Optimized Incremental Network Planning

Joachim Charzinski[1] and Uwe Walter[2]

[1] Siemens AG
Carrier Core Development / Innovations / Security
81359 München, Germany
`joachim.charzinski@siemens.com`
[2] Institut für Telematik
Universität Karlsruhe (TH)
76128 Karlsruhe, Germany
`walter@tm.uka.de`

Abstract. Network providers aim to offer a high level of service quality in order to satify their customers' requirements. One of the key factors to fulfil this requirement is a careful network design providing enough available transmission capacity. As data traffic tends to increase continuously, network operators regularly face the necessity to upgrade their network to match the growing demands. In this paper, we evaluate and compare different strategies for deciding how many and which links to upgrade. Calculations for example networks demonstrate the efficiency of the strategies in utilizing the newly added capacity. Since optimization of the network's routing further helps to increase resilience and allows a more efficient use of the available resources, we include this approach in our evaluations. Additionally, the possibility to include anticipated failure scenarios during routing optimization is also compared to the other strategies. It is shown that the straightforward approach to upgrade the most utilized link is not necessarily the best choice. Instead, an optimized upgrade planning including routing optimzation can deliver a higher resilience at lower cost.

1 Introduction

In times of increasing customer demands, declining profit margins, and growing pressure of competition, network providers face new challenges. Quality of service (QoS) guarantees, a very efficient network operation, and a high level of resilience are among the key requirements for modern packet-switched networks. Providing QoS requires sufficient available transmission capacity, since overloaded links and congested queues adversely affect QoS.

Even if a provider has dimensioned and configured a network appropriately, they still need to continuously monitor network utilization. Since Internet traffic increases steadily [1, 2], upgrades to the network's capacity are likely to be necessary at some time. Determining the point in time when new transmission capacity is required is not in the focus of this paper. Tools for link utilization monitoring and traffic matrix estimation [3–7] are available for this purpose.

A network operator finally faced with the necessity of increasing network bandwidth to match newly offered traffic must decide how many and which links to upgrade. While the straightforward approach would be to upgrade the most utilized link, other solutions might be more efficient. For example, adding a completely new interconnection could also relieve traffic hot-spots on congested links with the additional benefit of increased resilience against link failures. Depending on the network's size and complexity, choosing the best upgrade strategy can quickly become a difficult challenge. Questions like these do not only arise during incremental network upgrades, but also in the planning phase for new networks.

To use available network resources most efficiently, attention should also be paid towards an appropriate routing configuration. For example, the resilience of a network is enhanced if traffic flows do not aggregate on just a few links while leaving other connections under-utilized without reason. Therefore a lot of research has been done to optimize network routing for a given topology and traffic matrix [8–19].

Usually these approaches modify link metrics[3] (which are used by the routing protocol to determine the shortest paths) in such a way that the maximum link utilization is minimized. While alternatives for this sort of traffic engineering exist (like, e.g., via MPLS paths), this paper focuses on the described adaptation of link metrics.

It is even possible to anticipate possible link failures in the routing optimization [20–23]. In this case, link metrics are generated that help to prepare the network routing for a good performance, even under the given failure scenarios.

In Sec. 2 we introduce the traffic model, reference networks, and some basic assumptions used in our evaluations. The problem of incremental network planning is elaborated in Sec. 3. The perspective of routing optimization for traffic management is brought in by Sec. 4, showing that well-chosen routing parameters can drastically increase a network's utilization and its resilience to failures. Finally, in Sec. 5 different strategies for upgrading routing-optimized networks are presented and their performance results are compared.

2 Traffic Model and Reference Networks

Our evaluations are based on the three different reference networks A, B and C shown in Fig. 1. Network A is the COST 239 reference network [24] with 11 nodes and 26 bidirectional links. Its traffic matrix is taken from [24] and all link capacities are initially set to 100 Gbit/s. Network B is the KING [25] reference network with 20 nodes and 53 bidirectional links. Network C is a 26 nodes and 54 bidirectional links world-wide network taken from [26]. The traffic matrices for networks B and C are both constructed such that the traffic from a node N_a to a node N_b is proportional to the product of the populations of the regions around nodes N_a and N_b. In addition, the traffic matrices are initially scaled by

---

[3] Also known as link costs, interface costs, or link weights.

an arbitrary factor such that hop-count based routing in a failure-free network does not overload any link. The corresponding population sizes for Network B are given in Tab. 1. Population sizes for Network C can be found in [26].

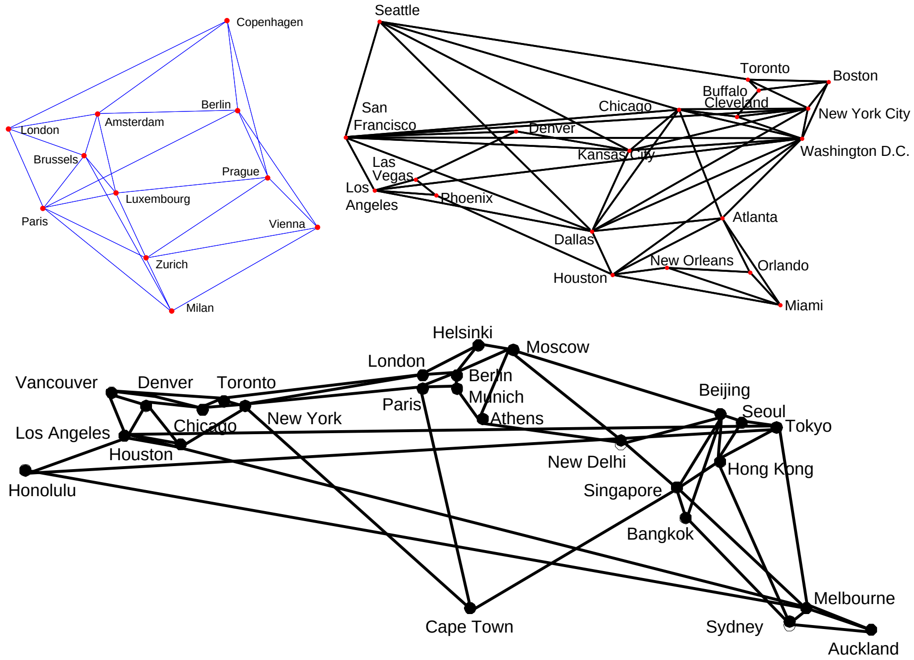

Fig. 1. Reference Network Topologies. Top left: Network A (COST 239), top right: Network B (KING Labnet), bottom: Network C (Worldnet)

Table 1. Population sizes used for calculating the traffic matrix of Network B. For reasons of compatibility with the test network in our network laboratory, only 10 of the 20 nodes actually are traffic sources or sinks. The other 10 nodes are transit nodes only.

Node	Population in 1000
Boston	3407
Chicago	8273
Dallas	3519
Houston	4177
Los Angeles	9519

Node	Population in 1000
Miami	2253
New York City	9314
San Francisco	1731
Seattle	2414
Washington	4923

For reasons of simplicity, in this study we assume

- homogeneous growth, i.e., the whole traffic matrix is scaled with the same factor as traffic grows and

- constant traffic flows, i.e., the difference in multiplexing gain for variable rate traffic on links with different capacities is neglected.

When traffic grows proportionally on all border-to-border relations, the task of finding the right network upgrade strategy that brings link loads down to an acceptable level again is equivalent to the task of reducing the maximum link load in the original network with unscaled traffic matrix. This is why we compare all strategies on the basis of their effect on the maximum link loads in a given network with a given traffic matrix.

Some of our investigations include failure cases, which is an important aspect of traffic management – there is little use in optimizing link capacities and guaranteeing QoS for an ideal network when in reality links fail occasionally. The common approach for failure investigations is to take the worst case single link failure into account [20, 22]. This means that over all possible single link failure cases and the corresponding re-routing, the maximum link load observed on any link is recorded as the "maximum link load for single failures".

In the following experiments, link utilizations were evaluated as if links could virtually carry more than 100 % of their nominal capacity. In a real network situation, this would translate into packet loss. In the network upgrade context of this paper, virtual utilizations of more than 100 % are seen as a reason for further upgrades, which is why it is not useful here to limit traffic at 100 % link utilization in the evaluations.

3 Incremental Network Planning

Increasing a network's capacity is usually done by increasing the capacity of one or more links by at least a factor of two. This comes from the fact that router line cards and link bandwidths are not available at arbitrary transmission speeds. Therefore, hardware upgrades usually at least double the available bandwidth [23]. Thus, we assume the step of doubling a link's capacity as the basic unit of network capacity upgrading.

In the initial network configuration, all interface cost metrics are set to the same value of 2. This means, fowarding traffic via any possible outgoing link is considered to be equally expensive. Since there is no cost difference between all links, the final output of the routing protocol produces what is known as "hop-count based" routing (a short introduction to the concept of interface costs is given at the beginning of chapter 4).

The first experiment is to upgrade the n_u most utilized links of a network and to check what value of n_u is required to significantly reduce the maximum link load in a network. As a basis for this procedure, Fig. 2 shows the link loads observed in networks A, B and C versus the link rank, i.e., the link's position in a sorted table of most loaded links for the 20 most loaded links in each network.

Each link is only indicated once with the maximum of the loads observed in each of the two directions. In order to make link loads predictable, the equal-cost multi-path (ECMP) option [27] of the routing algorithm is assumed to be turned

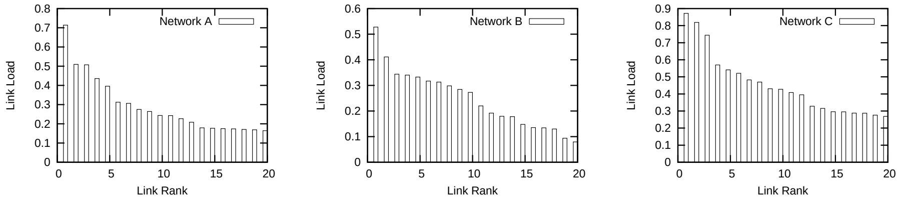

Fig. 2. Link utilizations (sorted) of the 20 most loaded links in Networks A, B and C with hop-count routing (all interface cost are equal). Left: Network A, Middle: Network B, Right: Network C.

on. Using ECMP ensures that in case of equal-cost paths, traffic is distributed equally among the two. It is out of the scope of this paper to discuss the precise details of the hash tables required to make this work in a real network without destroying the packet sequence within a connection. However, it is important to note that turning on ECMP is an important prerequisite for any kind of traffic engineering or traffic management to allow external tools to predict link utilizations. Otherwise, all equal-cost paths and the corresponding ambiguous routing decisions would lead to an ambiguity in load prediction.

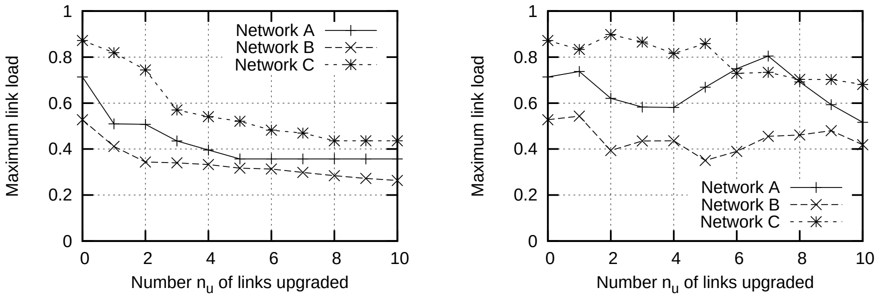

Fig. 3. Maximum link load in Networks A, B and C after upgrade of the n_u most loaded links to twice their original capacity. $n_u = 0$: no link upgraded (original maximum link load). Note that the data points have only been interconnected by lines to improve readability of the graph. Left: link metrics unchanged after upgrade, right: link metric of upgraded links divided by two.

In Fig. 3, the result of upgrading the n_u most loaded links in a network is visualized. The experiment was carried out as follows:

- Identify the n_u most loaded links in the original network. The load of a bi-directional link is defined as the maximum load of the two directions.
- Double the capacity of these links for both directions.
- For the right part of Fig. 3, set the link metric of the upgraded links to half the original value. This is done in the attempt to shift more traffic to the

upgraded link whose capacity was increased. By decreasing its (cost) metric, it appears cheaper to the routing protocol to direct traffic via this link, hence it attracts more traffic.

In the left part of Fig. 3, the link metrics are not changed after the upgrades, i.e. they remain homogeneous within the whole network (equal cost for all links).

- Re-compute link loads in the network and plot the maximum link load found versus the corresponding value of n_u.

The left part of Fig. 3 shows the expected result: maximum link loads after an upgrade generally follow the load distribution shown in Fig. 2 (displaying some similarities). However, a load reduction below half the original maximum link load is not possible by just doubling single link capacities – the previously most loaded link will limit the effect of this procedure to reducing the maximum link load to half the original maximum link load.

The right part of Fig. 3 reveals that just intuitively changing link metrics inversely proportional to the link capacity (as suggested as default convention in [29]) and [28] does not have the expected effect. Compared to the left part of the figure (capacity upgrade without change of link metrics), the result is much worse. In a number of cases, the maximum link load after an upgrade is higher than before. Due to the reduced metrics more load is attracted by the upgraded links. This traffic shift can lead to increased load on neighbor links that have to carry traffic previously carried elsewhere in the network. The heuristic of using link metrics inversely proportional to the link capacity leads to a significant waste of upgrade capital in all three networks.

Conclusion: The simple heuristic of combining link capacity upgrades with a reduction of link metrics is much less effective than upgrading capacities without changing metrics.

A straightforward alternative to the above approach is investigated in Fig. 4. Instead of determining the n_u most loaded links and then upgrading them all, the links are upgraded one by one. After upgrading one link and reducing its metric, link loads are determined according to the new routing and the link carrying the highest relative load is selected to be upgraded in the next step. As shown in Fig. 4, this heuristic reaches approximately the same performance as the simple and straightforward method of not changing the link metrics at all.

Instead of upgrading n_u links according to their *utilization before the upgrade* as in Fig. 4, the graph in Fig. 5 shows the result of upgrading *a single link* in the network and dividing its metric by two (as described above). Whereas some of the links lead to a higher maximum load when upgraded, there are others – not necessarily the ones that previously carried the highest utilization – that allow for a significant reduction of the maximum link load in the network. Comparing the results with Fig. 3 and Fig. 4, it can be seen that by carefully selecting the link to be upgraded according to the effect expected from the upgrade rather than to its utilization before the upgrade, in some cases the effect of the upgrade can be improved.

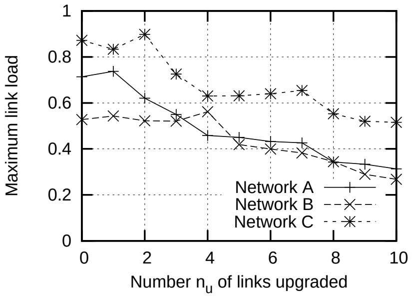

Fig. 4. Maximum link load in Networks A, B and C after upgrade of the n_u most loaded links to twice their original capacity. $n_u = 0$: no link upgraded (original maximum link load). Note that the data points have only been interconnected by lines to improve readability of the graph. Link metric of upgraded links is divided by two and links to be upgraded are selected sequentially.

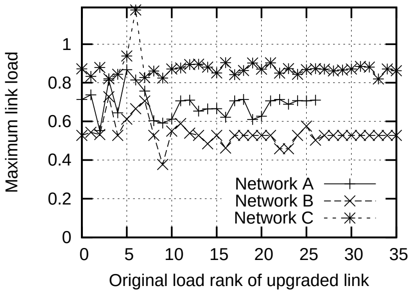

Fig. 5. Maximum link load in Networks A, B and C after upgrade of one link only to twice its original capacity. The maximum link load is plotted versus the rank r of the upgraded link in the original load distribution (Fig. 2). The metric of the upgraded link is divided by two. For reference, the leftmost value (rank 0) indicates the maximum link load before upgrading. For utilizations > 1.0 see the comment at the end of Sec. 2.

4 Routing Optimization

Link loads in a network can be significantly reduced by diverting traffic from highly utilized links to lightly utilized links. Apart from explicit methods like MPLS “Traffic Engineering”, an optimized load distribution can also be achieved by adjusting interface cost metrics, an integer parameter that is assigned to each unidirectional link in the network[4]. The sum of interface cost metrics determines the “cost” of a route – equivalent to the “length” of a path in “shortest path” routing – between two nodes, and thus influences the path selected for traffic between these nodes.

---

[4] Assigning the cost metric to an unidirectional link or to the interface that transmits traffic via the respective link, does not make a difference. Hence, the term “interface cost” or “link cost” denote the same value in the context of this paper.

The optimization tool used in this paper is based on a genetic algorithm improved by a special "directed mutation" operator [22]. The objective function measuring the quality of an individual solution (a set of cost metrics for all unidirectional links) to be optimized was different for the two application cases:

- normal operation: the objective function to be minimized is equal to the maximum of all link utilizations in the network for the given traffic matrix and metric set.
- optimization for single link failures: the objective function is equal to the maximum of all link utilizations observed in the network for the given traffic matrix and metric set *under all possible single link failure conditions.* This means that for each generation and each metric set in the population to be evaluated, all link failures, the corresponding re-routing and the corresponding load distribution have to be evaluated.

The optimization was carried out with 10000 generations per run.

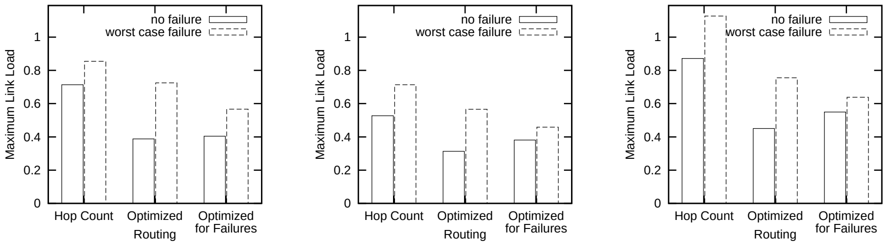

Fig. 6. Maximum link loads for normal operation and for worst single link failure with hop-count routing, optimized metrics and metrics optimized for single failure cases. Left: Network A, middle: Network B, right: Network C. For utilizations > 1.0 see the comment at the end of Sec. 2.

The optimization results are summarized in Fig. 6: In all three networks, the reduction of maximum link loads by routing optimization is in the order of 30–50 %. As can be expected, including link failures in the optimization has a slightly adverse effect on the maximum link utilization during failure-free operation, but yields the benefit of a significant reduction of link loads in the worst failure cases.

5 Optimized Incremental Network Planning

5.1 Extending an optimized network

For extending a network with optimized routing, the same two basic strategies as discussed in Sec. 3 are available: (a) increase the capacity of the n_u most utilized links or (b) increase the capacity of a link and divide its metric by two.

As already discussed along with Fig. 3, the effect of simply upgrading the n_u most loaded links is limited by the utilization of the link ranked n_u+1. As routing optimization leads to a much more equalized utilization of links than simple hop-count based routing, many links bear approximately the same utilization close to the maximum. E.g., in Network A, the ten most utilized links in the network with optimized routing have utilizations above 90% of the maximum link utilization – correspondingly 10 links would have to be upgraded to reduce the maximum utilization by 10%. In contrast, with hop-count based routing, the second most loaded link in Network A has less than 72% of the utilization that the most loaded link has (see Fig. 3) – allowing a single capacity upgrade to reduce the maximum link utilization in the network by 28%.

Fig. 7 reports results gained with a heuristic similar to the one in Fig. 5: For each single link, the option of doubling its capacity while dividing its metrics by a factor of two is tried out and the resulting maximum link utilization is reported in the graph.

The results in Fig. 7 show that this strategy bears a high risk of overloading other parts of the network. **None of the link upgrades results in lowering the maximum link load in the network** – the best result achieved is to have the same maximum link load as before the upgrade. In Fig. 7 this can be seen as for all of the load curves $L(k)$ there is $L_{up}(k) \geq L(0)$ for all $k > 0$ in all of the networks and both optimization cases.

5.2 Optimized Network Extension

The authors suggest the following, novel approach for upgrading a network with optimized routing. For the given network, "what-if" metric optimizations with different link upgrade options should be run. These "what-if" simulations evaluate the theoretical network condition, after a simulated upgrade of each link in question. The best results of these test scenarios should be selected as candidates for upgrades, as shown in Fig. 8.

In this way, the best link to upgrade is identified, which is not necessarily the link that had the highest utilization before the upgrade.

Fig. 8 shows that both in the case of optimization for the failure-free network and optimization for single failures, upgrading a single link and re-optimizing metrics reduces the maximum link load in most cases. If the link to be upgraded is selected according to the effect achievable after metric re-optimization, very good results can be achieved. The best result is not necessarily achieved by upgrading the link that carried most load before the upgrade.

To upgrade a network running with optimized routing metrics, re-optimization of metrics is required together with the upgrade. Selecting the link to be upgraded according to the load reduction achievable after re-optimization yields best results.

6 Summary and Conclusions

The different strategies shown in Figs. 3, 5, 7 and 8 are summarized in Tab. 2. In this table, the last row of each column indicates the figure that displays the experiment results of the given strategy, so its definition can be found.

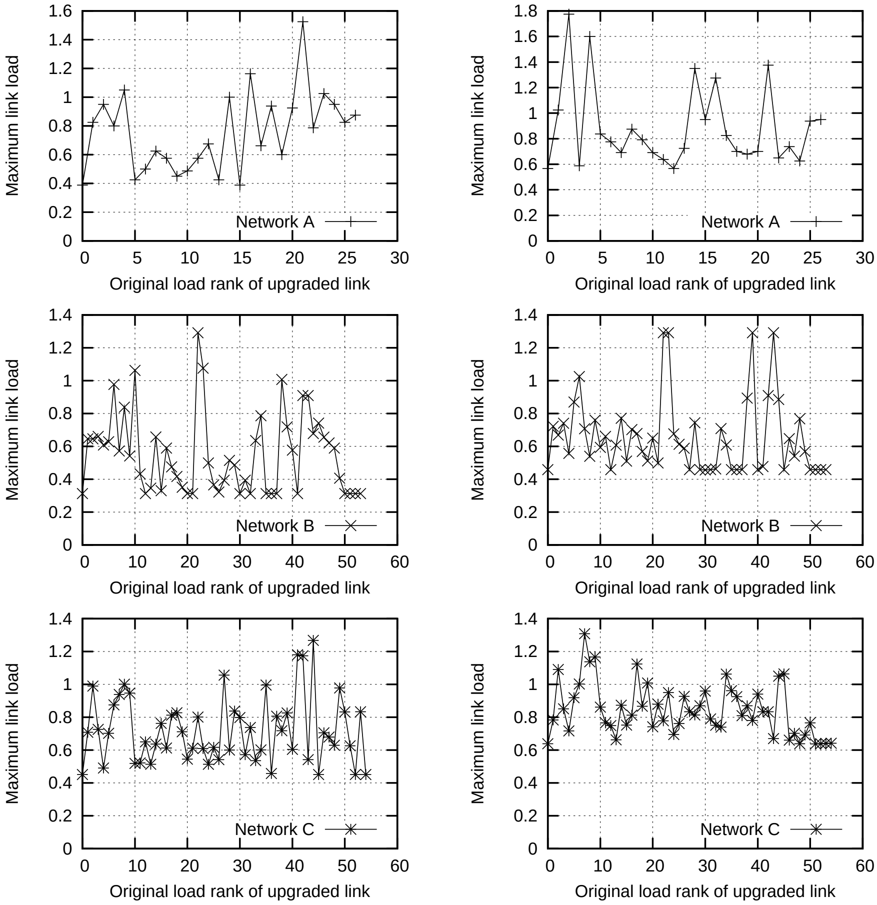

Fig. 7. Link loads in Network A (top) to C (bottom) after upgrading link k versus original load rank k of upgraded link without metric re-optimization. Heuristic: metric of upgraded link divided by two. Left: without link failures, right: originally optimized for link failures and load under worst case single link failure. The leftmost value (link rank 0) indicates the corresponding maximum link load before the upgrade. For utilizations > 1.0 see the comment at the end of Sec. 2.

Fig. 9 gives a summary of relative reductions of maximum link loads achievable with the different strategies. Strategies S2, S4 and S5 do not lead to a significant reduction of link loads despite the investment into more capacity in the network. While in Strategy S3 the heuristic of simply dividing the link metrics by two for the upgraded link works fairly well, the same strategy completely fails if applied to a network with optimized metrics (S4, S5).

For networks without optimized routing metrics, the best strategies are S1 and S3. For networks with optimized routing metrics, the upgrade must be combined with metric re-optimization to benefit from increased link capacity. Note

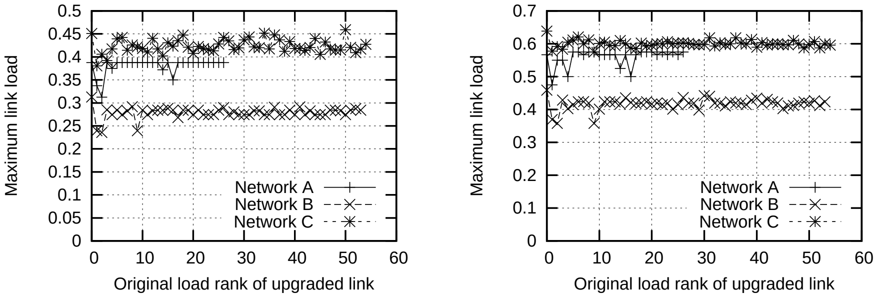

Fig. 8. Link loads after upgrading versus original load rank of upgraded link including metric re-optimization. Left: without link failures, right: optimization for link failures and load under worst case single link failure. The leftmost value (link rank 0) indicates the corresponding maximum link load before the upgrade.

Table 2. Summary of upgrade strategies.

Strategy	S1	S2	S3	S4	S5	S6	S7
Basic routing scenario							
homogeneous metrics (hop-count)	x	x	x				
metrics optimized for normal operation				x		x	
metrics optimized for single link failures					x		x
Choice of link to upgrade							
most loaded	x	x					
most effect after upgrade			x	x	x		
most effect after upgrade and metric re-optimization						x	x
metric change after upgrade							
none	x						
metric of upgraded link divided by 2		x	x	x	x		
re-optimize						x	x
see Fig.	3(L)	3(R)	5	7(L)	7(R)	8(L)	8(R)

that with optimized routing, the load reduction is relative to the values reported in Fig. 6 which are already significantly lower than for non-optimized routing.

Summary of findings for networks without optimized routing metrics:

- Upgrading one link without changing metrics is about as effective as the divide-by-two heuristic.
- A simple strategy of dividing metrics by two for upgraded links can be counter-productive.
- The metric reduction heuristic should be combined with searching for the right link to upgrade, but even then it is not better than simply upgrading the most loaded link without changing metrics.

Summary of findings for networks with optimized routing metrics:

- Optimized routing can deliver resilience against single failures at a lower maximum link utilization than hop-count based routing without resilience.

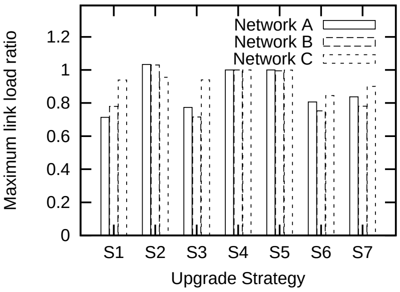

Fig. 9. Summary of relative link load reductions achievable by doubling the capacity of one link in Networks A, B and C. Results are ratio of maximum link load after upgrade to maximum link load before upgrade in the respective routing scenario. Strategies are explained in Tab. 2.

- Simply upgrading the most loaded link makes much less sense than in a non-optimized network, because in an optimized network many links have roughly the same load.
- Using the metric reduction heuristic is of no use at all.
- Combining link upgrade with metric re-optimization will almost certainly help reducing link loads, no matter which link is upgraded.
- Deriving the choice which link to upgrade from optimization runs will give best results.

In future work, the mechanisms discussed here should be combined with real-life constraints such as different cost for links of different length, or operators' desire to take latencies into account in routing optimization. Other extensions or constraints, such as dealing with fully occupied router frames that do not allow upgrading certain links or links terminating at a certain router, are straightforward to include in the proposed upgrading strategies.

Acknowledgements

The authors would like to thank Christoph Reichert for letting them use his powerful metric optimization tool to generate the results reported in this paper.

References

1. Odlyzko, A.M.: Internet traffic growth: Sources and implications. In: Proceedings of Conference on Optical Transmission Systems and Equipment for WDM Networking II, Boston, USA. (2003)
2. Fomenkov, M., Keys, K., Moore, D., k claffy: Longitudinal study of Internet traffic from 1998-2003. In: Winter International Symposium on Information and Communication Technologies (WISICT), Cancun, Mexico. (2004)

3. Feldmann, A., Greenberg, A., Lund, C., Reingold, N., Rexford, J., True, F.: Deriving traffic demands for operational IP networks: methodology and experience. In: SIGCOMM '00: Proceedings of the conference on Applications, Technologies, Architectures, and Protocols for Computer Communication, Stockholm, Schweden. (2000)
4. Medina, A., Taft, N., Salamatian, K., Bhattacharyya, S., Diot, C.: Traffic Matrix Estimation: Existing Techniques Compared and New Directions. In: Proceedings of the ACM SIGCOMM Conference, Pittsburgh, USA. (2002)
5. Zhang, Y., Roughan, M., Duffield, N., Greenberg, A.: Fast accurate computation of large-scale IP traffic matrices from link loads. In: Proceedings of the 2003 ACM SIGMETRICS International Conference on Measurement and Modeling of Computer Systems, New York, USA. (2003)
6. Zhang, Y., Roughan, M., Lund, C., Donoho, D.: An Information-Theoretic Approach to Traffic Matrix Estimation. In: Proceedings of the ACM SIGCOMM Conference, Karlsruhe, Germany. (2003)
7. Gunnar, A., Johansson, M., Telkamp, T.: Traffic matrix estimation on a large IP backbone: a comparison on real data. In: Proceedings of the 4th ACM SIGCOMM Internet Measurement Conference (IMC), Taormina, Italy. (2004)
8. Riedl, A.: A Versatile Genetic Algorithm for Network Planning. In: Proceedings of EUNICE 98, Munich, Germany. (1998)
9. Fortz, B., Thorup, M.: Internet Traffic Engineering by Optimizing OSPF weights. In: Proceedings of IEEE Infocom. (2000)
10. Lorenz, D.H., Orda, A., Raz, D., Shavitt, Y.: How good can IP routing be? Technical report, Center for Discrete Mathematics & Theoretical Computer Science (DIMAX) (2001)
11. Riedl, A.: A Hybrid Genetic Algorithm for Routing Optimization in IP Networks Utilizing Bandwidth and Delay Metrics. In: Proceedings of IEEE Workshop on IP Operations and Management (IPOM), Dallas, USA. (2002)
12. Ericsson, M., Resende, M., Pardalos, P.: A genetic algorithm for the weight setting problem in OSPF routing. Journal of Combinatorial Optimization **6** (2002)
13. Buriol, L.S., Resende, M.G.C., Ribeiro, C.C., Thorup, M.: A memetic algorithm for OSPF routing. In: Proceedings of 6th INFORMS Telecommunications Conference, Boca Raton, USA. (2002)
14. Fortz, B., Thorup, M.: Optimizing OSPF/IS-IS Weights in a Changing World. IEEE Journal on Selected Areas in Communications **20** (2002)
15. Fortz, B., Rexford, J., Thorup, M.: Traffic Engineering With Traditional IP Routing Protocols. IEEE Communications Magazine **40** (2002)
16. Mulyana, E., Killat, U.: An Alternative Genetic Algorithm to Optimize OSPF Weights. In: Proceedings of Internet Traffic Engineering and Traffic Management, 15-th ITC Specialist Seminar, Würzburg, Germany. (2002)
17. Fortz, B., Thorup, M.: Increasing Internet Capacity Using Local Search. Computational Optimization and Applications **29** (2004)
18. Gous, A., Afrakhteh, A.: Traffic Engineering Through Automated Optimisation of Routing Metrics. In: Trans-European Research and Education Networking Association (TERENA), Rhodes, Greece. (2004)
19. Rexford, J.: Route optimization in IP networks. In: Handbook of Optimization in Telecommunications. Kluwer Academic Publishers (2005)
20. Nucci, A., Schroeder, B., Bhattacharyya, S., Taft, N., Diot, C.: IGP Link Weight Assignment for Transient Link Failures. In: Proceedings of the 18th International Teletraffic Congress (ITC-18), Berlin, Germany. (2003)

21. Fortz, B., Thorup, M.: Robust optimization of OSPF/IS-IS weights. In: Proceedings of International Network Optimization Conference (INOC), Evry/Paris, France. (2003)
22. Reichert, C., Magedanz, T.: A Fast Heuristic for Genetic Algorithms in Link Weight Optimization. In: 5th International Workshop on Quality of Future Internet Services (QoFIS), Barcelona, Spain. (2004)
23. Hasslinger, G., Schnitter, S., Franzke, M.: The Efficiency of Traffic Engineering with Regard to Link Failure Resilience. Telecommunication Systems Journal **29** (2005)
24. Batchelor, P., et al.: Ultra High Capacity Optical Transmission Networks: Final report of Action COST 239. CIP, Zagreb, Croatia (1999) ISBN 953-184-013-X.
25. Schollmeier, G., Charzinski, J., Kirstädter, A., Reichert, C., Schrodi, K., Glickman, Y., Winkler, C.: Improving the Resilience in IP Networks. In: Workshop on High Performance Switching and Routing (HPSR 2003), Torino, Italy. (2003)
26. Milbrandt, J., Menth, M., Kopf, S.: Adaptive Bandwidth Allocation for Wide Area Networks. In: COST-279 Management Committee Meeting, Antalya, Turkey. (2005)
27. Moy, J.: OSPF Version 2. IETF, RFC 2328 (1998)
28. Cisco Systems Inc.: ATM Switch Router Software Configuration Guide. (2001)
29. Oran, D.: OSI IS-IS Intra-domain Routing Protocol. IETF, RFC 1142 (1990)