Optimization of backup tree structures, reducing spare capacity in optical networks, while retaining protection speed.

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Abstract **One of the research activities within the Broadband Communication Network group (part of the Department of Information Technology, INTEC) deals with the optimal design, planning and/or dimensioning of networks. The goal of this 2-page abstract is to give a description, suitable for outsiders, illustrating how a certain network design problem was tackled. By decomposing the problem and by using Integer Linear Programming (ILP), graph algorithms and heuristic methods, it could be solved for practical problem instances in a reasonable amount of time. The concerned network problem is a spare capacity allocation problem targeted specifically for future optical networks and its protocols ([1]).**

Keywords **spare capacity allocation, shared protection, Backup Tree, ILP, heuristic, MPLambdaS, network resilience, network survivability, protection switching**

I. The Problem

A. Context|

Optical Transport Networks (OTNs) can be represented as a graph comprising a set of nodes (sources and destination of network traffic) connected via links. The traffic is transported via connections called lightpaths. Since node or link failures in OTNs can affect a vast amount (hundreds of Gbit/s) of traffic, recovery against (at least single) failures is crucial. This can be realized by a technique called Dedicated Protection (DP). To protect the primary working path (WP1) used to establish the connection n1–n7, we set up a backup path (BP1), as depicted in the left part of Figure 1. When a failure is detected along the WP1, there will be a switchover to BP1 in the source. Likewise, detection and switch over in the destination node will occur. This is a fast and simple scheme. Note that such working paths (WPs) or backup paths (BPs) consume resources in the network. In the left figure, one can count nine needed (unidirectional) wavelengths, providing two protected network connections (lightpaths).

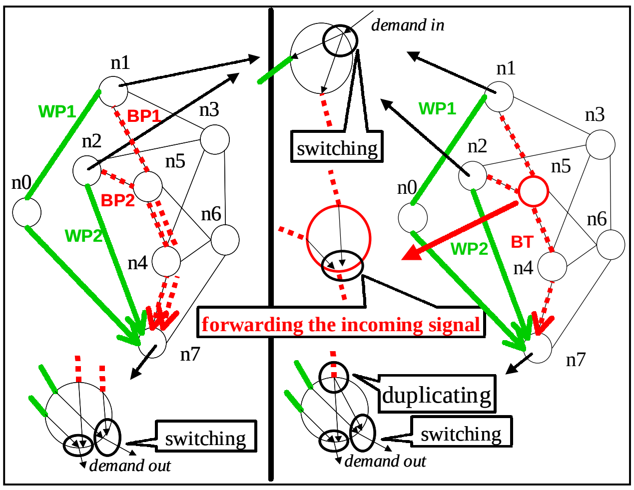

Figure 1: left: two Dedicated Protected connections; right: the Working Paths protected by a Backup Tree

Network failures are rare events, but from the customer point-of-view they often take unacceptably long to be solved. Furthermore, the network operator wants to reduce the cost of delivering his service of providing e.g. the two protected connections to the customer. Both arguments lead to the fact that an operator often only wants to protect at a single network failure (link or node) at a time.

The right part of the figure shows how to reduce the number of required resources *while retaining the simple but extremely fast dedicated protection switching*, under the assumption of single failures. In contrast to the network on the left, we let (fatter) node n5 forward the incoming signal (along the dotted backup wavelengths), whether it comes from n1 or n2, to a *single* outgoing rest of the path towards the destination node n7. Assuming that only WP1 or WP2 will fail at a given time, node n5 will only see one incoming signal at a time. This can be accomplished by making WP1 and WP2 link and node disjoint, as in the figure. As such, *one* **Backup Tree** (BT) protects both WPs from n1 and from n2 (both to the same destination n7). Thus, compared to the solution at the left, we deliver the same service using two (directed) wavelengths less.

Note that using a (directed) *tree structure* going to a single destination node (more details can be found in [1]), nodes like n4 and n5 can be pre-configured (defined in [2]) at set-up time to forward signals from specified incoming ports to one specified outgoing port. This is exactly the same as what was done in the dedicated protection solution and allows for the same fast protocol action. At failure time, the nodes n4 and n5 do what they were told to do (long before).

B. Optimization Problem Definition

The purpose of BTs is to lower the total capacity consumption of wavelengths in the network to fulfill and protect a traffic demand in an OTN (taking into account some restrictions inherent to optical networks). The question to answer is how to place the Working Paths (WPs) and Backup Trees (BTs) in order to minimize the (link weighted) amount of used wavelengths. A BT will protect some of the WPs towards a given single destination node provided that they are disjoint. A BT can be seen as a "shared representation" of a collection of overlapping backup paths (compare the left and the right part of the figure to see this).

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Given a directed graph, with a node-connectivity of at least 2 (in order to enable protection), given a cost for the use of a wavelength (= capacity unit) on a link and a given traffic demand between the nodes, then, the optimization problem is in essence:

- the Working Paths (WPs) should fulfill the connection demand
- a Backup Path (BP) should be (node) disjoint with its WP
- WPs of connections to the same destination node should be mutually disjoint as much as possible
- BPs of disjoint WPs to the same destination should be overlapping as much as possible
- BPs of disjoint WPs to the same destination that overlap should form a tree structure (a BT) to that destination (so once they overlap they should continue to overlap until the destination node is reached)
- the objective is to minimize the cost in terms of wavelengths that are consumed by the WPs and the BT (the cost is based on the known cost for having a directed wavelength on a given link)

II. Solution Approach

A. Basic idea

This optimization problem is highly coupled, making it hard to solve. The problem can be split up into independent subproblems: one for each destination node (with the demanded working connections to it as input). Next, the basic idea to solve such a subproblem was to *divide the whole set of demanded connections towards a single destination node, into smaller sets of working connections that are to be protected by the same sole BT.* For each such a smaller set, the routing of the WPs and the BT can be done (like depicted by in the right part of figure (or even like in the left part, where we have one BT for each WP)). This routing needs to meet the constraints described above. The smaller sets where these routing constraints indeed can be met, need to be identified. Next, the cheapest combination of them fulfilling together the original whole set of demand (towards that single destination node) should be pointed out.

B. Brute force

The problem can be formulated as one large ILP problem with binary, integer and continuous variables (see [9]). Unfortunately, because no fast algorithm exists for solving an ILP with a lot of discrete variables -- one of the state of the art solvers can be found at [3] --, this (brute) ILP approach proved unfeasible for realistic network sizes.

C. Decomposition

Therefore the problem was split up into **3 components** that are depending on each other and ***several techniques***. A first component was called the **"Subdemand Space Reducer" (SSR)** and has the task to determine the ***sets of working connections (subdemands)*** that can efficiently share their BPs in one and the same BT. This was done by gradually building up towards larger sets and recursively eliminating non-feasible or non-efficient subdemands.

Next, a **"Routing"** component was assigned the responsibility to look for a minimum cost routing for the WPs and the corresponding BT for a given a set of working connections. After a first ***ILP*** implementation, a ***simple but fast heuristic graph algorithm*** based on ***Minimum Cost Node Disjoint Flows (MCF)*** ([6]) and ***Steiner Tree*** ([7]) estimates, was introduced.

The last component **"Combining & Partitioning"** strives to find a minimum cost combination of the sets of working connections (in the reduced space of the subdemand sets from above) that fulfills the given input demand of working connections. A straightforward ***ILP approach*** was sufficiently fast for the used input data, but faster ***heuristic*** algorithms exist for this kind of ***covering positive linear programming problems (see [8])***.

III. Example Result

Aimed with a computational feasible approach and in order to look at the benefits of BTs, we took a realistic long-haul OTN network (that can be found in [5]), having 14 nodes, 28 links. This OTN provides 2.5 Gbps uni-directional wavelength paths for an IP layer. The IP layer was fed a realistic traffic demand (supplied with IP MPLS working traffic and local protection providing resilience against IP router failures) and the resulting OTN demand was derived consisting of 144 connections.

The described approach (using heuristic routing) for the dimensioning of the complete network (= all destinations, several BTs per destination) indicated a reduction of 16.74% in total cost when using BTs instead of dedicated node-disjoint path protection (DP).

IV. Conclusions

We illustrated a single layer network problem, featuring joint routing and dimensioning of spare and working resources. By decomposing the problem and by using several techniques, it could be solved for practical problem instances in a reasonable amount of time. We have the intention to include in our poster a more detailed and graphical illustrated description of the rationale for the problem, the problem description itself, the approach to it and the results. These can also be found in [4].

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ABSTRACT < 150 WORDS:

One of the research activities within the Broadband Communication Network group (part of the Department of Information Technology, INTEC) deals with the optimal design, planning and/or dimensioning of networks. The goal of our poster is to give a description, suitable for outsiders, illustrating how a certain network design problem was tackled. We illustrated a single layer network problem, featuring joint routing and dimensioning of spare and working resources. By decomposing the problem and by using several techniques, it could be solved for practical problem instances in a reasonable amount of time. A detailed and graphical illustrated description of the rationale for the problem, the problem description itself, the approach to it and the results will be presented.