The efficiency of Traffic Engineering (TE) with Regard to Failure Resilience

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- Focus on capacity upgrading process for steady traffic increase
- Strategy for link upgrades with TE & failure resilience yielding maximum utilization
- Examples & Outlook

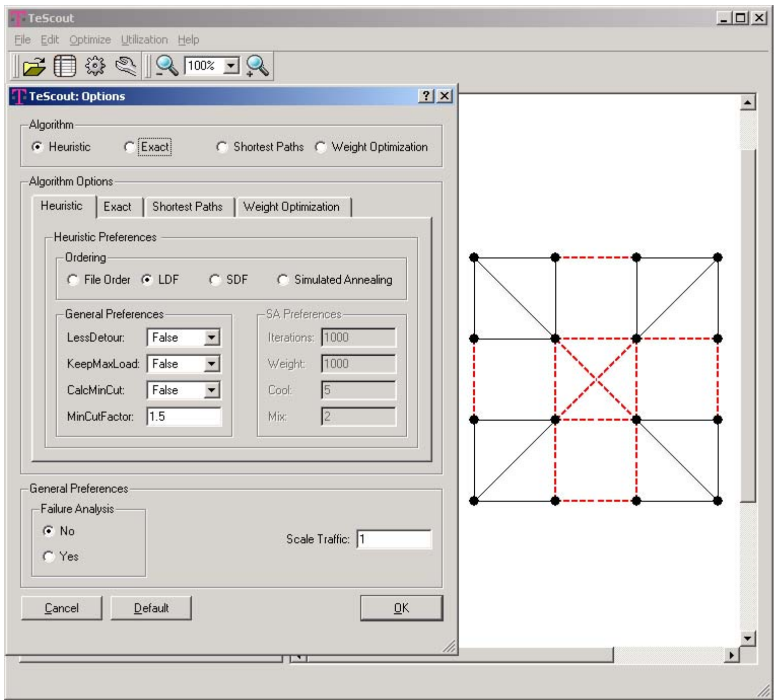
Traffic Engineering (TE) & Multiprotocol Label Switching

- Shortest path routing in pure IP networks without TE leads to unbalanced load, which cannot be efficiently controlled
- Multiprotocol label switching (MPLS) provides
  - Label Switched Paths (LSP) from source to destination
  - Measurement per LSP to obtain the traffic matrix
  - Full mesh of LSP between edge routers: difficult to operate
  - QoS support (for DiffServ & IntServ)
  - Virtual private networks (VPN)
- Integration of MPLS with the optical layer (GMPLS, ASON)

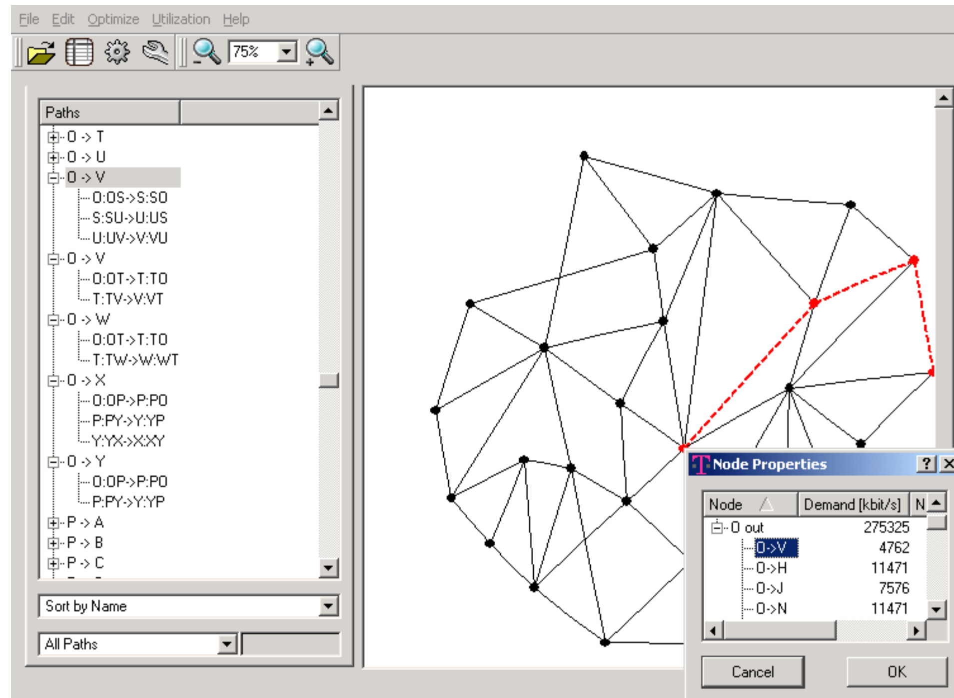
Traffic Engineering: Algorithms for Load-Balancing

- Main optimization goal
  - Minimize the maximum load on the network links ⇒
    Allows for largest overall traffic increase
    until next upgrade when some load threshold is exceeded
- Optimization algorithms: *TE-Scout* tool developed at T-Systems
  - Simulated annealing (single path per demand)
  - Linear programming (multiple paths per demand possible)
  - Algorithm based on max-flow-min-cut principle
  - Link weight adaptation
    Heuristics for pure IP networks studied by [Fortz & Thoroup]

TE-Scout Tool:
Optimization & representation of path designs

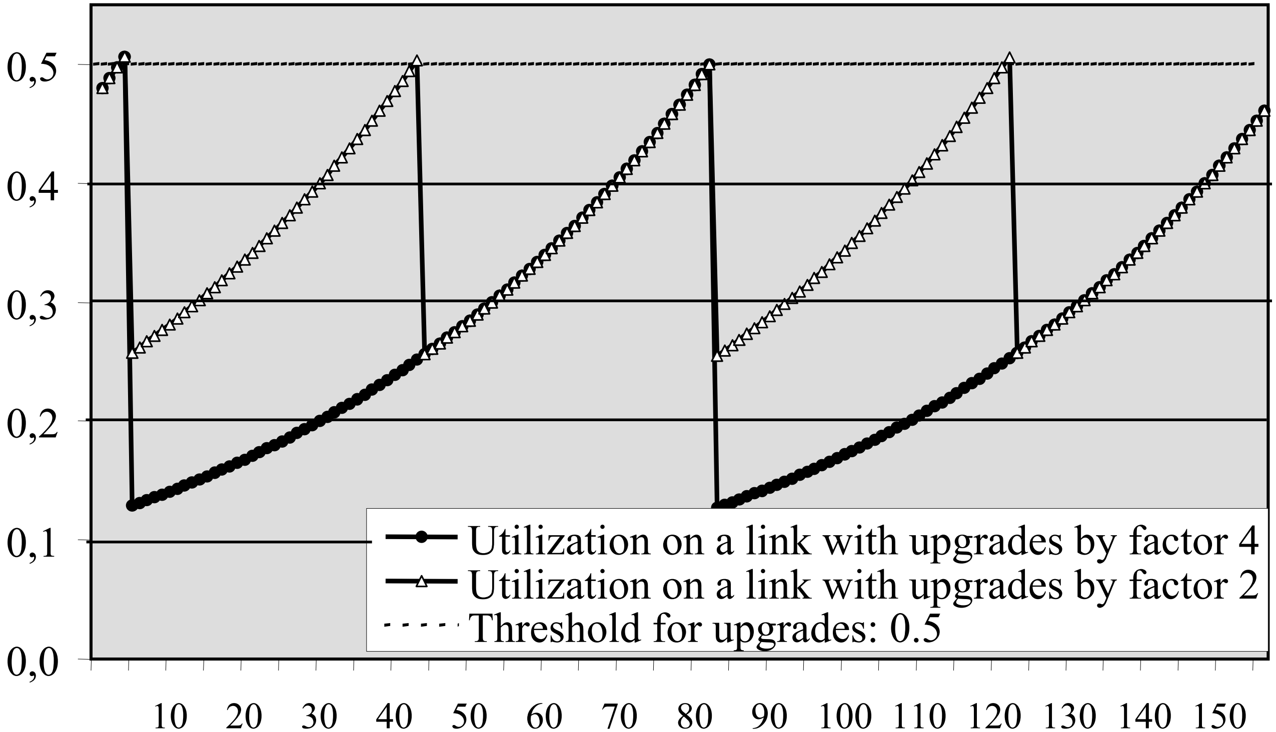


Options for applying
optimization algorithms



Visualization of
paths for traffic demands

Utilization gaps for link upgrades without TE



IP link upgrades to 2- (or 4-)fold capacity reduce the link load to ½ (¼)

Traffic engineering (TE) can use new capacity after a reoptimization with traffic shifts on link

TE yields more constant load close to threshold

Mean load u for threshold based upgrades without TE:

$$u = \frac{T_{\text{Upgrade}}}{F_{\text{Upgrade}} D_{\text{Upgrade}}} \int_0^{D_{\text{Upgrade}}} \exp(\omega x)\, dx = T_{\text{Upgrade}} \frac{1 - 1/F_{\text{Upgrade}}}{\ln(F_{\text{Upgrade}})};$$

$$F_{\text{Upgrade}} = 2 \Rightarrow u = 0.72\, T_{\text{Upgrade}}$$
$$F_{\text{Upgrade}} = 4 \Rightarrow u = 0.54\, T_{\text{Upgrade}}$$

Capacity expansion with TE regarding failures

Assumption: link upgrades are done to twice the capacity

Expansion strategy to decide, which link upgrade to do next:

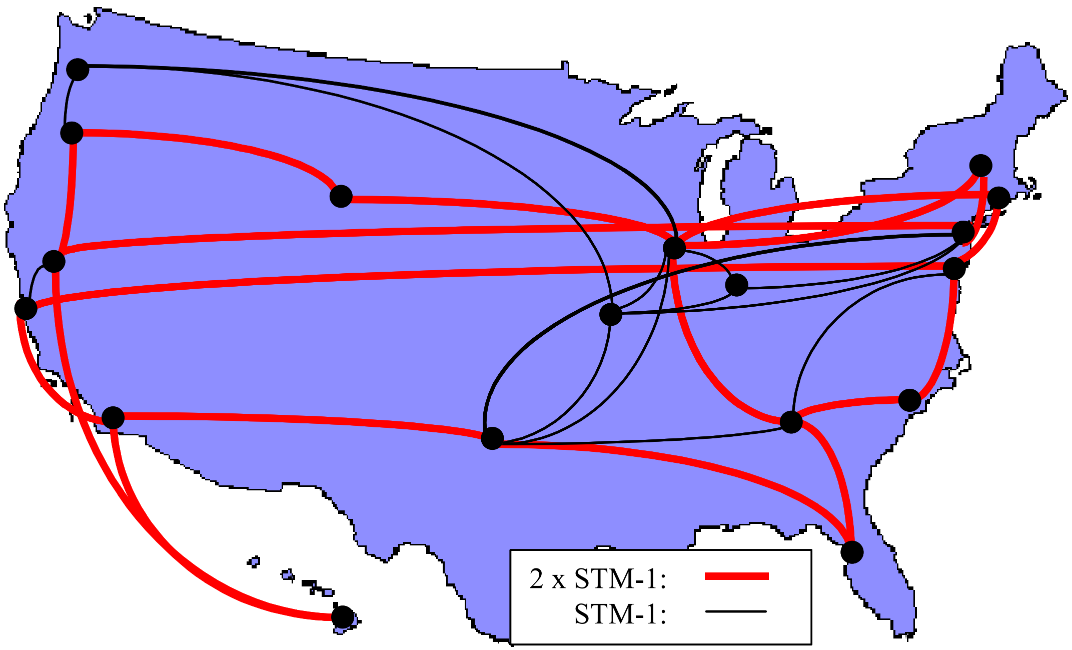
Optimized load balancing solution are computed by the TE tool

- for the worst cases of single link failures, which cause the largest reduction of allowable throughput including those, whose throughput is no more than 10% better than the worst case(s)
  in combination with
- all link upgrades
- Score function for measuring the improvement of a link upgrade with regard to the considered worst failures

⇒ The link yielding the highest score is to be upgraded next

Capacity assignment with regard to single link failures

- Example: Logical Sprint IP backbone topology [Fraleigh et al. 2003]
- Allowable effective mean load: $L \overset{def}{=} \lambda_{\max} \sum_{j,k=1}^{N} d_{\min}(j,k) t_{jk} / \sum_{e \in E} cap(e) \approx 66\%$



$d_{\min}(j,k)$: number of hops on the shortest $j \rightarrow k$ path

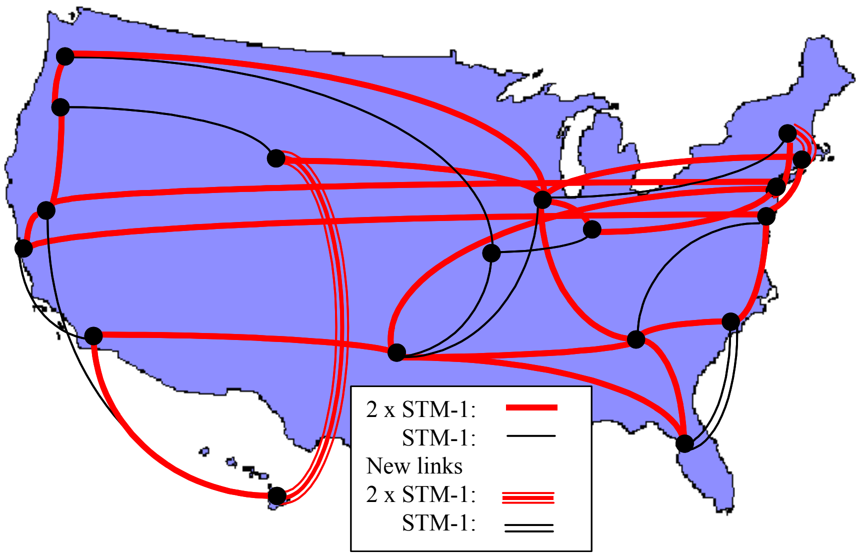
t_{jk}: traffic demand $j \rightarrow k$

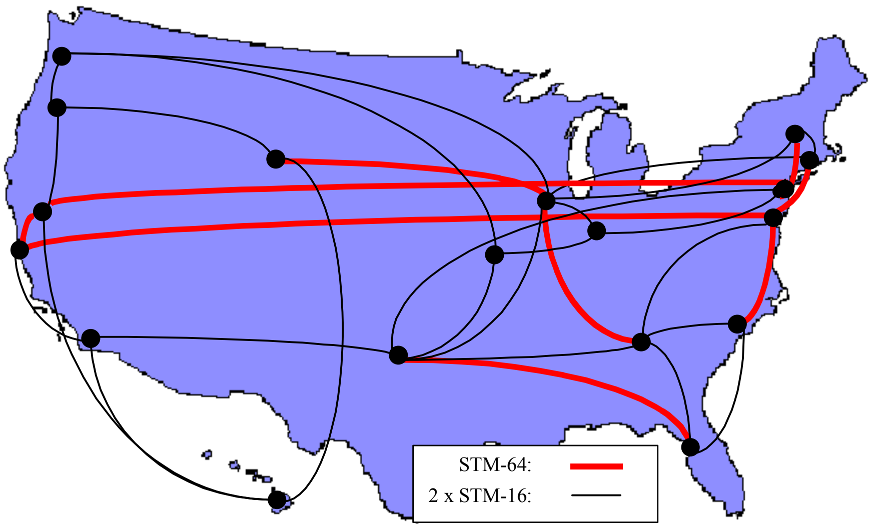
$\lambda_{\max} T$: maximum allowable traffic throughput with TE optimization

$cap(e)$: capacity of link e

Modified topology with connectivity degree of 3

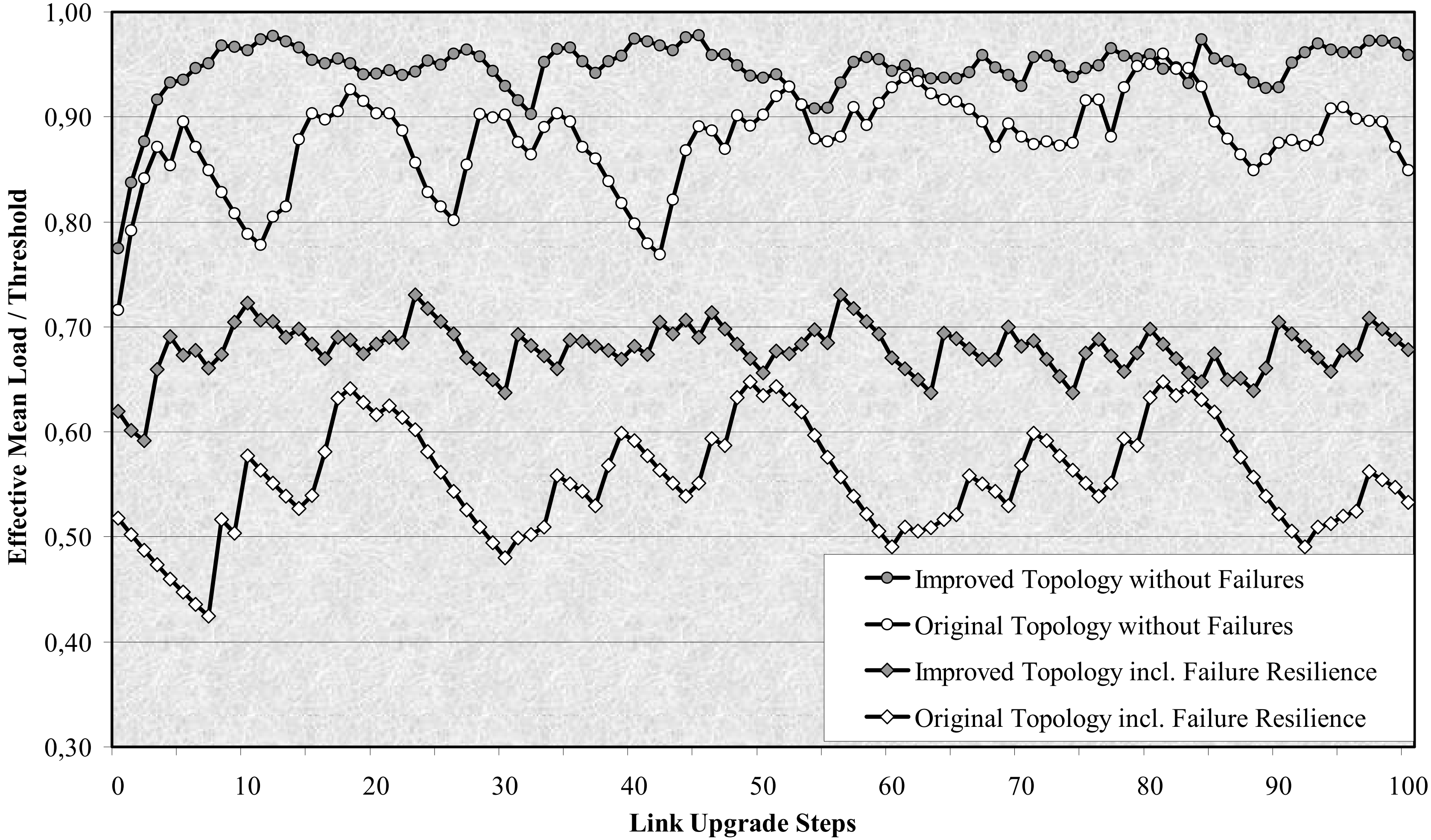
Different capacity assignments achieving 73% effective mean load
encountered after 23 and after 174 steps of a link upgrade process





The long term effective mean load is
- 56% in the original topology
- 68% in the modified topology

Ressource utilization during a link by link capacity expansion process for increasing traffic



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Long term mean effective load during a link upgrade process		
Percentage relative to threshold regarding QoS demands	**Original topology**	**Modified topology (connectivity degree 3)**
Traffic Engineering (TE) for normal operation	**89 %**	**94 %**
Shortest path routing (SPF) for normal operation	**72 %**	**72 %**
Traffic Engineering (TE) including failure resilience	**56 %**	**68 %**
Shortest path routing (SPF) including failure resilience	**42 %**	**47 %**

Conclusions & Outlook

- Load balancing yields about 20-30% more throughput during upgrade processes for increasing traffic in normal operation
- The traffic engineering gain compared to shortest path routing
  - improves when failure resilience is included
  - improves for optimized topologies (higher connectivity)
- Special upgrade strategies are required for TE; computation of alternative upgrading decisions with the help of TE-tools
- For further study: Upgrading strategies;
  Cost functions extending the goal of resource utilization in optimization of topology and capacity assignment