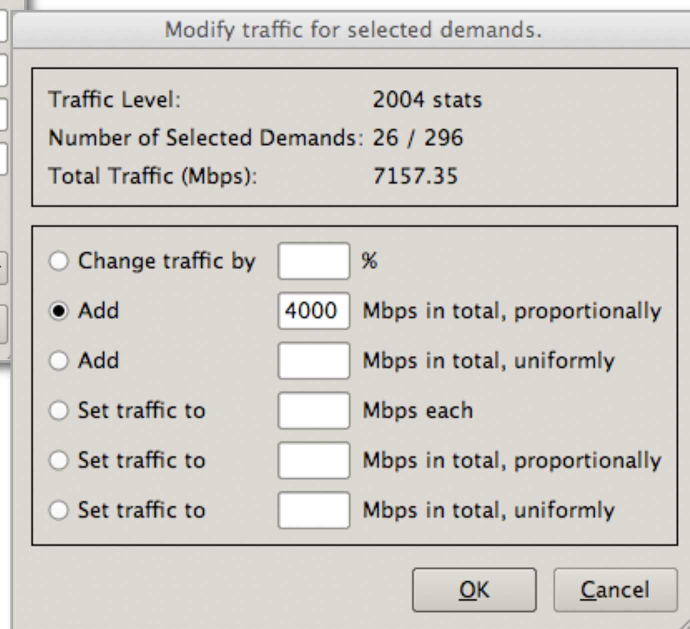
Evaluate New Services, Growth,…

Scenario: Product marketing expects 4 Gbps growth in SF based on some promotion

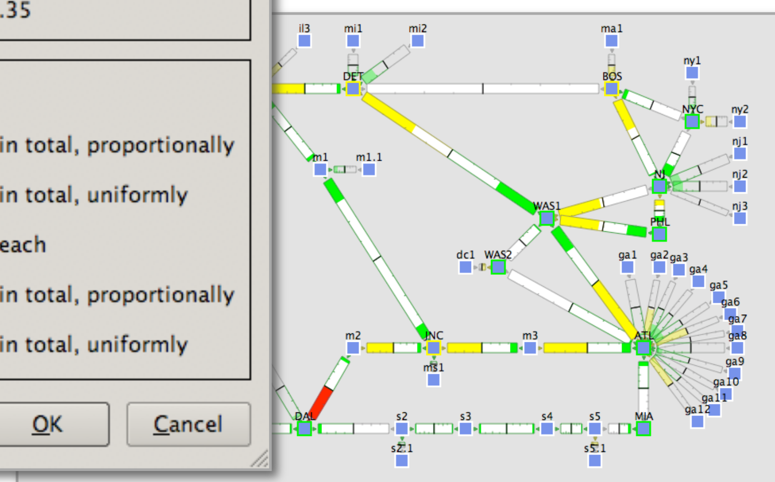
- Identify flows for new customer



- Add 4Gbps to those flows



- Simulate results



- Congested link in **RED**

Optimization/ Traffic Engineering

Network Optimization

- Network Optimization encompasses network engineering and traffic engineering
  - Network engineering

    Manipulating your network to suit your traffic
  - Traffic engineering

    Manipulating your traffic to suit your network

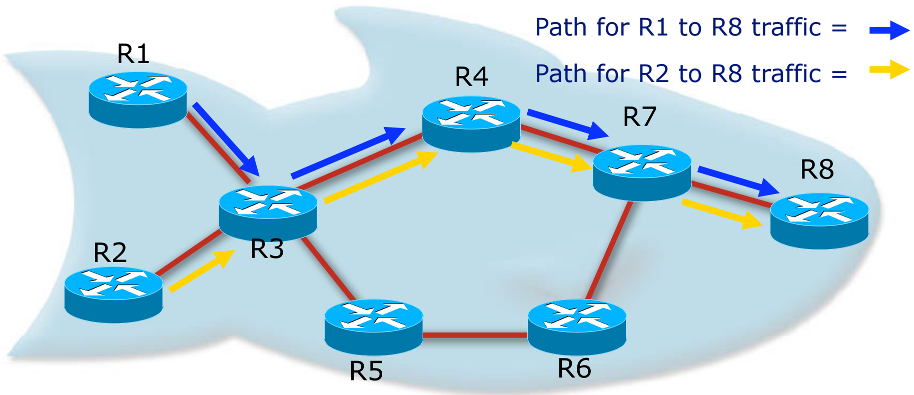
- Whilst network optimization is an optional step, all of the preceding steps are essential for:
  - Comparing network engineering and TE approaches
  - MPLS TE tunnel placement and IP TE

Network Optimization: Questions

- What optimization objective?
- Which approach?
  - IGP TE or MPLS TE
- Strategic or tactical?
- How often to re-optimise?
- If strategic MPLS TE chosen:
  - Core or edge mesh
  - Statically (explicit) or dynamically established tunnels
  - Tunnel sizing
  - Online or offline optimization
  - Traffic sloshing

IP Traffic Engineering: The Problem

- Conventional IP routing uses pure destination-based forwarding where path computation is based upon a simple additive metric
  - Bandwidth availability is not taken into account



- Some links may be congested while others are underutilized
- The traffic engineering problem can be defined as an optimization problem
  - Definition – "*optimization problem*": A computational problem in which the objective is to find the best of all possible solutions

    ➔ Given a fixed topology and a fixed source-destination matrix of traffic to be carried, what routing of flows makes most effective use of aggregate or per class (Diffserv) bandwidth?

    ➔ How do we define most effective … ?

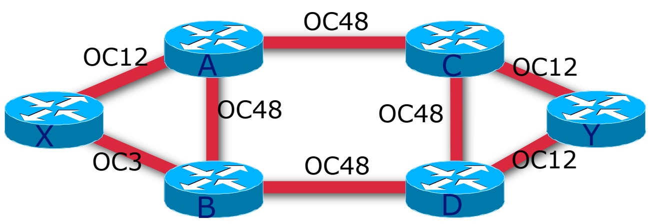
    ➔ Maximum Flow problem [MAXFLOW]

IP Traffic Engineering: The objective

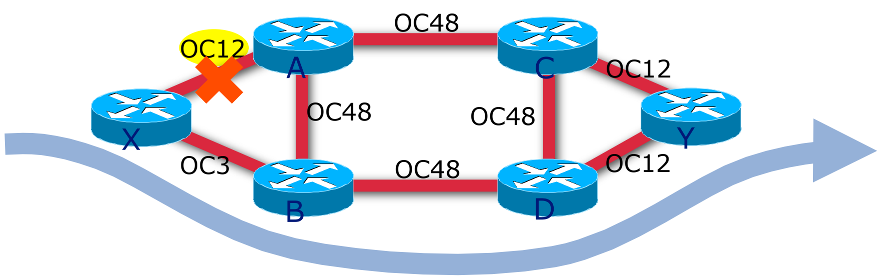
- What is the primary optimization objective?
  - Either …

    minimizing maximum utilization in normal working (non-failure) case
  - Or …

    minimizing maximum utilization under single element failure conditions
- Understanding the objective is important in understanding where different traffic engineering options can help and in which cases more bandwidth is required
  - Other optimization objectives possible: e.g. minimize propagation delay, apply routing policy …
- Ultimate measure of success is cost saving

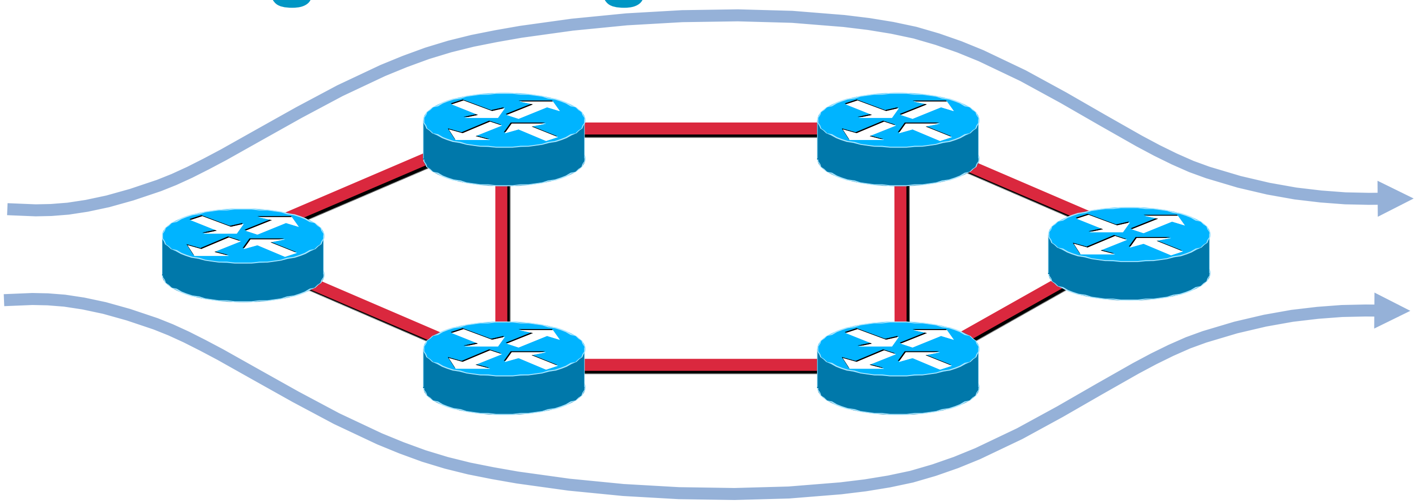


- In this asymmetrical topology, if the demands from X➔Y > OC3, traffic engineering can help to distribute the load when all links are working



- However, in this topology when optimization goal is to minimize bandwidth for single element failure conditions, if the demands from X➔Y > OC3, TE cannot help - must upgrade link X➔B

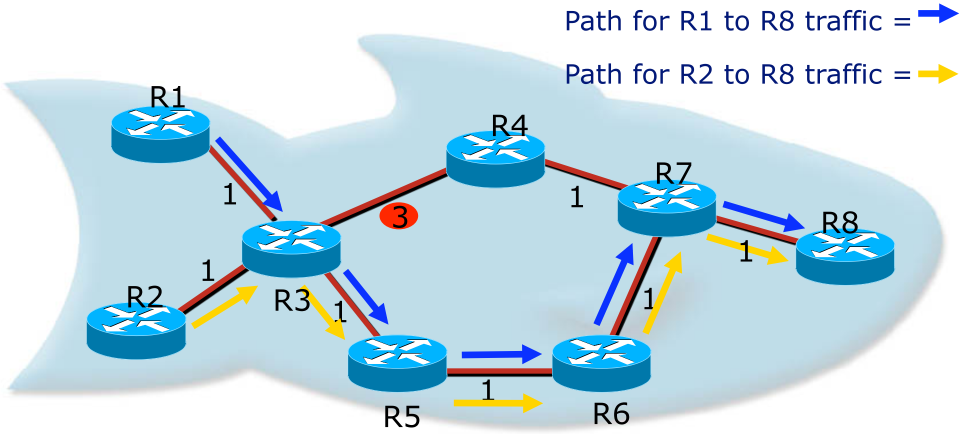
Traffic Engineering Limitations



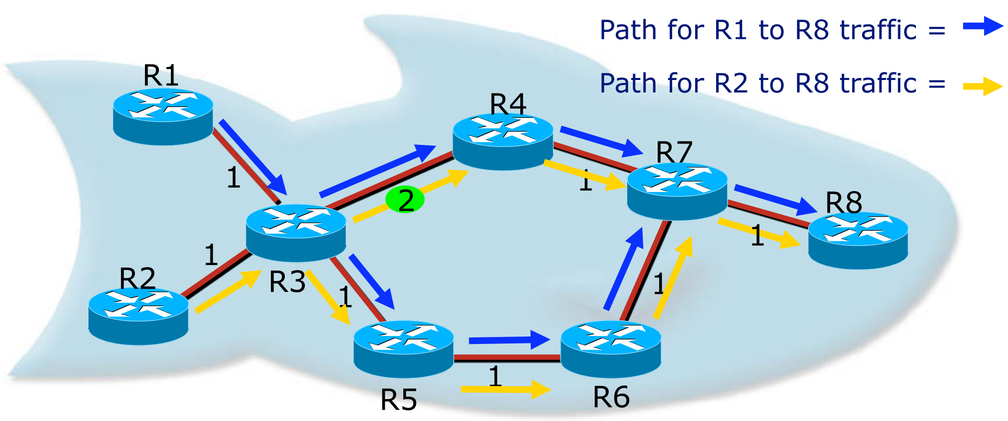
- TE cannot create capacity
  - e.g. “V-O-V” topologies allow no scope strategic TE if optimizing for failure case
    - Only two directions in each “V” or “O” region – no routing choice for minimizing failure utilization
- Other topologies may allow scope for TE in failure case
  - As case study later demonstrates

IGP metric-based traffic engineering

- … but changing the link metrics will just move the problem around the network?



- … the mantra that tweaking IGP metrics just moves problem around is not generally true in practise
  - Note: IGP metric-based TE can use ECMP

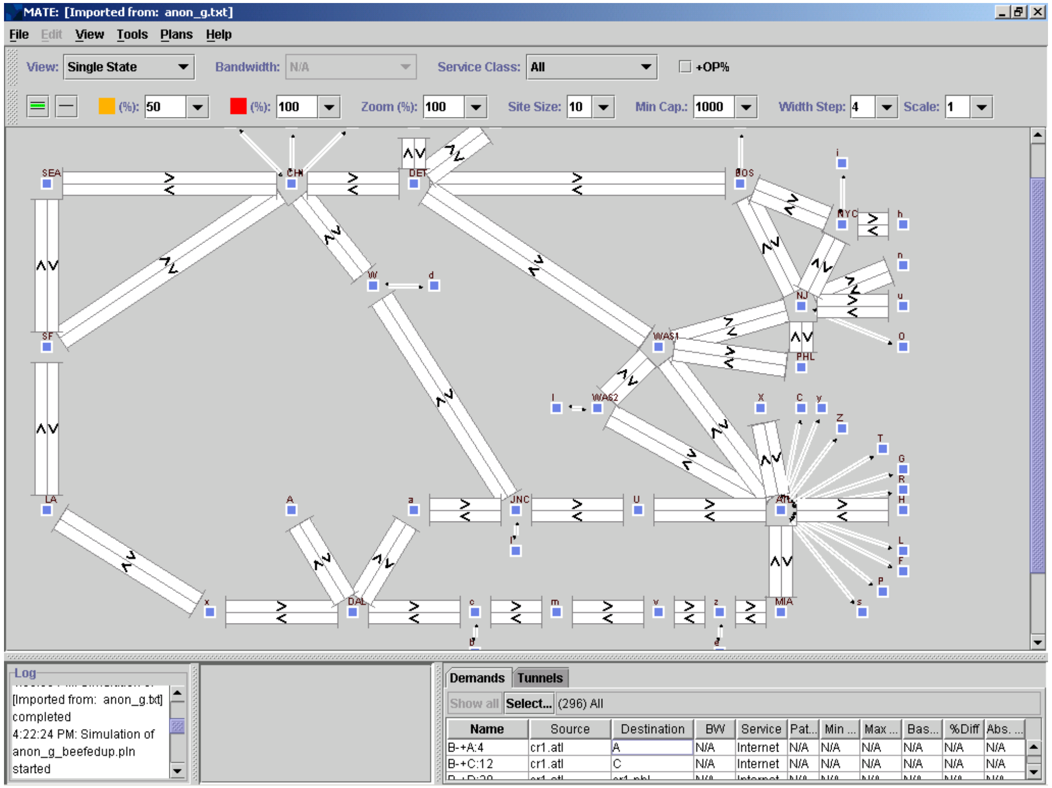


IGP metric-based traffic engineering

- Significant research efforts ...
  - B. Fortz, J. Rexford, and M. Thorup, "Traffic Engineering With Traditional IP Routing Protocols", IEEE Communications Magazine, October 2002.
  - D. Lorenz, A. Ordi, D. Raz, and Y. Shavitt, "How good can IP routing be?", DIMACS Technical, Report 2001-17, May 2001.
  - L. S. Buriol, M. G. C. Resende, C. C. Ribeiro, and M. Thorup, "A memetic algorithm for OSPF routing" in Proceedings of the 6th INFORMS Telecom, pp. 187188, 2002.
  - M. Ericsson, M. Resende, and P. Pardalos, "A genetic algorithm for the weight setting problem in OSPF routing" J. Combinatorial Optimization, volume 6, no. 3, pp. 299-333, 2002.
  - W. Ben Ameur, N. Michel, E. Gourdin et B. Liau. Routing strategies for IP networks. Telektronikk, 2/3, pp 145-158, 2001.
  - …

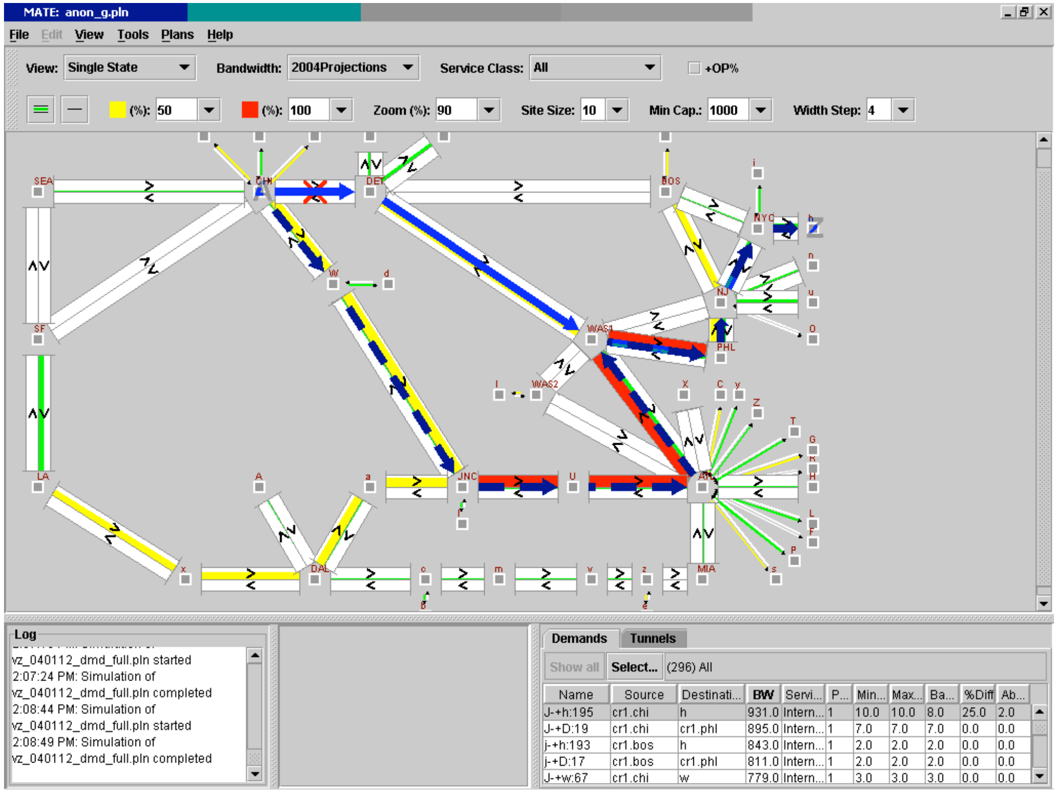
IGP metric-based traffic engineering: Case study

- Proposed OC-192 U.S. Backbone
- Connect Existing Regional Networks
- Anonymized (by permission)



Metric TE Case Study: Plot Legend

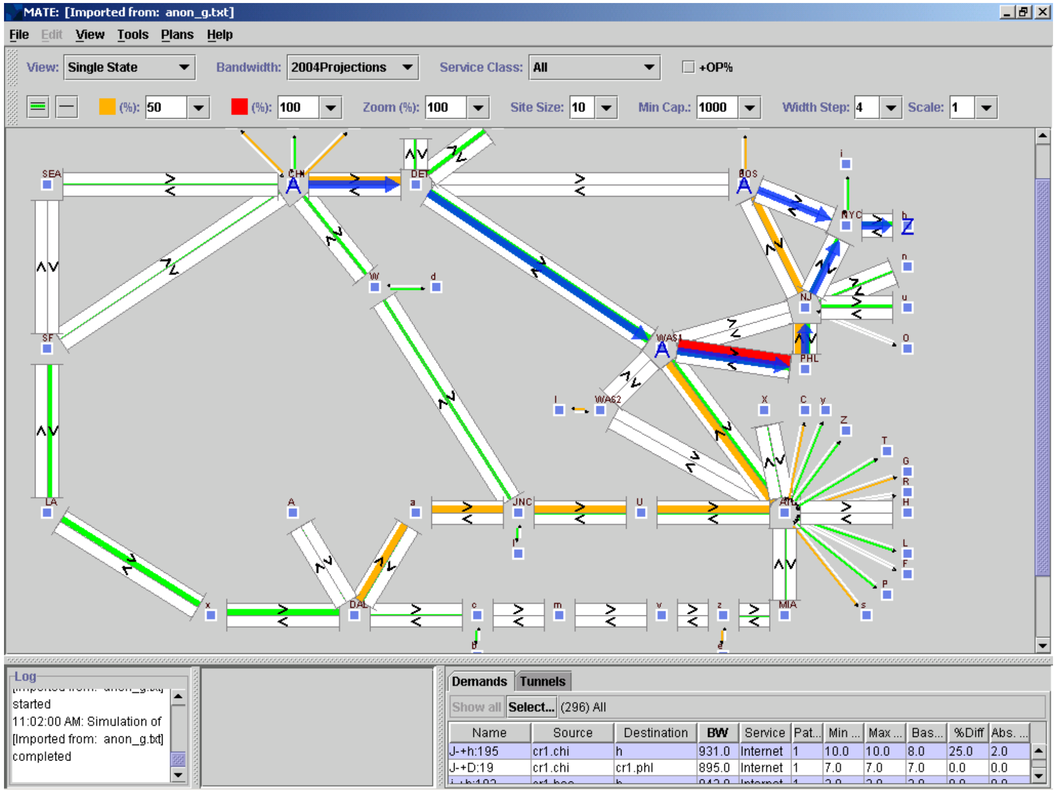
- Squares ~ Sites (PoPs)
- Routers in Detail Pane (not shown here)
- Lines ~ Physical Links
  - Thickness ~ Speed
  - Color ~ Utilization
    - Yellow ≥ 50%
    - Red ≥ 100%
- Arrows ~ Routes
  - Solid ~ Normal
  - Dashed ~ Under Failure
- X ~ Failure Location



Name	Source	Destinati...	BW	Servi...	P...	Min...	Max...	Ba...	%Diff	Ab...
J-+h:195	cr1.chi	h	931.0	Intern...	1	10.0	10.0	8.0	25.0	2.0
J-+D:19	cr1.chi	cr1.phl	895.0	Intern...	1	7.0	7.0	7.0	0.0	0.0
j-+h:193	cr1.bos	h	843.0	Intern...	1	2.0	2.0	2.0	0.0	0.0
j-+D:17	cr1.bos	cr1.phl	811.0	Intern...	1	2.0	2.0	2.0	0.0	0.0
J-+w:67	cr1.chi	w	779.0	Intern...	1	3.0	3.0	3.0	0.0	0.0

Metric TE Case Study: Traffic Overview

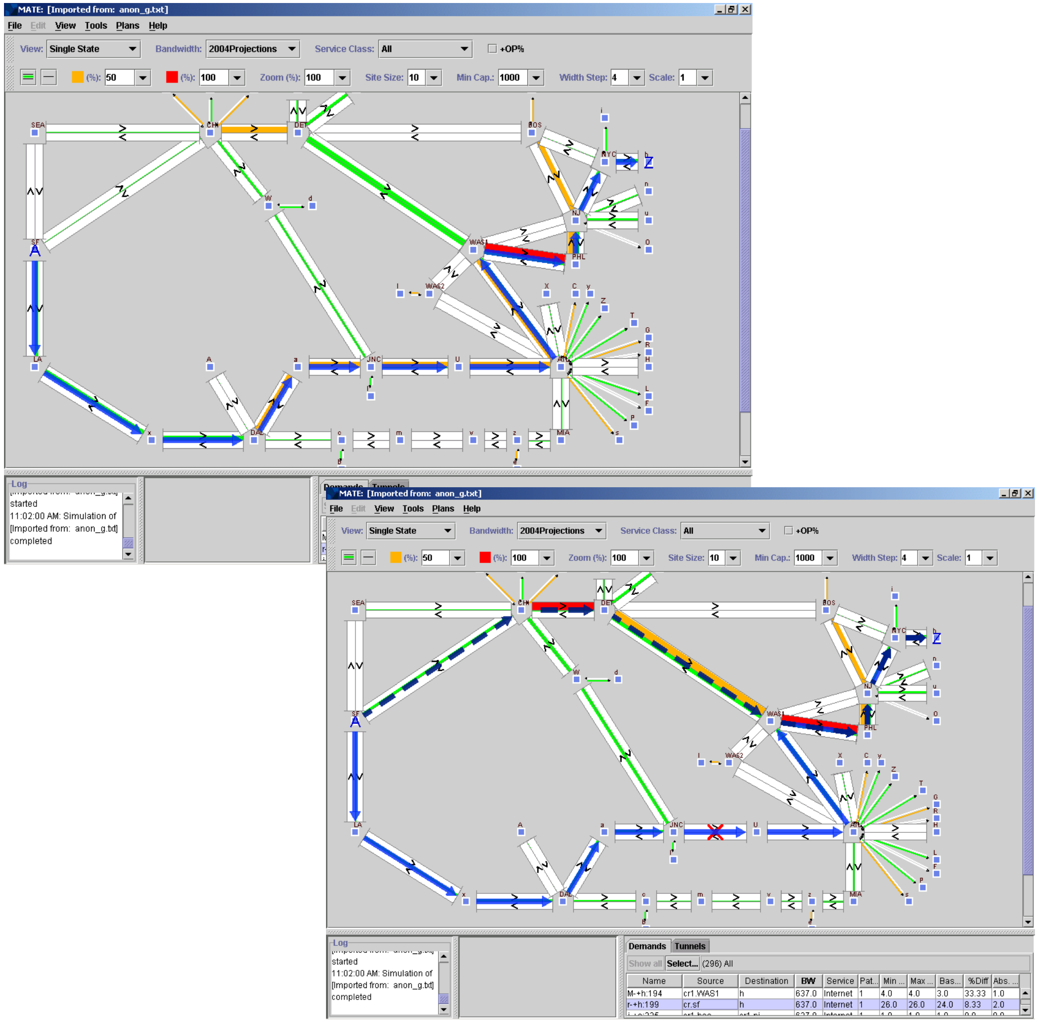
- Major Sinks in the Northeast
- Major Sources in CHI, BOS, WAS, SF
- Congestion Even with No Failure



Metric TE Case Study:
Manual Attempt at Metric TE

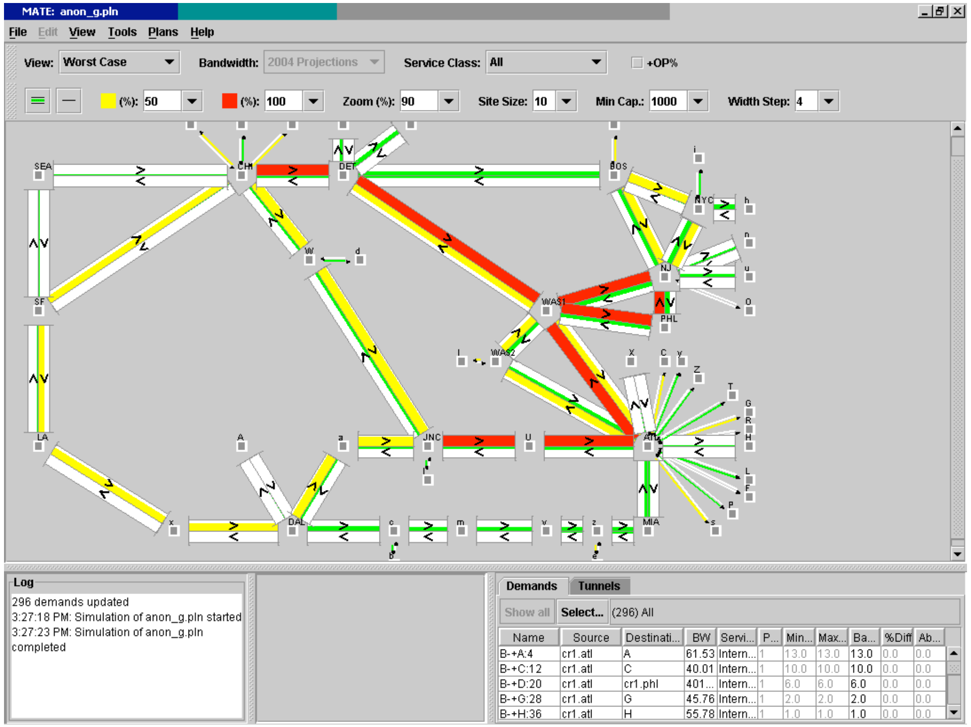
- Shift Traffic from Congested North

- Under Failure traffic shifted back North



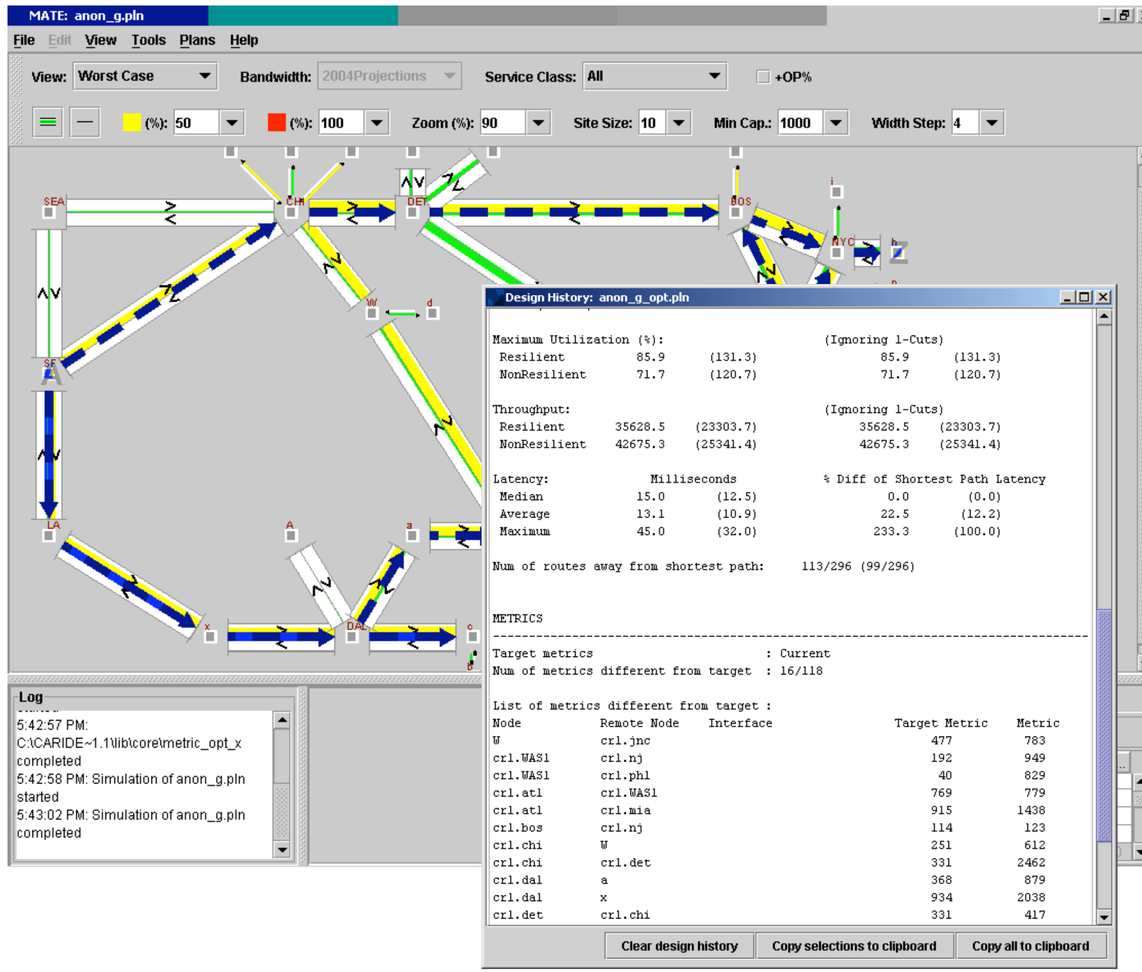
Metric TE Case Study: Worst Case Failure View

- Enumerate Failures
- Display Worst Case Utilization per Link
- Links may be under Different Failure Scenarios
- Central Ring+ Northeast Require Upgrade



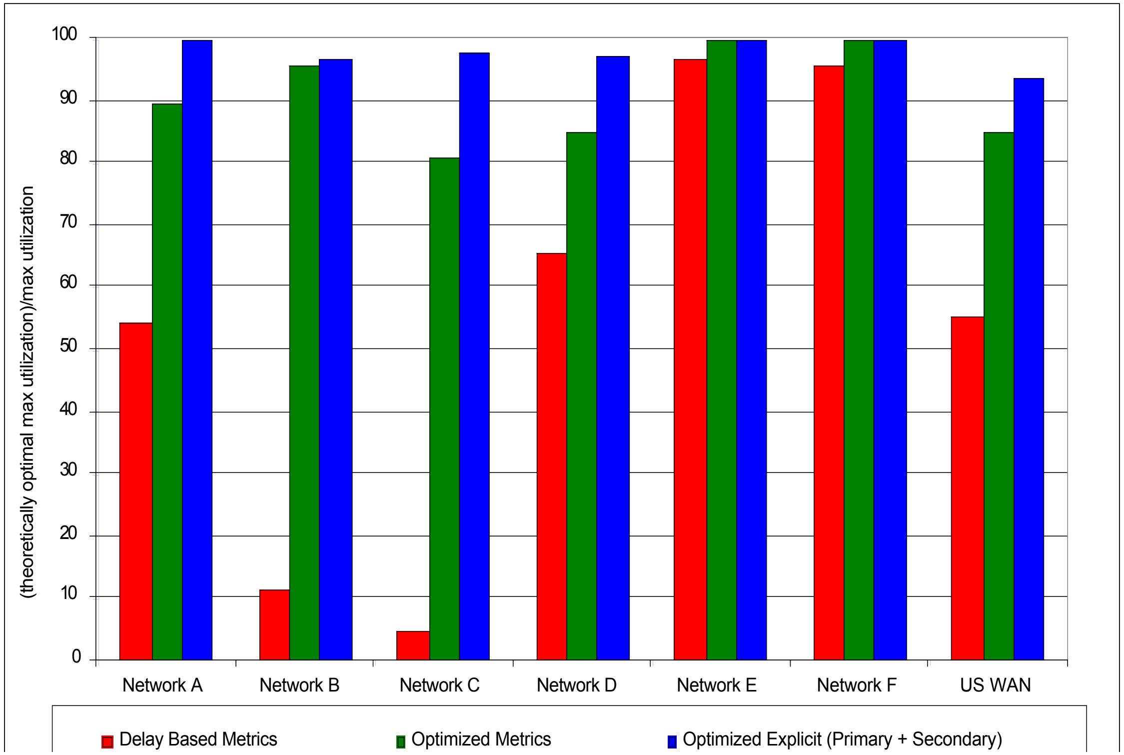
Metric TE Case Study:
New Routing Visualisation

- ECMP in congested region
- Shift traffic to outer circuits
- Share backup capacity: outer circuits fail into central ones
- Change 16 metrics
- Remove congestion
  - Normal (121% -> 72%)
  - Worst case link failure (131% -> 86%)



Metric TE Case Study: Performance over Various Networks

- See: [Maghbouleh 2002]
- Study on Real Networks
- Single set of metrics achieves 80-95% of theoretical best across failures
- Optimized metrics can also be deployed in an MPLS network
  - e.g. LDP networks



MPLS TE deployment considerations

- Dynamic path option
  - Must specify bandwidths for tunnels
    - Otherwise defaults to IGP shortest path
  - Dynamic tunnels introduce indeterminism and cannot solve “tunnel packing” problem
    - Order of setup can impact tunnel placement
    - Each head-end only has a view of their tunnels
    - Tunnel prioritisation scheme can help – higher priority for larger tunnels
- Static – explicit path option
  - More deterministic, and able to provide better solution to “tunnel packing” problem
    - Offline system has view of all tunnels from all head-ends

Tunnel Sizing

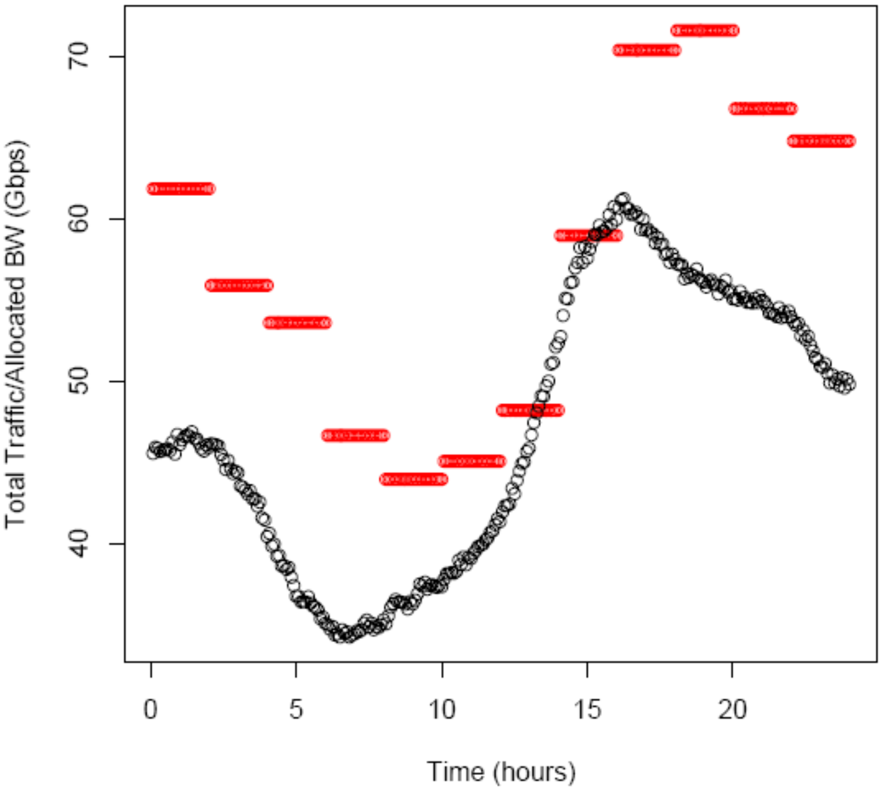
- Tunnel sizing is key …
  - Needless congestion if actual load >> reserved bandwidth
  - Needless tunnel rejection if reservation >> actual load

    Enough capacity for actual load but not for the tunnel reservation
- Actual heuristic for tunnel sizing will depend upon dynamism of tunnel sizing
  - Need to set tunnel bandwidths dependent upon tunnel traffic characteristic over optimisation period

Tunnel Sizing

- Online vs. offline sizing:
  - Online sizing: autobandwidth
    - Router automatically adjusts reservation (up or down) based on traffic observed in previous time interval
    - Tunnel bandwidth is not persistent (lost on reload)
    - Can suffer from "bandwidth lag"
  - Offline sizing
    - Statically set reservation to percentile (e.g. P95) of expected max load
    - Periodically re-adjust – not in real time, e.g. daily, weekly, monthly

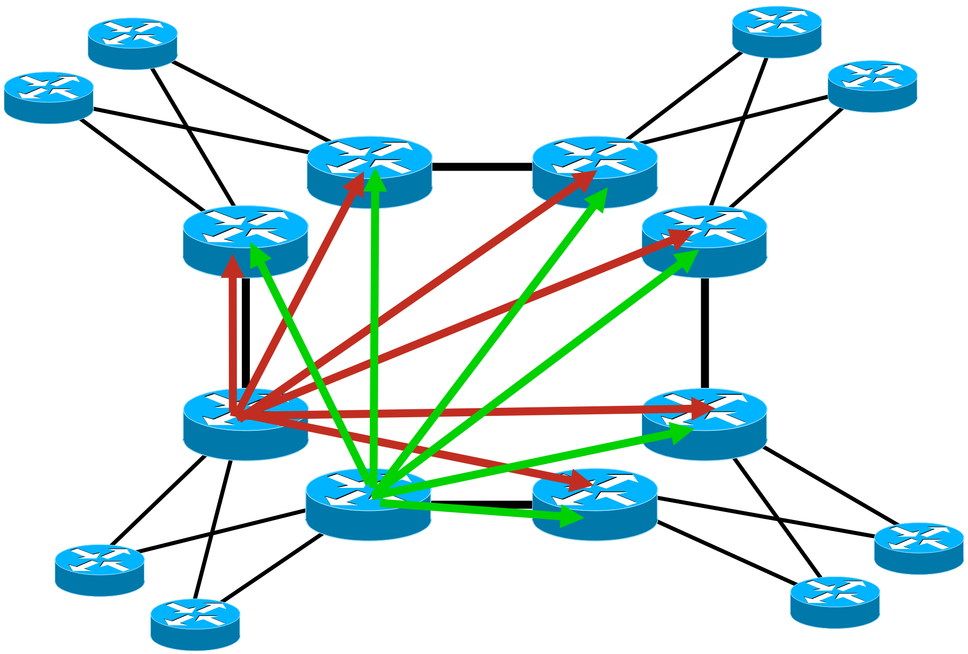
"online sizing: bandwidth lag"



Tunnel Sizing

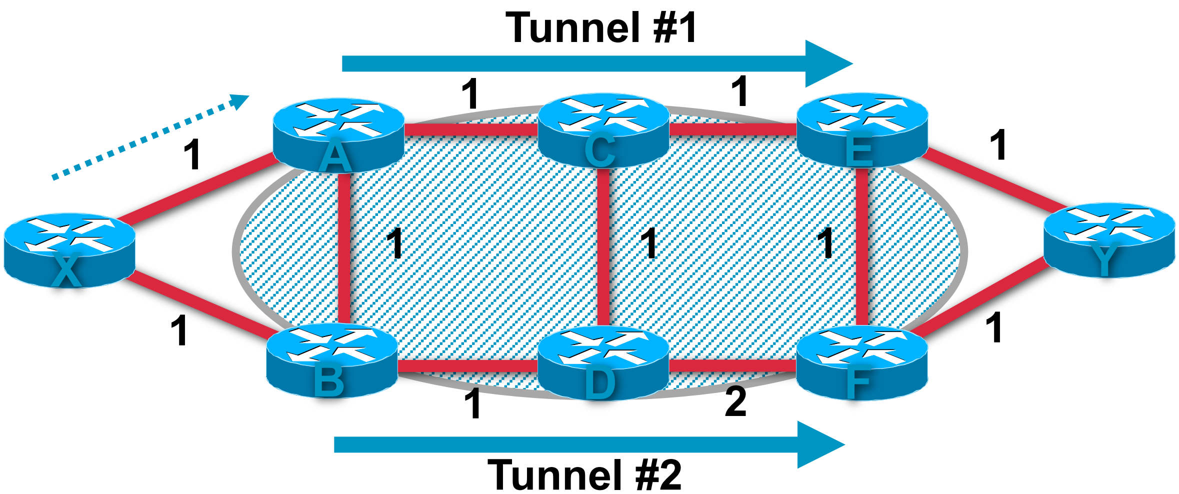
- When to re-optimise?
  - Event driven optimisation, e.g. on link or node failures
    - Won't re-optimise due to tunnel changes
  - Periodically
    - Tunnel churn if optimisation periodicity high
    - Inefficiencies if periodicity too low
    - Can be online or offline

Strategic Deployment: Core Mesh



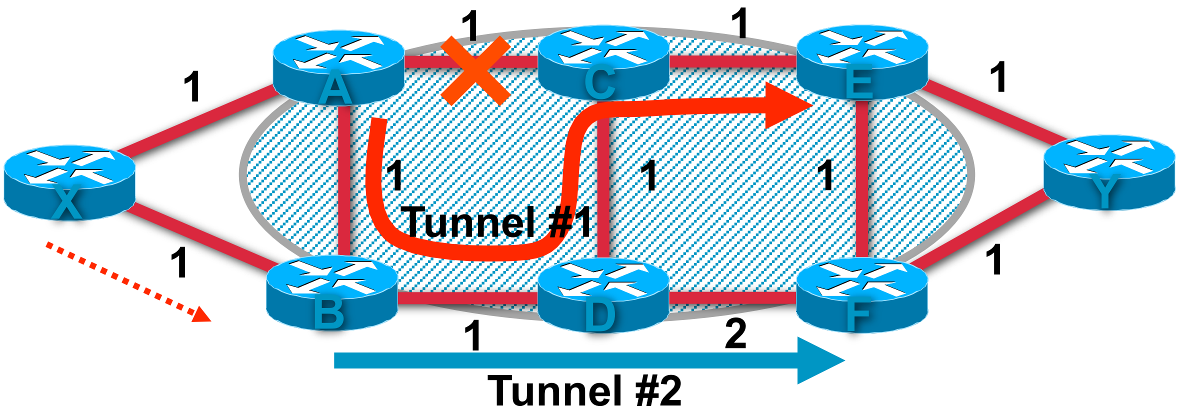
- Reduces number of tunnels required
- Can be susceptible to “traffic-sloshing”

Traffic “sloshing”



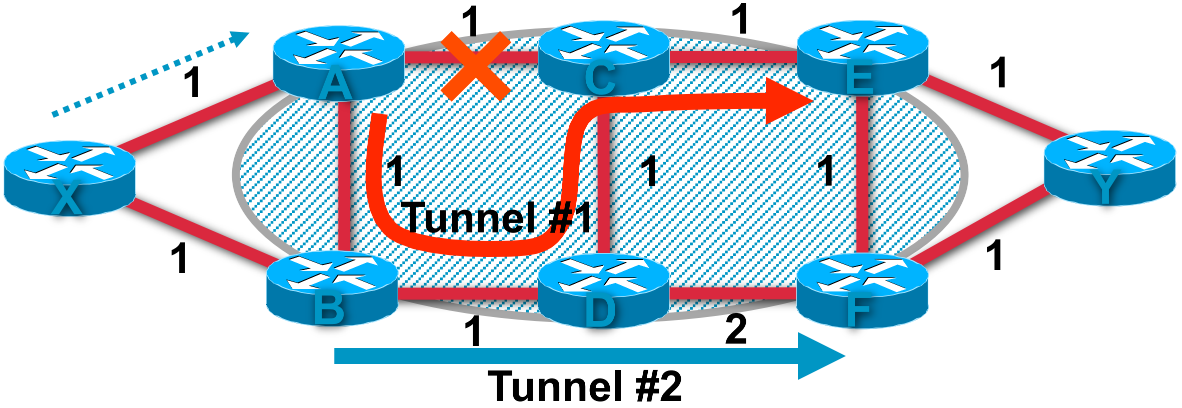
- In normal case:
  - For traffic from X ➔ Y, router X IGP will see best path via router A
  - Tunnel #1 will be sized for X ➔ Y demand
  - If bandwidth is available on all links, Tunnel from A to E will follow path A ➔ C ➔ E

Traffic “sloshing”



- In failure of link A-C:
  - For traffic from X ➔ Y, router X IGP will now see best path via router B
  - However, if bandwidth is available, tunnel from A to E will be re-established over path A ➔ B ➔ D ➔ C ➔ E
  - Tunnel #2 will not be sized for X ➔ Y demand
  - Bandwidth may be set aside on link A ➔ B for traffic which is now taking different path

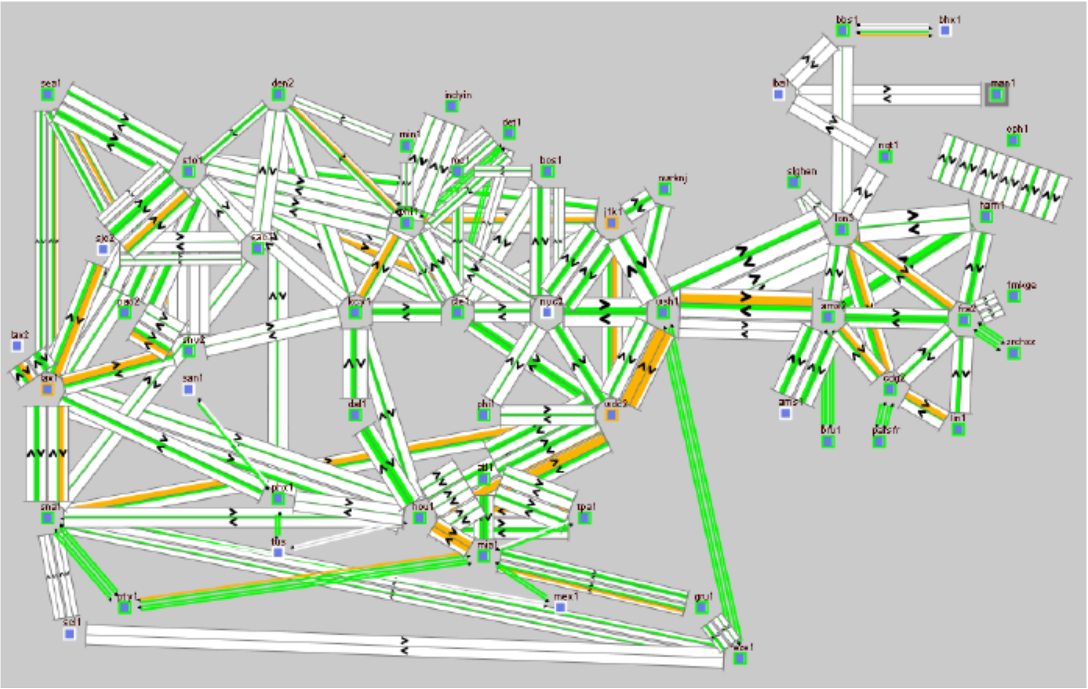
Traffic "sloshing"



- Forwarding adjacency (FA) could be used to overcome traffic sloshing
  - Normally, a tunnel only influences the FIB of its head-end and other nodes do not see it
  - With FA the head-end advertises the tunnel in its IGP LSP
    - Tunnel #1 could always be made preferable over tunnel #2 for traffic from X ➔ Y
- Holistic view of traffic demands (core traffic matrix) and routing (in failures if necessary) is necessary to understand impact of TE

TE Case Study 1: Global Crossing*

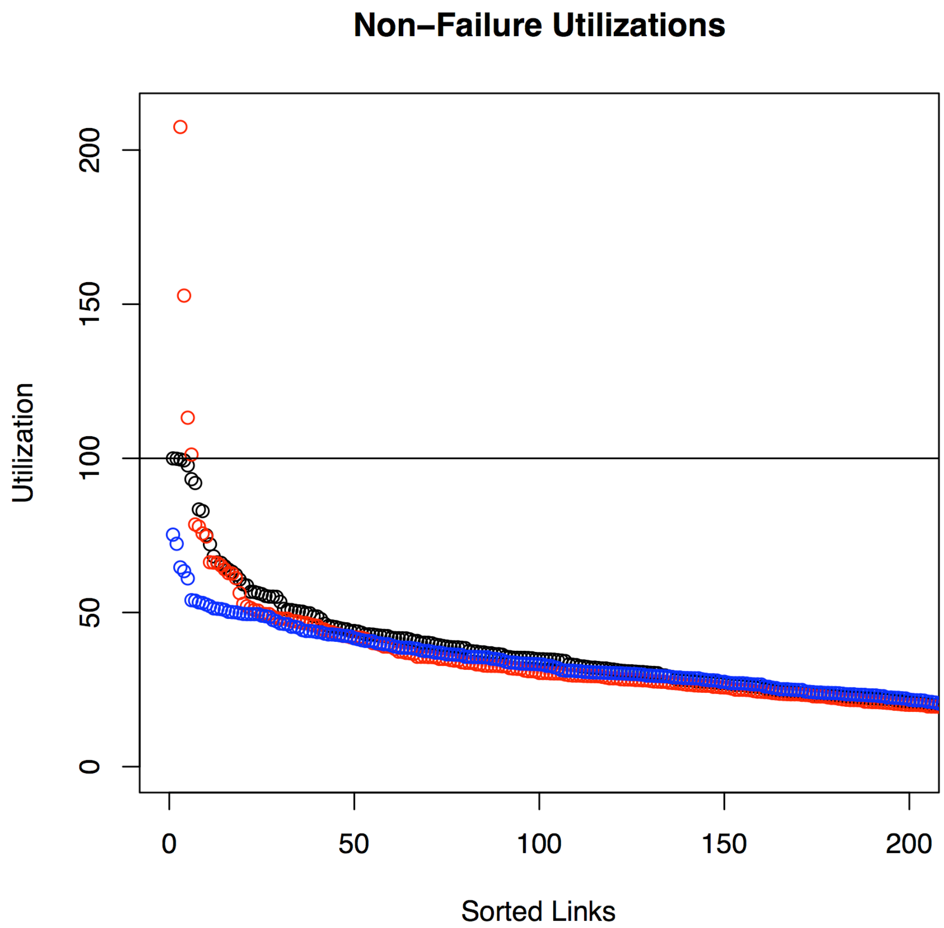
- Global IP backbone
  - Excluded Asia due to migration project
- MPLS TE (CSPF)
- Evaluate IGP Metric Optimization
  - Using 4000 demands, representing 98.5% of total peak traffic
- Topology:
  - highly meshed



(*) Presented at TERENA Networking Conference, June 2004

TE Case Study 1: Global Crossing

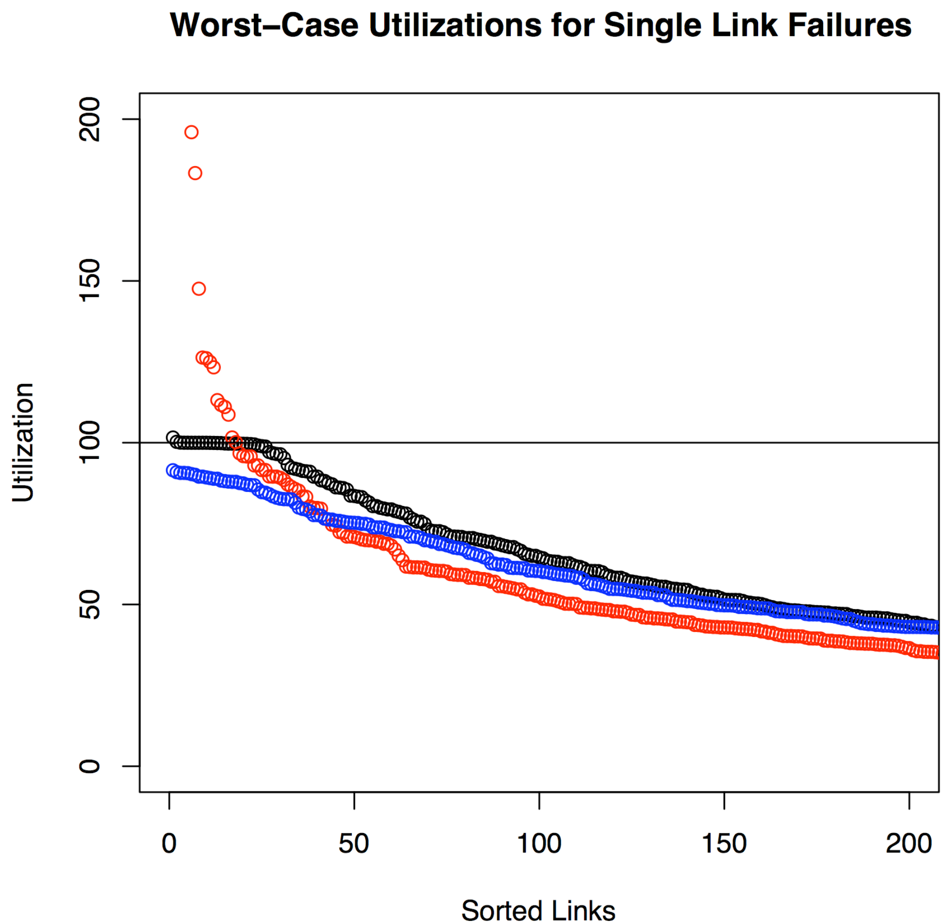
- Comparison:
  - Delay-based Metrics
  - MPLS CSPF
  - Optimized Metrics
- Normal Utilizations
  - no failures
- 200 highest utilized links in the network
- Utilizations:
  - Delay-based: RED
  - CSPF: BLACK
  - Optimized: BLUE



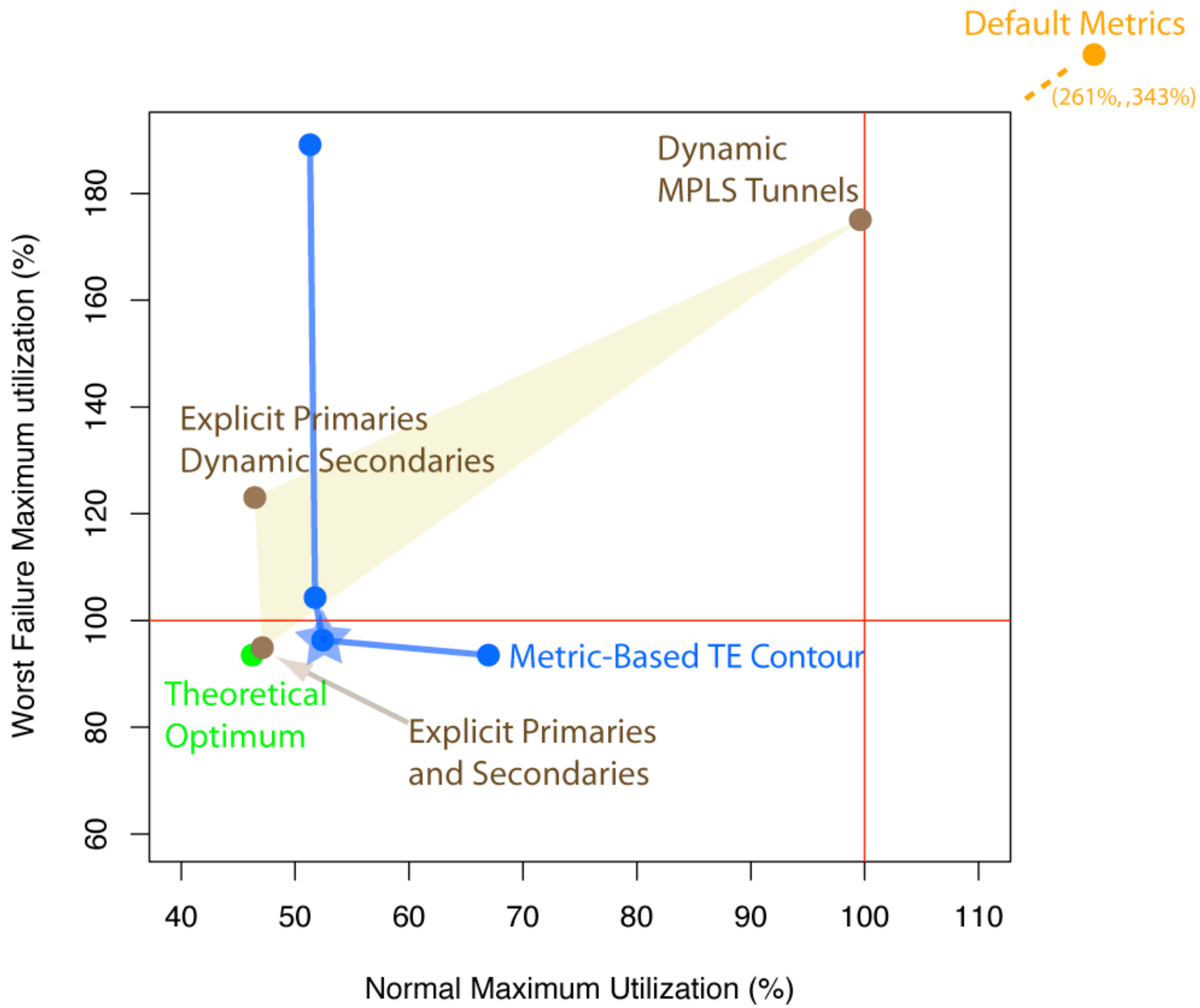
TE Case Study 1: Global Crossing

- 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



TE Case Study 2: Deutsche Telekom*

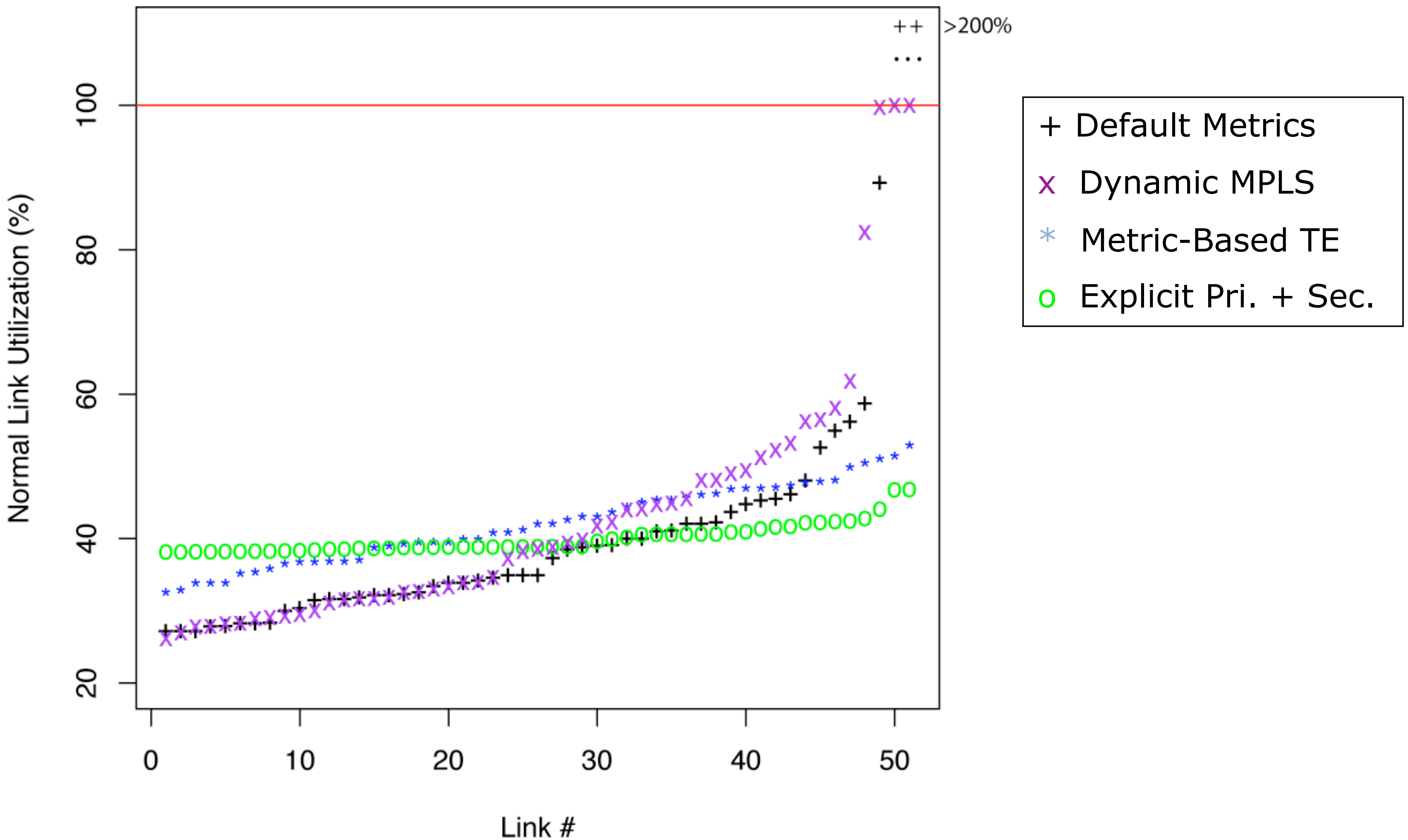


(*) Presented at Nanog 33, by Martin Horneffer (DT)

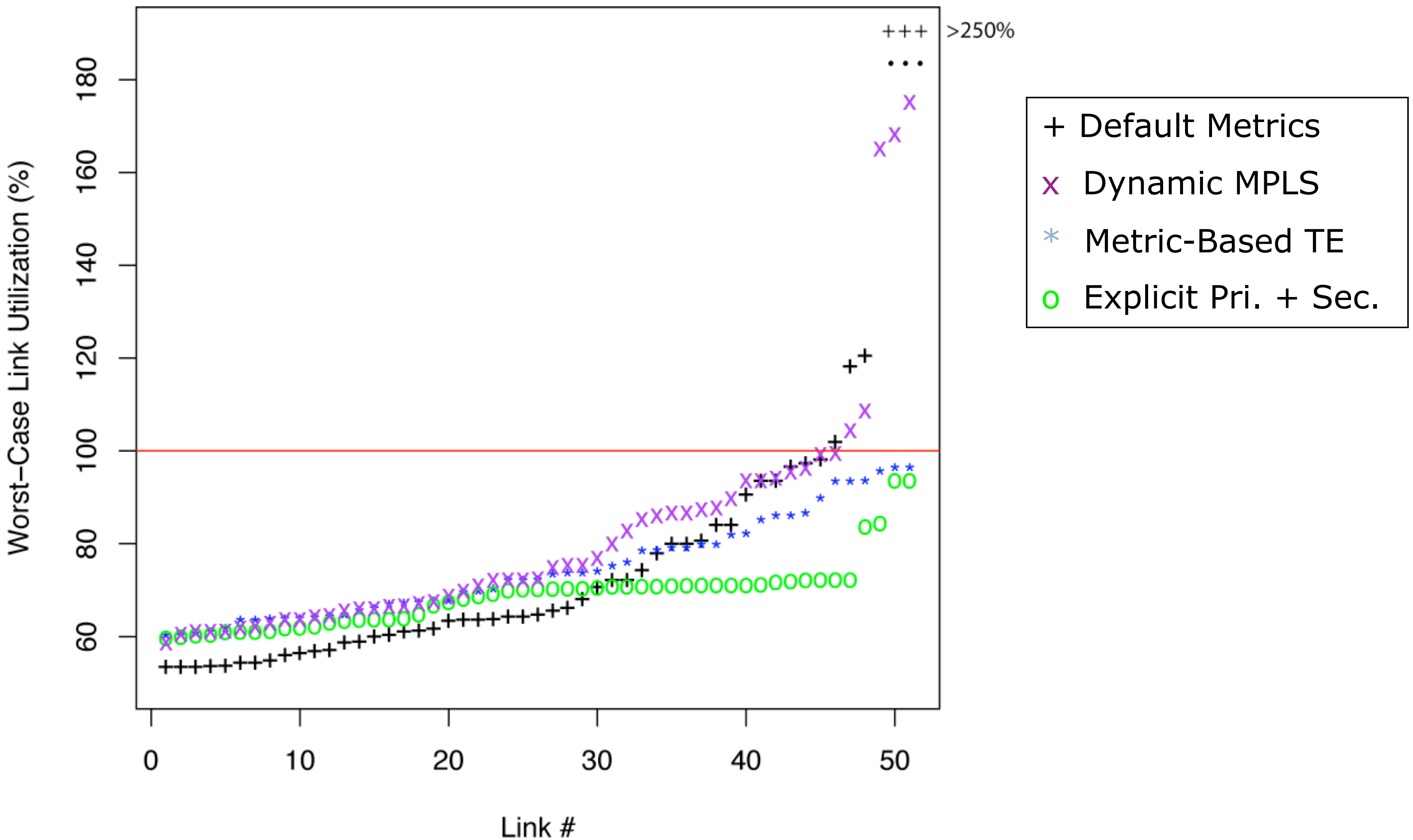
TE Case Study 3

- Anonymous network…
- TE Options:
  - Dynamic MPLS
    - Mesh of CSPF tunnels in the core network
    - “Sloshing” causes congestion under failure scenarios
  - Metric Based TE
  - Explicit Pri. + Sec. LSPs
  - Failures Considered
    - Single-circuit, circuit+SRLG, circuit+SRLG+Node
    - Plot is for single-circuit failures

Top 50 Utilized Links (normal)



Top 50 Utilized Links (failures)

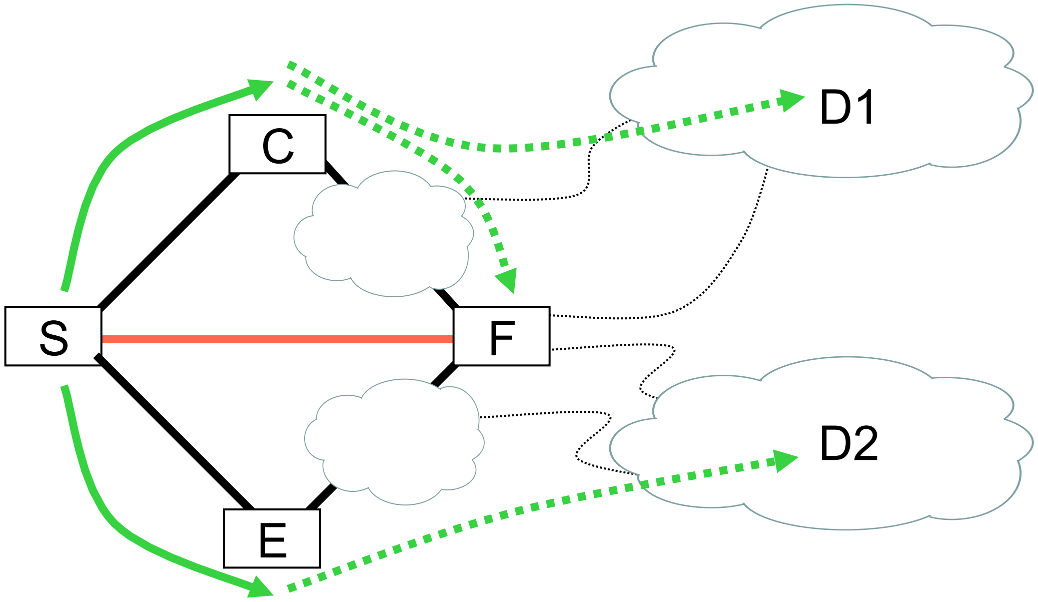


Traffic Engineering Experiences

- Some meshing in the topology required to save costs
- Metric TE
  - Simple to deploy
  - Requires uniform capacities (within regions)
- MPLS TE
  - Dynamic tunnels
    - Very resilient and efficient
    - Tunnel mesh and sizing issues, non deterministic
  - Explicit tunnels
    - Very efficient
    - Requires complex solutions to deploy

Planning for LFA FRR

Per-Prefix LFA Algorithm



- For IGP route D1, S's primary path is link SF.
- S checks for each neighbor N (<>F) whether ND1 < NS + SD1 (Eq1)
  - "does the path from the neighbor to D1 avoid me?"
  - If so, it is a loop-free alternate (LFA) to my primary path to D1

One backup path per primary path

- Default tie-break
  1. Prefer primary over secondary
  2. Prefer lowest backup path metric
  3. Prefer linecard disjointness
  4. Prefer node disjointness
- CLI to customize the tie-break policy
  - Default is recommended. Simplicity.

Benefits

- Simple
  - the router computes everything automatically
- <50msec
  - pre-computed and pre-installed
  - prefix-independent
  - Leverage IOS-XR Hierarchical dataplane FIB
- Deployment friendly
  - no IETF protocol change, no interop testing, incremental deployment

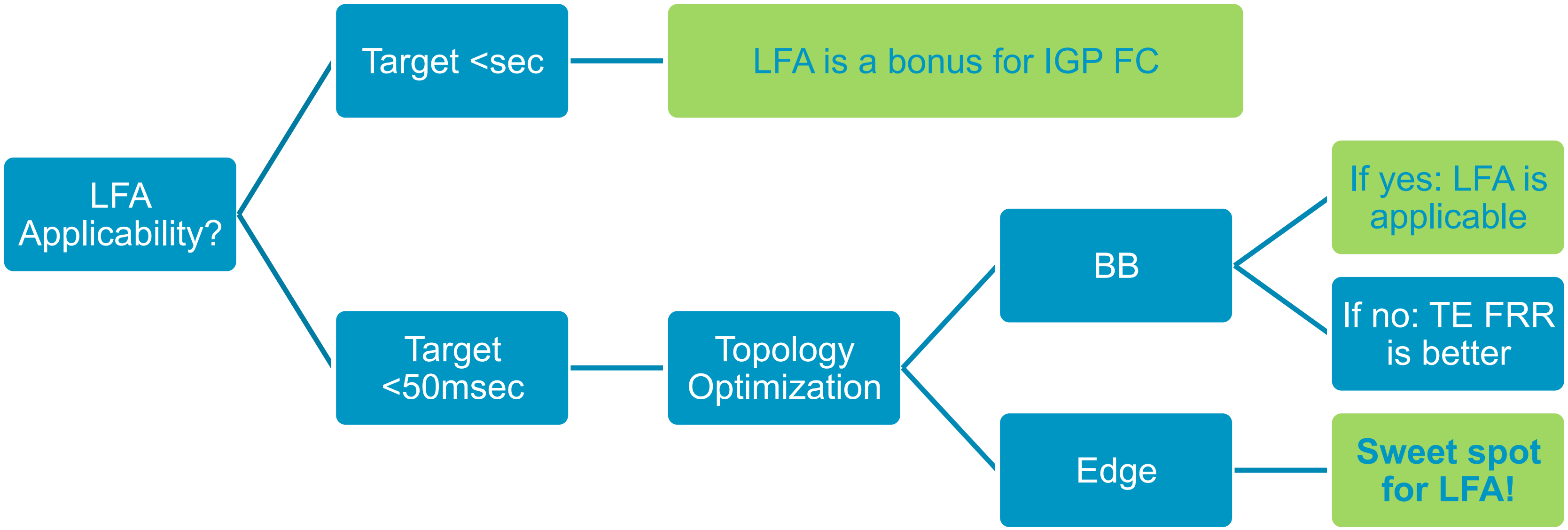
Benefits

- Good Scaling
- No degradation on IGP convergence for primary paths
- Capacity Planning
- Node Protection (Guaranteed or De Facto)
  - an LFA can be chosen on the basis of the guaranteed-node protection
  - simulation indicate that most link-based LFA’s anyway avoid the node (ie. De Facto Node Protection)

Constraints

- Topology dependent
  - availability of a backup path depends on topology
  - Is there a neighbor which meets Eq1?

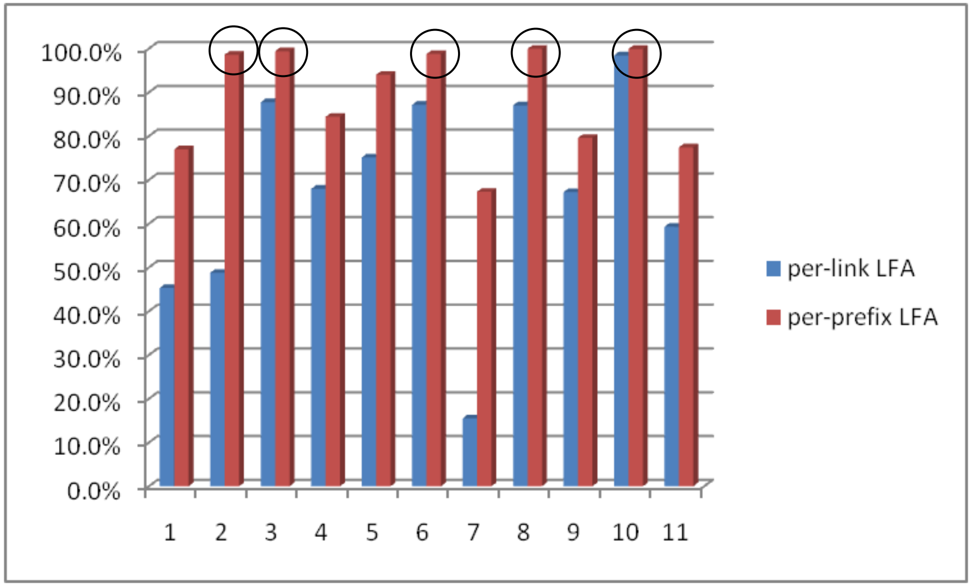
Deployment



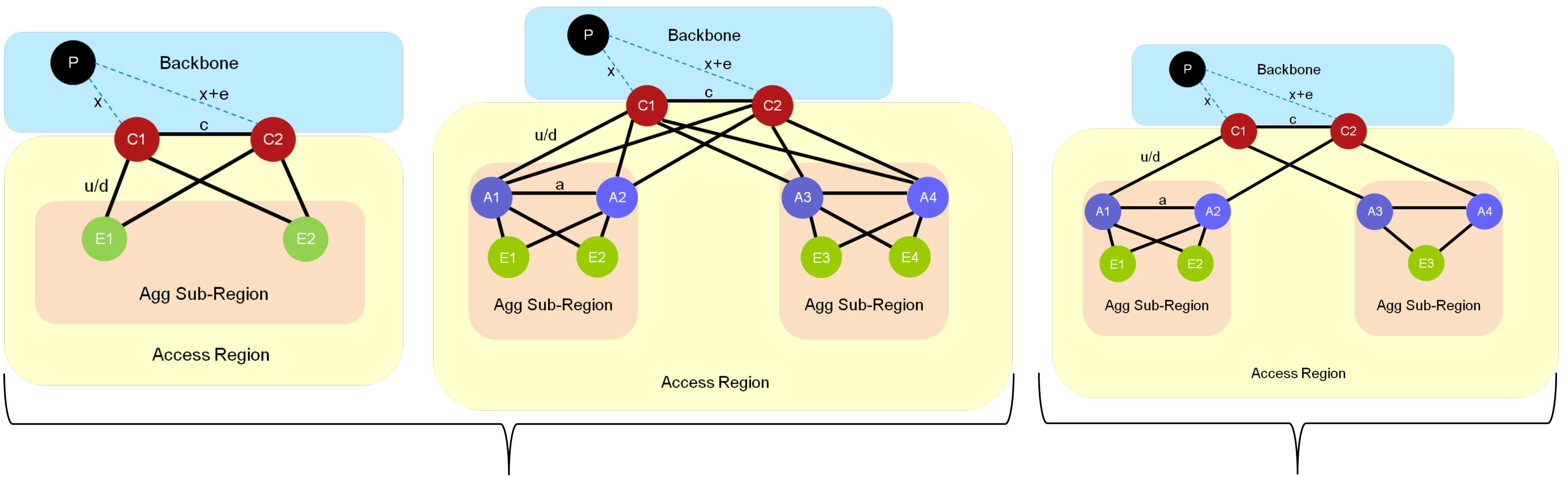
draft-ietf-rtgwg-lfa-applicability-00

Backbone Applicability

- Based on ~10 SP backbone topologies
  - Link LFA: 70% of the links are protected
  - Prefix LFA: 94% of the prefixes across all links are protected
- Some SP's selected LFA FRR for the backbone
  - implies a tight process to plan the topology
  - needs tools such as Cariden Mate
  - 5 topologies are well above 95% protection
  - Per-Prefix LFA is likely selected for its better coverage



Access/Aggregation Topologies



100% link and node protection

Zero u-Loop

99% link and node protection

Zero u-Loop

- Assuming a few IGP metric rules described in draft-filsfils-lfa-applicability-00

- A reference to consult if interested
- Slight modification to slide 17. The solution will be called “Remote LFA” and an ietf draft should be released in the next weeks.

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LFA (Loop-Free Alternates) Case Studies in Verizon’s MPLS Network

Ning So, Verizon Inc., ning.so@verizonbusiness.com
Fengman Xu, Verizon Inc., fengman.xu@verizonbusiness.com
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Tony Lin, WANDL Inc., thl@wandl.com

www.mpls2010.com

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Coverage Case Studies for Various Networks

Topology	#links/#nodes	Per-link LFA Coverage	Per-prefix LFA Coverage
T1	4.2	49%	73%
T2	2.1	22%	73%
T3	6.5	51%	68%
T4	3.0	36%	70%
T5	5.7	45%	69%
T6	1.7	42%	72%
T7	2.5	56%	90%

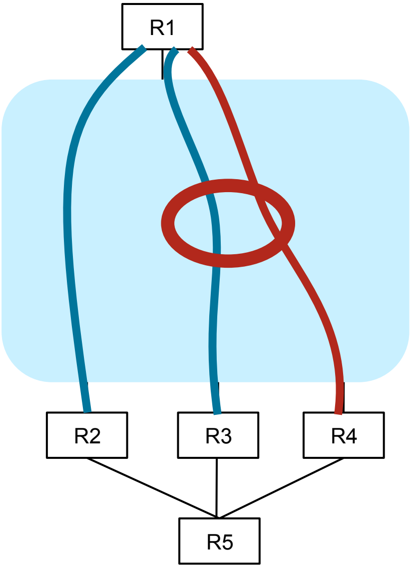
- Coverage studies performed for various carriers and service providers.
- Topologies varied in terms of link-to-node ratio, protocols (RSVP-TE FRR in inner core and LDP in outer core), flat and hierarchical topologies.
- Per-prefix LFA coverage also computed and included for comparison.

10

IP/Optical Integration

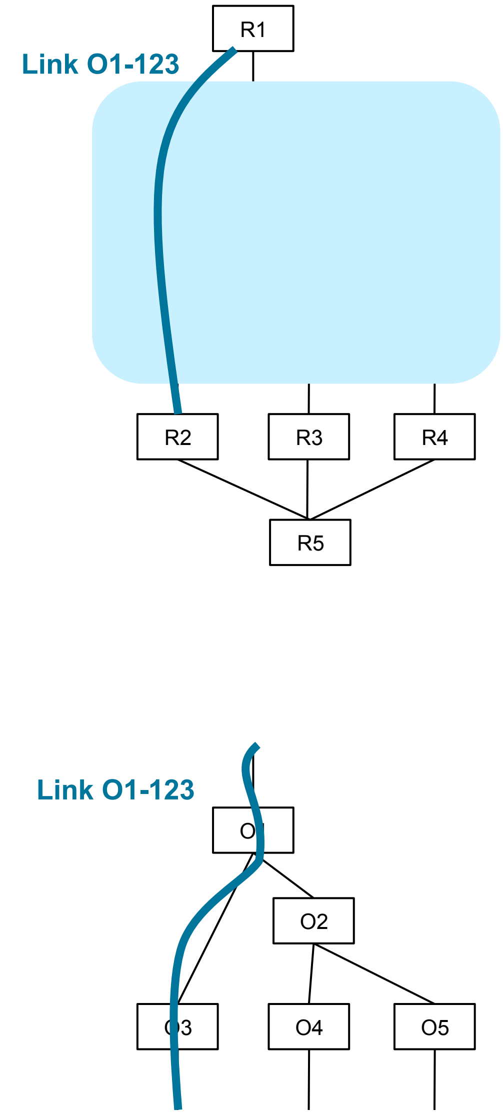
SRLG

- To backup R1R4, R2 or R3?
- R2: disjoint optical path!



Circuit ID

- Multi-Layer Planning optimization requires mapping circuits between L3 and L0 topologies
- Circuit ID acts as glue between L3 topology and underlying L0 topology
- Other applications:
  - troubleshooting
  - disjointness



SRLG and Circuit ID Discovery

- Current: retrieve info from optical NMS and map the SRLG's to L3 topology. Labor intensive.
- Near future: automated discovery from the router L3 control plane thanks to L3/L0 integration

Fasted DWDM provisioning

Does OTN really make sense for
Core Router Bypass?

Gerstel, Batchellor, Spraggs, Filsfils
Cisco Systems

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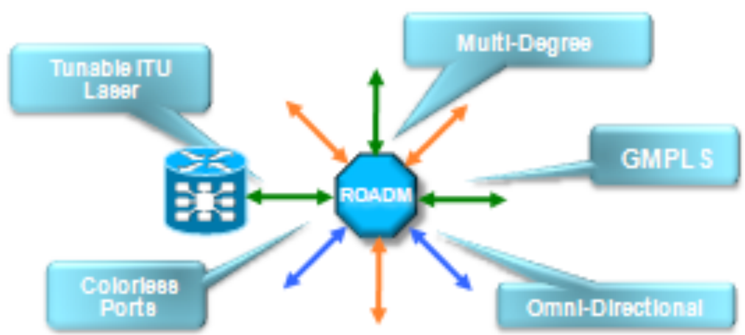
What really help is faster DWDM provisioning

- Slow DWDM provisioning leads to provision spare bandwidth a long time in advance and hence the perception that IP core utilization is not high enough
- Fully reconfigurable DWDM layer play a significant role solving this issue



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14

A final example

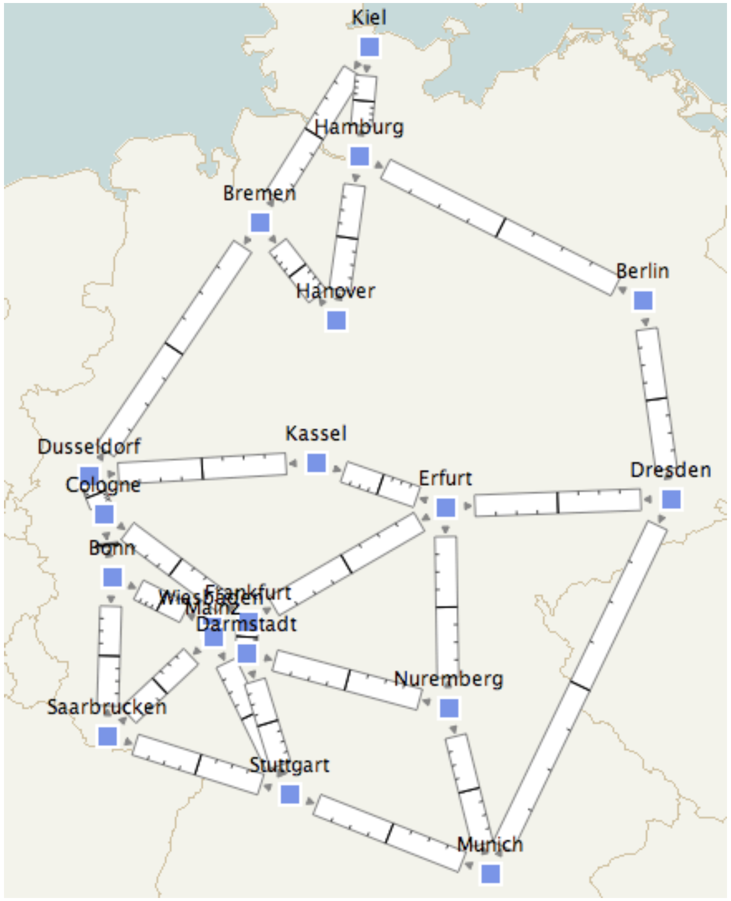
Network Design

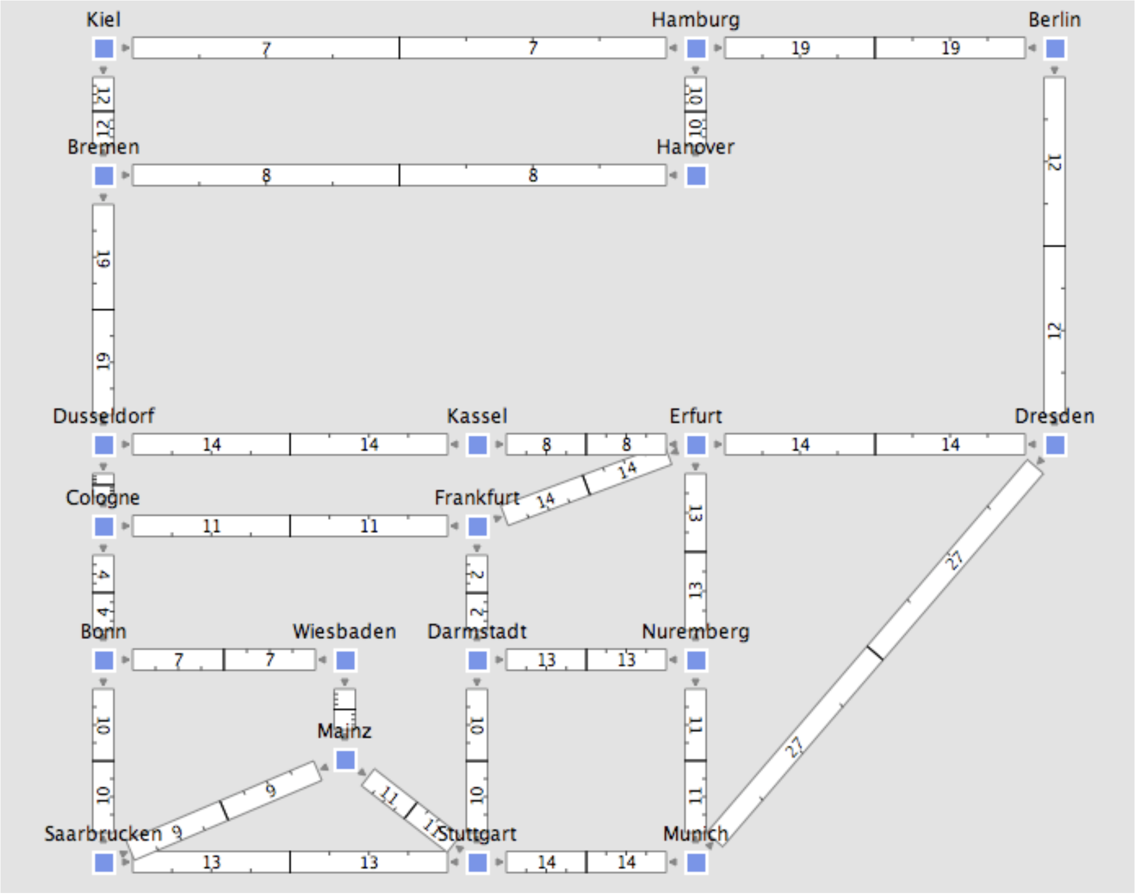
- For Mobile backbone network
  - Fictional (German) topology
- IP over optical
- Projected Traffic Matrix
- Objectives:
  - Cost effective
  - Low delay
  - IPFRR LFA coverage
- Topology:
  - IP/Optical
  - 6 core sites

Base Network Design

- Optical Design Rules:
  - Core links over shortest delay *diverse* optical path
    - N:1 protection
  - Remote PE's homes into the closest P, and second closest P over *diverse* path
- IP Design Rules
  - 2 P-routers in core sites, 2 PE-routers in all sites
  - E(dge)-routers prepresent traffic sources (behind PE's)
  - Lowest Delay routing:
    - IGP metrics inter-site links: 10 * delay
  - IGP metrics intra-site according to 'draft-filsfils-rtgwg-lfa-applicability-00'

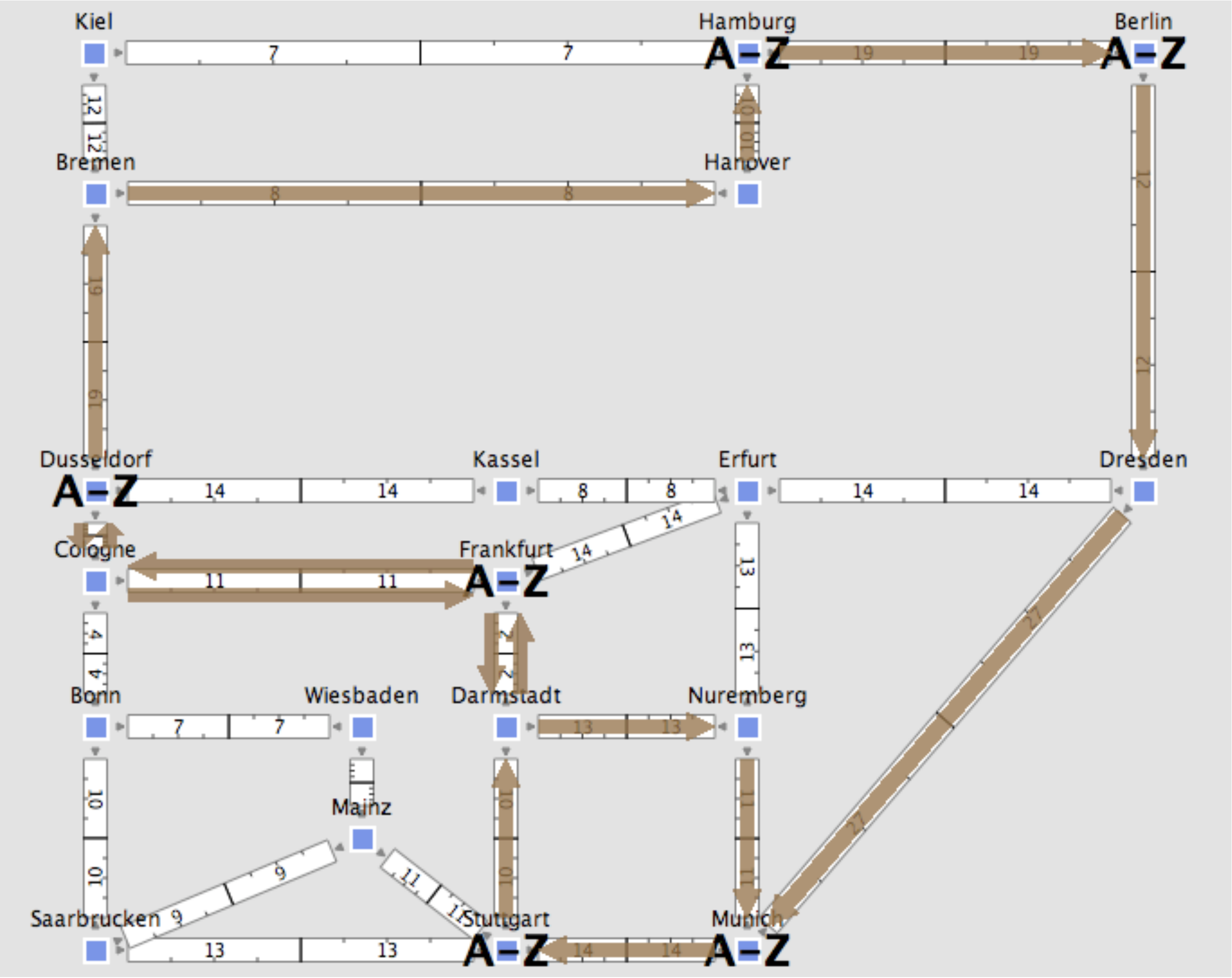
Optical network (geographic/schematic)



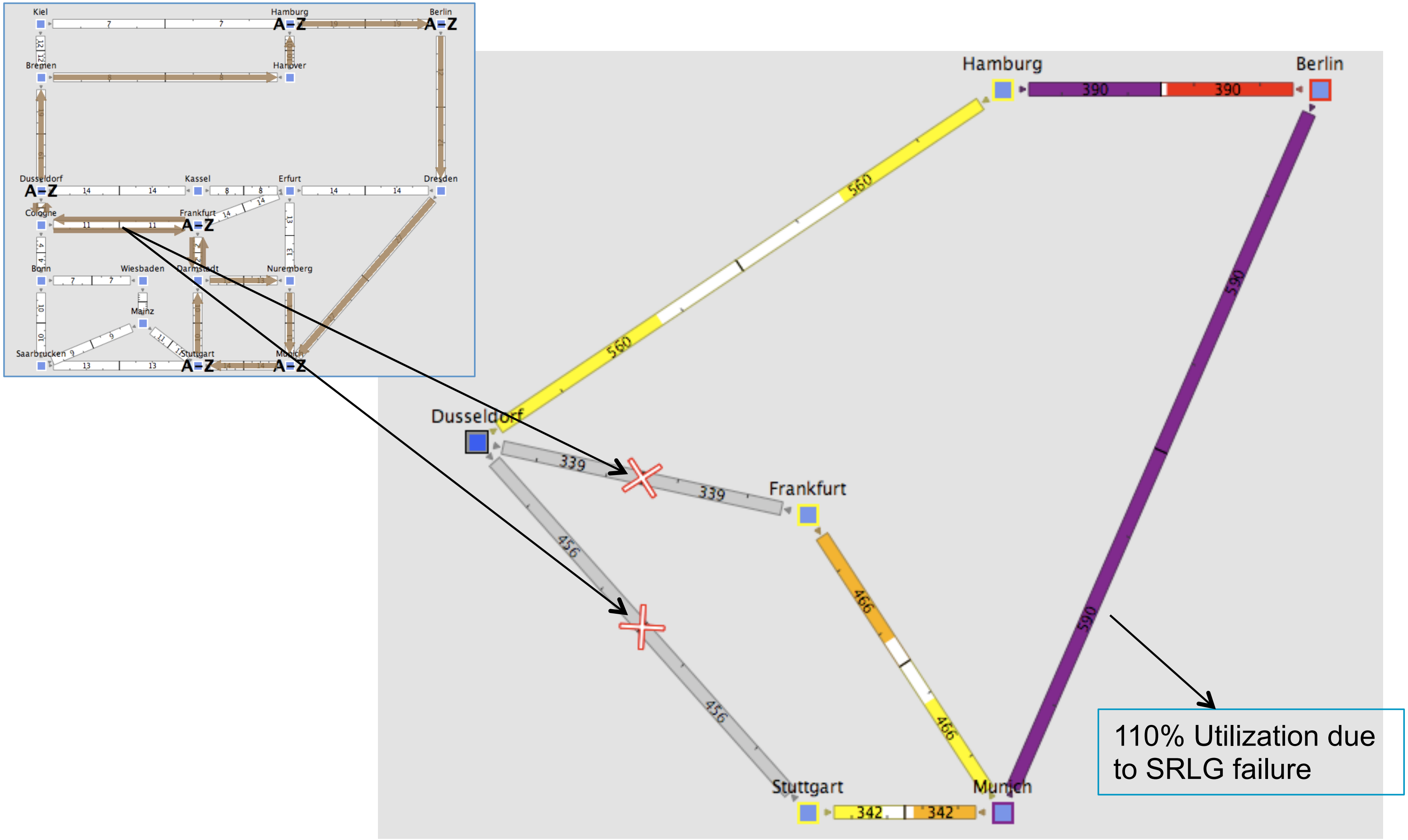


Circuit routing over optical network

- 6 core sites
- IP circuits routed over shortest delay paths
- Note: fiber used for more than one circuit around Frankfurt

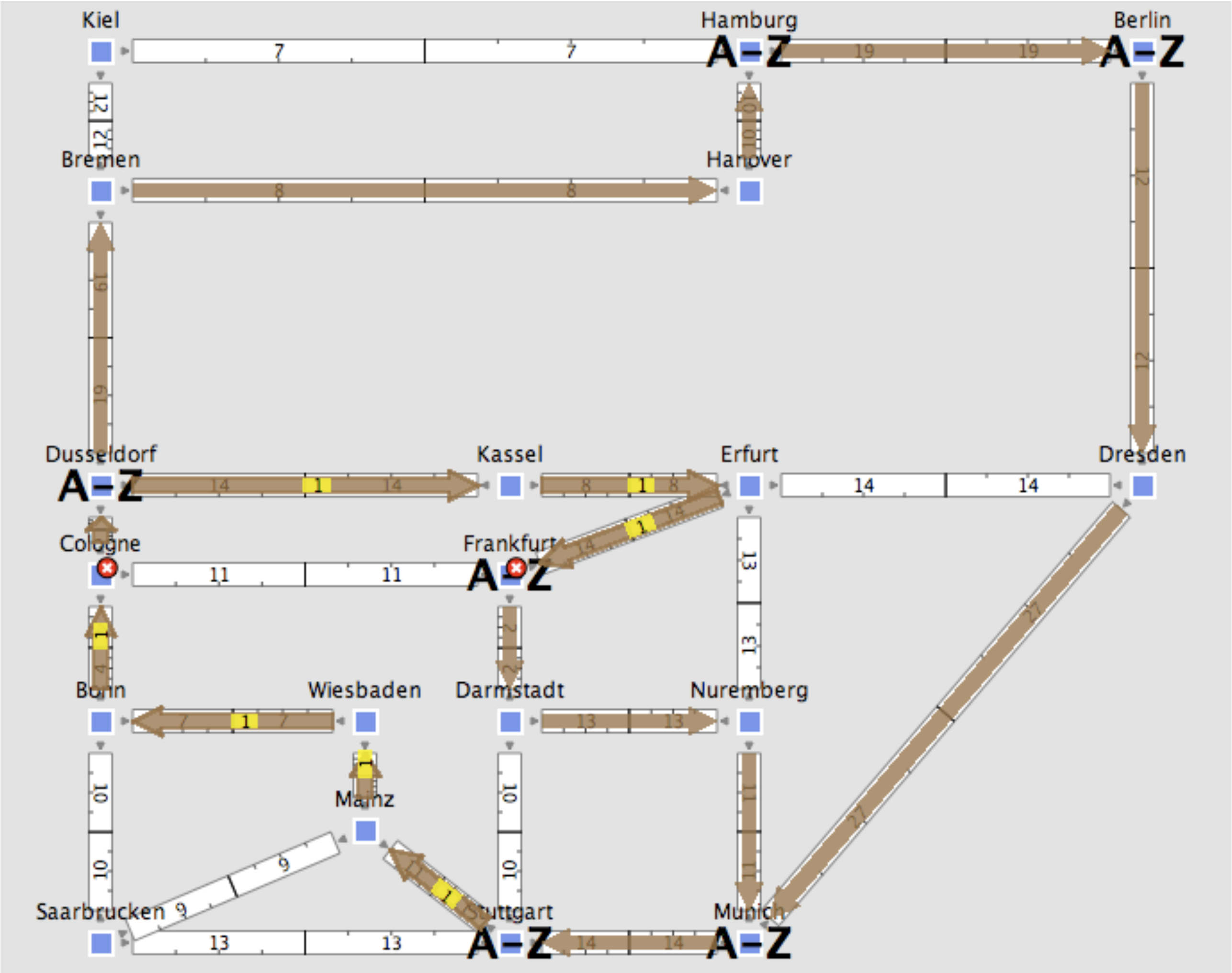


SRLGs on IP layer



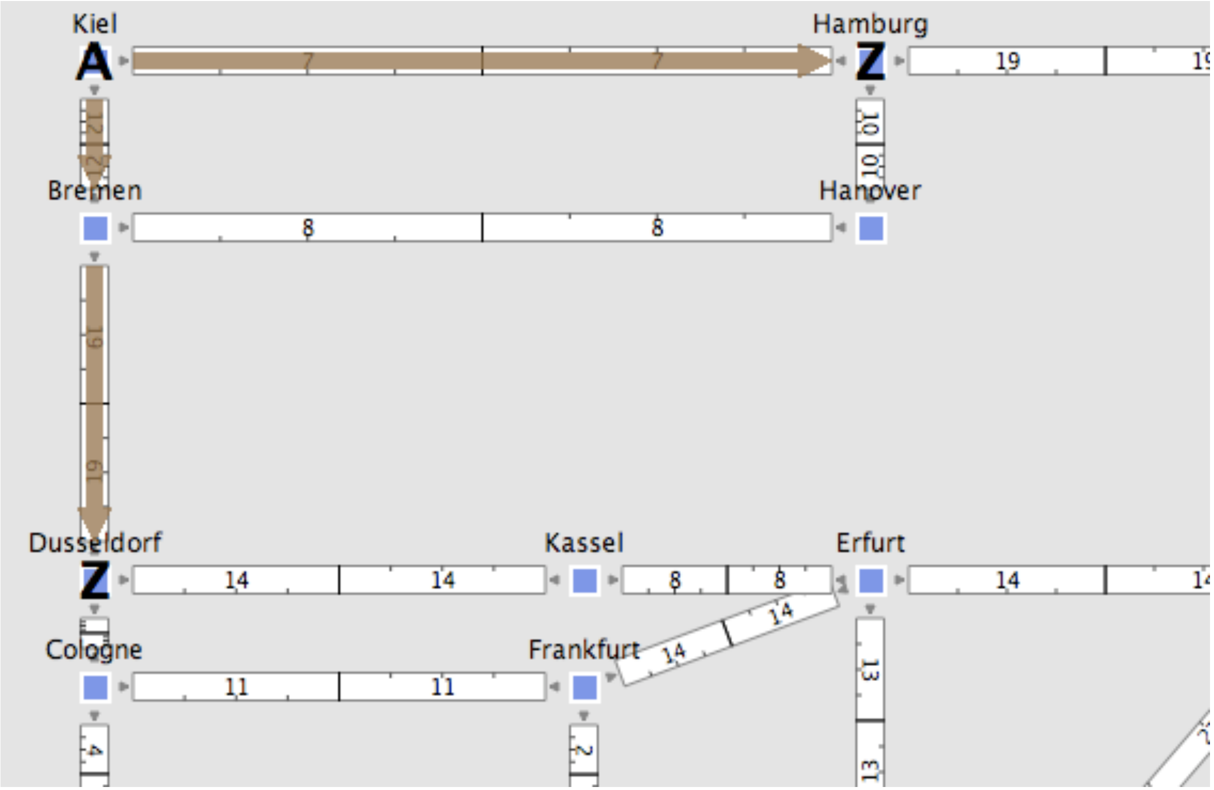
Create diverse routing on optical layer

- Move *Dusseldorf-Stuttgart* away from *Frankfurt*
- Move *Dusseldorf-Frankfurt* away from *Cologne*



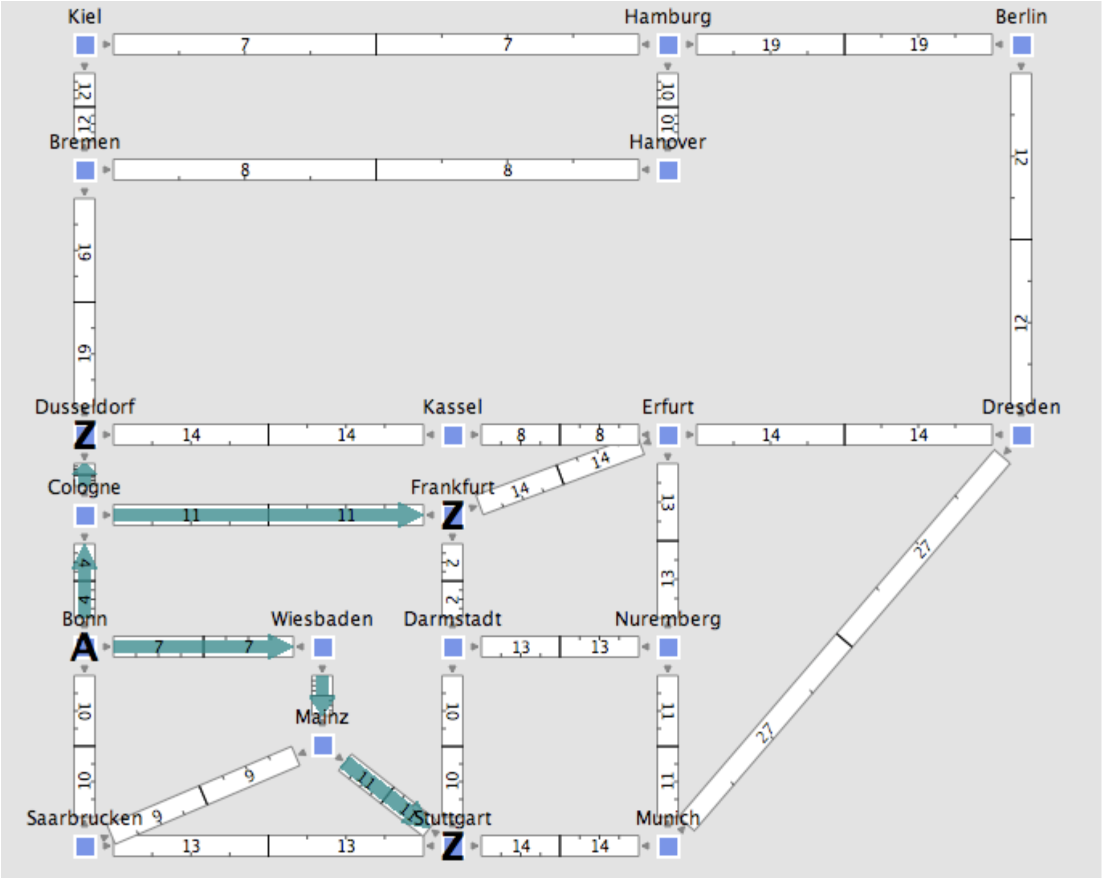
Add remote PE's

- 1. Kiel
  - Closest PE is Hamburg
  - 2nd closest Dusseldorf
  - Diverse!



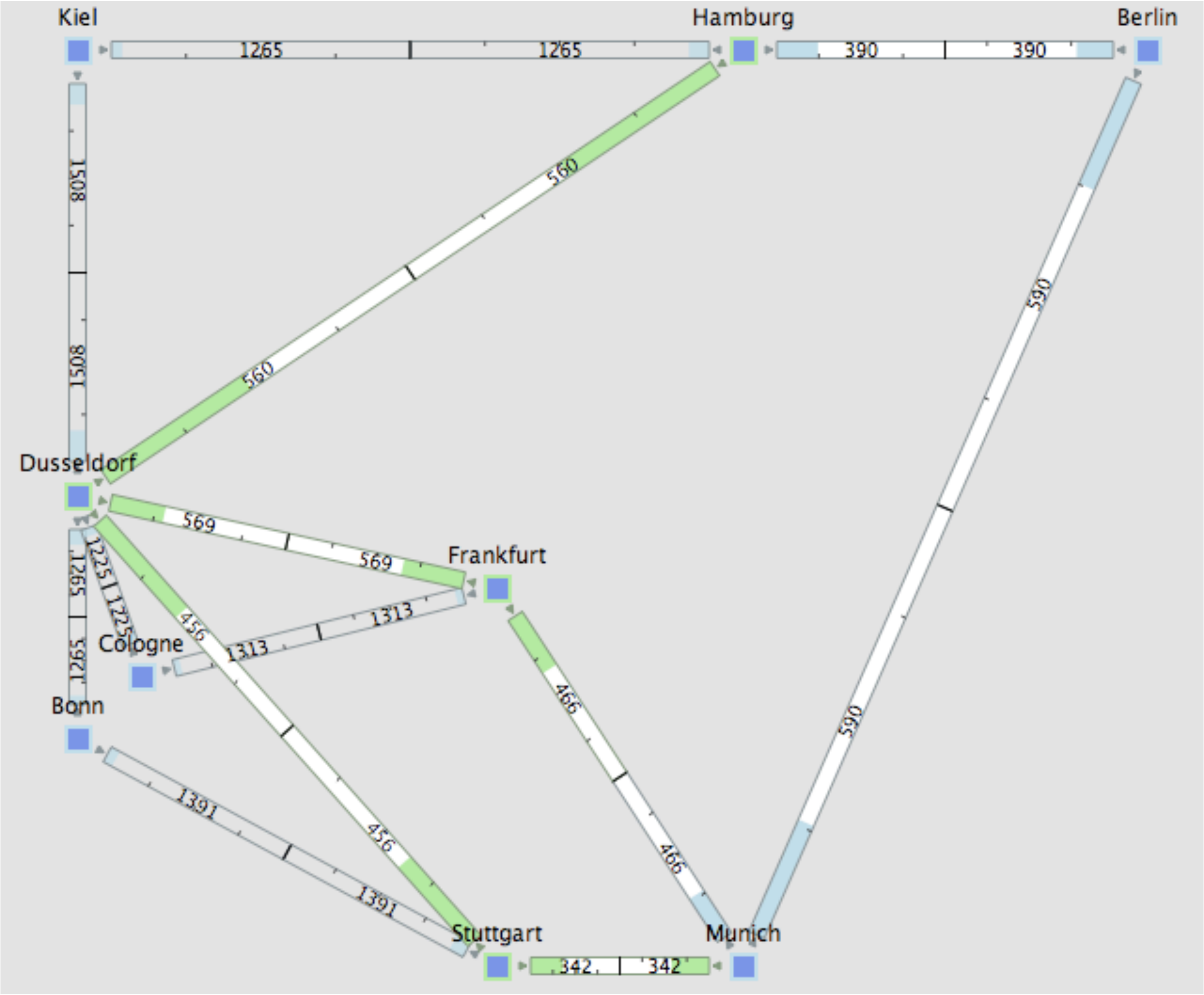
Add Remote PE's

- 2. Bonn
  - Closest PE is Dusseldorf
  - 2nd closest Frankfurt: *but not diverse*
  - Excluding the links Bonn-Cologne and Cologne-Dusseldorf, Stuttgart is 2nd closest PE
- 3. etc…



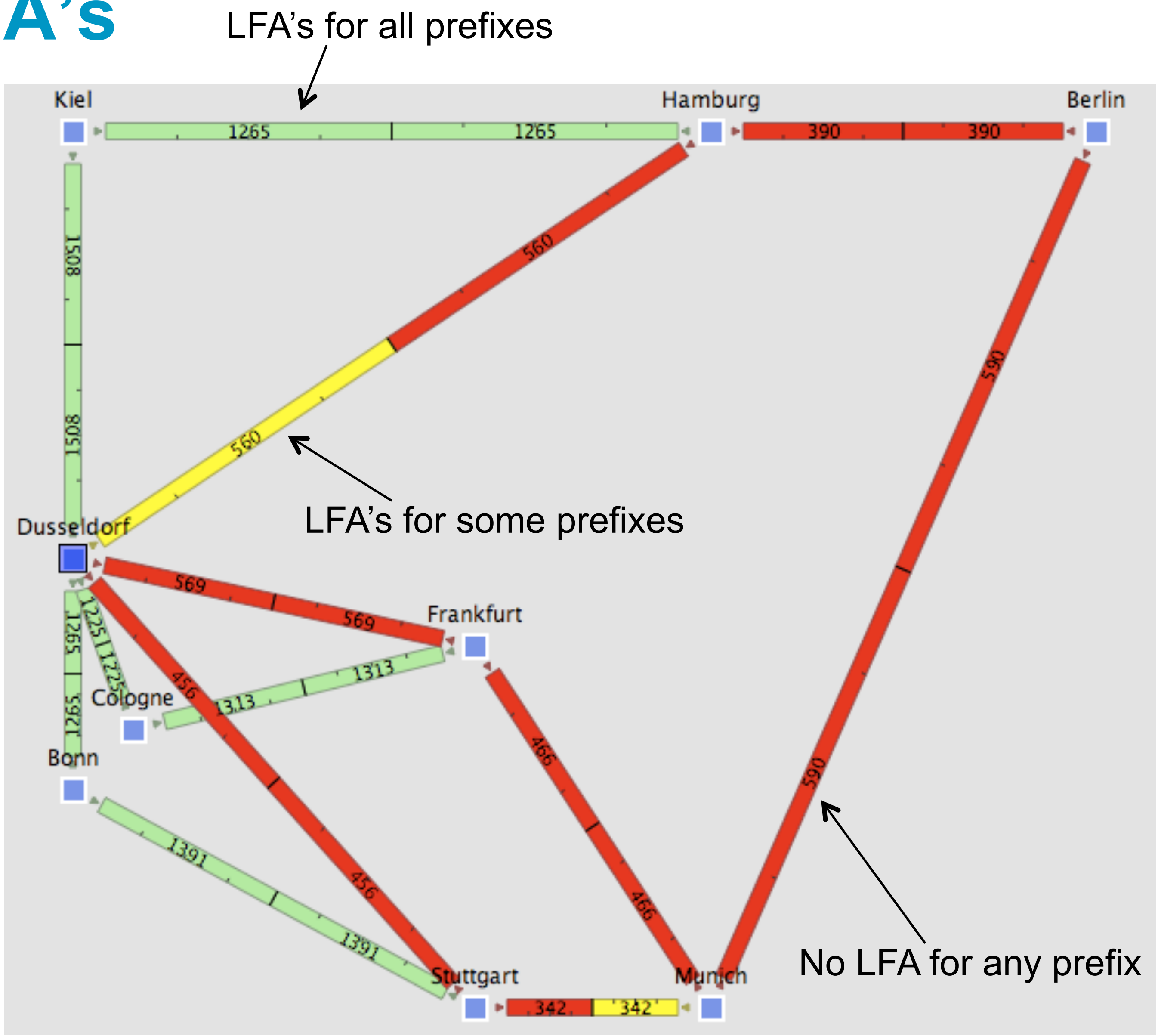
Final IP topology

- Highest utilization due to any circuit or SRLG failure is 90%
- Saving of 20% due to diversity of Dusseldorf-Frankfurt and Dusseldorf-Stuttgart



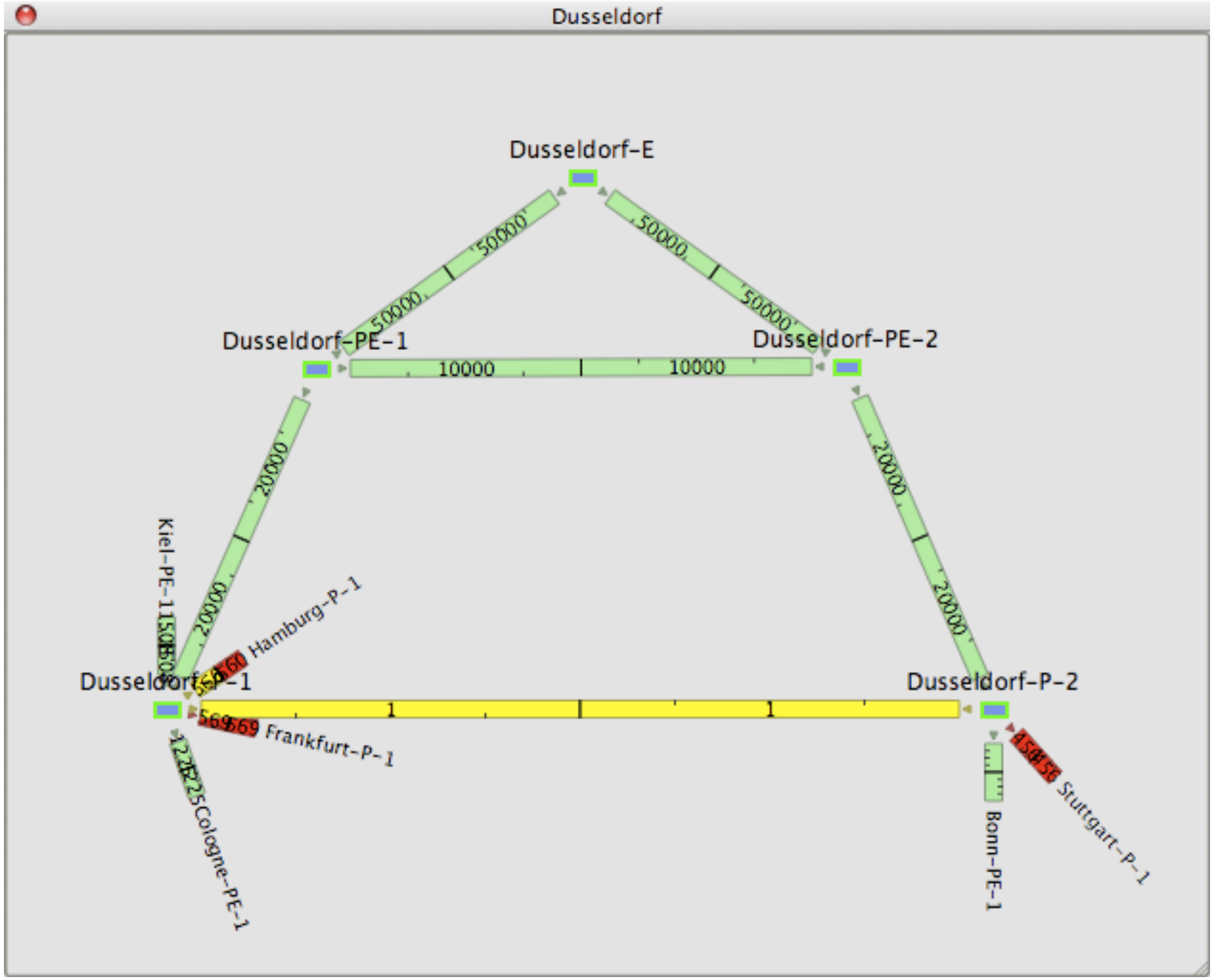
IPFRR LFA's

- 75% of interface traffic has an LFA available
- Some inter-site links are not protected due to ring topology



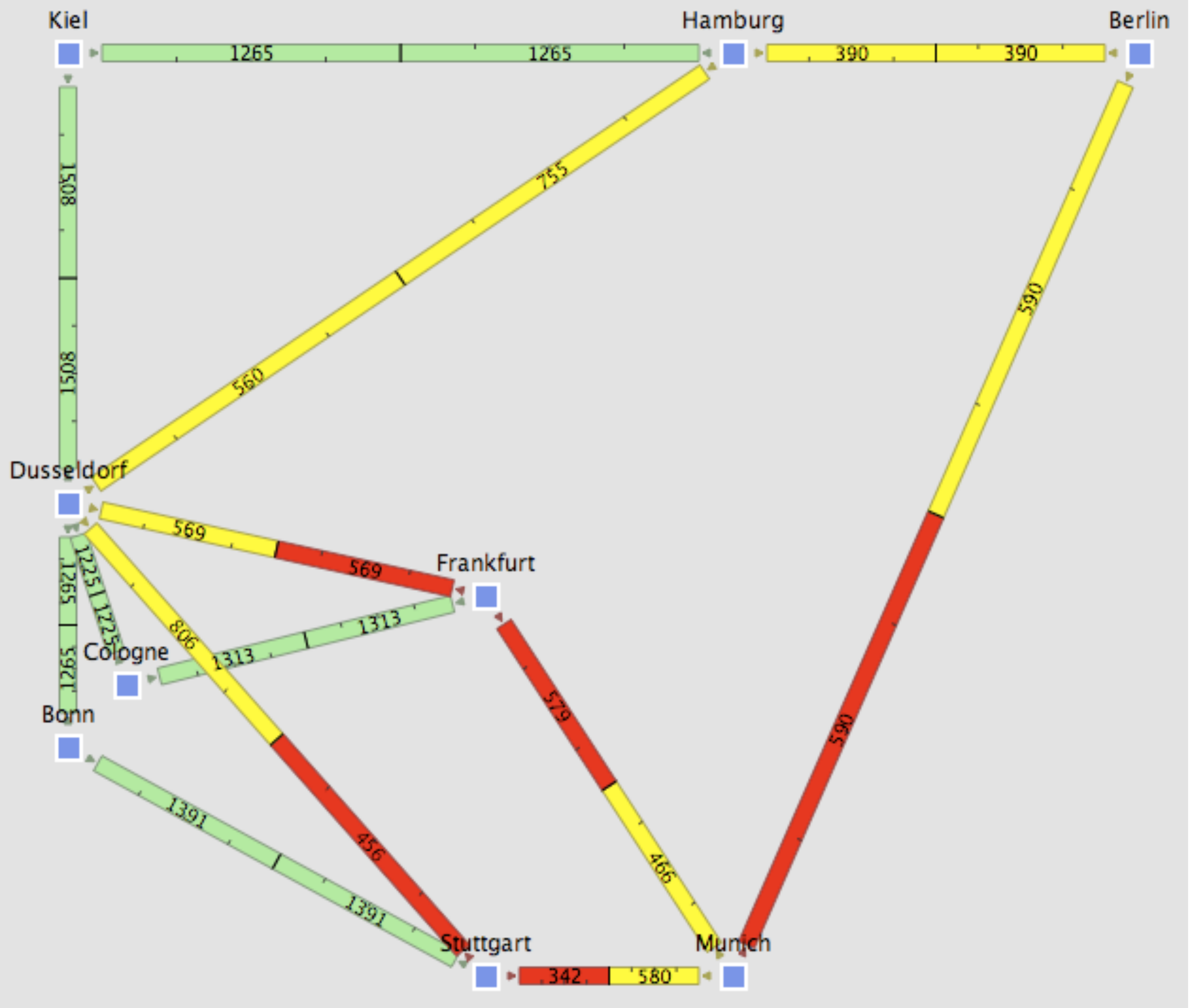
IPFRR LFA's: site view

- LFA applicability draft section 3.3: Square



IPFRR LFA's: metric optimization

- IPFRR coverage on core links has improved
- Average delay went up with 0.2 ms



Conclusion

Conclusion

- Capacity Planning is essential for enforcing SLA with min capacity
- Router vendors to provide input data
  - Traffic Matrix (neftlow v9)
  - Base Topology (LSDB)
  - QoS and Routing Policy
  - near-future: IP/Optical integrated data
- Planning tools to provide
  - Traffic Matrix Deduction
  - Simulation and Optimization engine
  - Consulting service
- SP to put the process in practice

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