A Software Architecture for a Photonic Network Planning Tool

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Abstract

In this work we present a software tool for the planning of multi-layer photonic backbone networks. We consider the *Routing and Assignment of Wavelengths* problem (called RAW) in the optical layer and include a consideration of the electrical layer. The resulting planning problem is very complex, which can be shown by the fact that already the RAW problem is NP-hard. Our approach for a software architecture embeds heuristic and non-deterministic optimization algorithms in a framework of a Simulated Annealing based optimization method. Furthermore, we try to separate the algorithms from the complex data structure of the network model by providing so called *Access Interfaces*. Therefore, different algorithms can be added as modules to the optimization environment.

1. Introduction

Networks with photonic technology might play a leading role in satisfying future broadband requirements. In the field of wide area networks WDM (Wavelength Division Multiplexing) is a mature optical technology for high data rate transmission. However, network providers must extent their existing network infrastructure in order to use the advantages of the photonic technology. Therefore, future networks will contain a multi-layer structure with an electrical layer and a WDM based optical backbone layer.

Comprehensive network planning that is necessary due to the high costs of network components must consider many aspects as for example timescale aspects, transmission and switching technology aspects, network area aspects (access network and core network), or network level aspects (physical level and logical level) [3].

First, this paper considers some physical restrictions of photonic networks. Then, we propose a multi-layer network model and describe an approach for a planning process. Finally, we present some results considering the usage of the optical layer.

2. Photonic Networks

2.1 Photonic Backbone Networks

Future photonic wide area networks will probably originate from current networks, because due to economical restrictions the network providers will not be able to build completly new networks. This network evolution might happen by the extension of electrical switching nodes with optical switching functionality. Therefore, photonic networks will have two transport layers, and we denote them as electrical and optical layer. Although, there is only electrical switching in the electrical layer, optical point-to-point transmission in addition to electrical transmission is possible. Familiar transfer modes in this layer are SDH/SONET or ATM. In the optical layer there is both, optical transmission and optical switching. Large optically switched traffic streams will be carried on wavelength paths building a backbone structure in the optical layer.

2.2 The RAW Problem

A Wavelength Path (WP) is a path between two nodes that are not necessarily adjacent. To establish a WP, it is necessary to find an unallocated, identical wavelength on all links of the WP route. Thus, it is possible to have unused wavelength resources in a network. The task to minimize the unused resources is NP-hard [2].

By usage of Virtual Wavelength Paths (VWPs) the RAW problem does not exist. Wavelength converters for each channel in every node enable the whole usage of the provided wavelength resources. However, wavelength converters cause additional costs. Until now, the question whether the wasting of wavelength resources costs more than the usage of wavelength converters has not been answered.

In [3], further restrictions to photonic technology are described, as for example the limitation of the maximum transmission distance, or the restrictions caused by the tuning speed of optical switching components.

3. Approach for a Network Model

3.1 Modelling Network Elements

This section describes the design of elements in order to model the network (see figure 1). There are two basic node types in our network model, namely *endnodes* and *switching nodes*. Endnodes represent traffic sources and traffic sinks with the aggregated traffic of many single users. This aggregated traffic can be assumed to be a constant parameter during the planning process. Dynamic variations over time can be neglected by taking the peak rate demand as a basis for the traffic requirement between a pair of endnodes.

The electrical layer can be divided into circuit and path layer. The paths (e.g. ATM VPs) are transport paths with multiplexing functionality. Our model does not consider the division in circuit layer and path layer. We simplify the electrical layer by considering only transport paths and denote them as electrical paths.

Switching nodes are divided into electrical and optical switching nodes. Electrical switching nodes have switching functionality for electrical paths guided in the electrical layer. Accordingly, optical switching nodes have switching functionality for WPs (or VWPs) guided in the optical layer. Furthermore, there are hybrid nodes comprising an electrical and an optical switching node at the same location. Only inside a hybrid node a transition between electrical and optical layer exists. At this location the multiplexing of electrical paths into optical paths and vice versa is possible. The multiplexed traffic of an electrical path can be divided arbitrarily into data streams for multiple WPs (or VWPs). Accordingly, the demultiplexed traffic of a WP (or VWP) can also be divided arbitrarily into data stream for electrical paths .

Our model considers ducts between node pairs describing "candidate links". Along these links the laying of fibres is possible.

3.2 Modelling Network Costs

There are two basic cost elements, namely *transmission costs* and *switching costs.* Examples for transmission costs are costs by building ducts and costs by installing fibres. WP lengths also influence transmission costs because the number of electrical regenerators and amplifiers depends on the path length. Traffic passing through a switching node has important influence on the switching costs by its volume and its direction (e.g. transitions to a different layer or remaining in the same layer). Our model employs several non-linear cost functions for electrical and optical switching nodes using the traffic volume as function argument. The exact definition of these functions is impossible today, because important parameters are still not fixed. Investigations in photonic hardware elements (e.g. crossconnects) are in a phase that does not allow a quantitative fixing of many cost parameters. Therefore, the design of a flexible software architecture is very important in order to enable easy changes of cost functions and cost parameters.

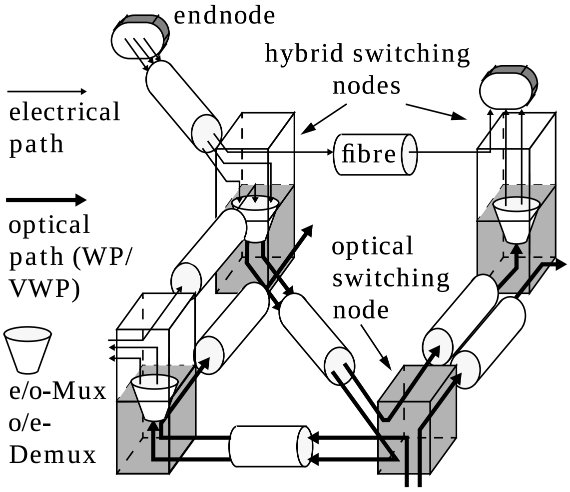

Figure 1: Network model

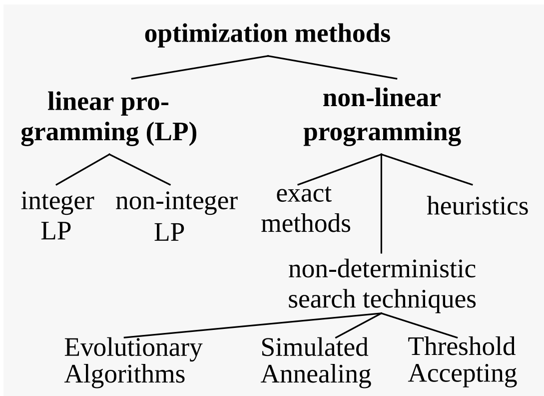

Figure 2: Optimization methodes

4. Approach for a Planning Process

4.1 Optimization Method

The task of our photonic network planning tool is to compute a valid network solution while considering given parameters. The tool must find a solution with a cost value below a given limit by iterative improvements of valid solutions. We transform this task to finding a (sub-) optimal solution for a discrete optimization problem. A valid solution comprises routing all traffic demands from the sources to the sinks. The routing requires to consider both, the electrical and the optical layer. The wavelength assignment restrictions for the routing in the optical layer must taken into account, too. Due to the integrated treatment of electrical layer and optical layer, which has a NP-hard problem as sub-problem, the entire problem is very complex.

One possible classification of optimization methods is given in figure 2. The developed tool uses a combination of the non-deterministic search technique Simulated Annealing (SA) and heuristics. Into the framework of SA a mix of heuristic and non-deterministic transformations is embedded.

SA is an optimization method that imitates a natural process. By slowly metal annealing, the atoms are able to overcome local energy minima. Therefore, by occupying optimal positions the atoms are able to achieve the global energetic optimum. For our task, state transitions are produced by the transformations of the SA method. If the quality of the new state q_{new} is better than the quality of the old state q_{old}, the new state is accepted. If the quality of the new state is worse than the quality of the old state, the new state is accepted with the probability of

$$p = e^{(q_{old} - q_{new})/T} .$$

T is the temperature, that is reduced during the optimization. Due to the probability p there is a certain chance to escape from local optima. This chance decreases with falling temperature.

The kind of transformation is crucial for the success of the optimization. We implemented a mix of non-deterministic and heuristic transformations. Non-deterministic transformations allow in principle to reach every state in the state space. Heuristics can not guarantee that. Because of non-deterministic transformations there is the warranty to reach a state over a quality limit (that means below a cost limit), if such a state exists and the optimization runs infinite time. The problem of non-deterministic transformations is that finding good states can require non-acceptable time. Heuristics usually find solutions with improved quality in a short time.

4.2 Hierarchy of the Software Structure

The chosen software architecture consists of a three level hierarchy. Level 1 comprises the wavelength assignment of the WPs. This means that only for the WP-concept (and not for the VWP-concept) the existence of level 1 is necessary. Level 2 holds routing information of WPs (or VWPs) in the optical layer. WPs begin and end at hybrid switching nodes and lie completely in the optical layer. The routing information for electrical paths is stored in level 3. Beside the storage of the sequence of switching nodes in the electrical layer, the storage of the transitions into the optical layer of any path is important. Each level holds its own data structures, methods to manipulate them, and methods to manipulate data structures of the lower level. The entire data of all levels constitues a valid network solution. Transformations of SA use the methods of the different levels in order to create new network solutions. We emphasize that only the integrated consideration of all levels allows to find a vaild solution. E.g., if there is a transformation with the task to reroute electrical paths, the first step of this transformation is to manipulate the appropriate electrical path lists that hold the order of the used switching nodes in the electrical layer (level 3). But there is the possibility that obsolete or new routes of electrical paths contain transitions in the optical layer. Therefore, a manipulation of the data of level 2 holding all WPs (or VWPs) could be necessary. It must be possible to add or remove WPs (or VWPs) and change the traffic volume of the WPs (or VWPs). If it is required to add or remove a new WP, a manipulation of data in level 1 is additionally necessary. The WP must allocate a wavelength in order to achieve a valid network solution.

Every level has an Access Interface (AI) simplifying the integration of new transformations. The AI methods ensure that only the manipulation of data in that level is possible in which the transformation algorithm wants to work. The forced manipulation of lower level data is encapsulated and executed automatically. Therefore, transformations do not need to consider all levels, but can focus on one level (see also figure 3). The benefit of the encapsulation of lower level data manipulation is the achievement of modularity. Transformations are modules trying to manipulate data using an algorithm that does not know the entire structure of the optimization environment. The AIs are interfaces between the modules and the optimization environment.

Furthermore, polymorphistic structures are designed. Path lists of level 3 store additionally to the transitions into the optical layer the sequence of the (electrical) switching nodes. Path lists of level 2 store the order of the (optical) switching nodes, too. Polymorphism is given by the existence of the same AI calls for level 2 and level 3 allowing manipulation of the switching node order of paths.

Until now, the task of transformations is to find a solution by employing algorithms changing data of only one level directly. A selection of such transformations is given in chapter 4.3. The considerations do not include yet transformations trying to optimize multiple levels together. An example of such a transformation is given by the CAP (colouring adaptive path graph) algorithm [1] that tries to optimize heuristically level 1 and level 2 together. For such transformations the AI must provide additional methods, that do not lead to automatic manipulation of lower level data.

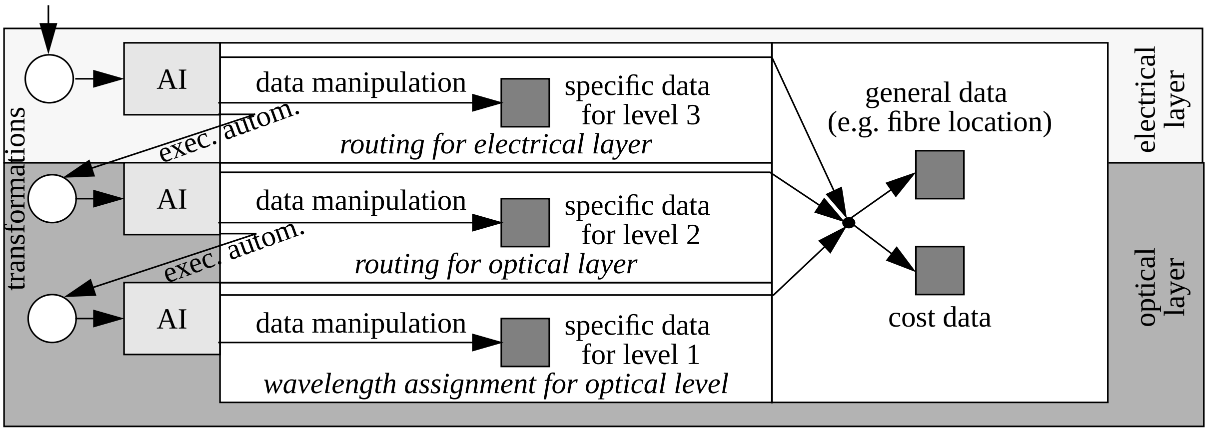

Figure 3: Integration of transformations in the optimization environment

4.3 Transformation Algorithms

In this section we present the implemented transformations of our tool (see also figure 4). The *path transformation* is a non-deterministic transformation that modifies the switching node sequence of an electrical path in the electrical layer or a WP (or VWP) in the optical layer. The *duct transformation* tries to reroute all paths using a chosen duct in order to generate unused ducts. This transformation has a heuristic nature, because it work according the rule: "It is better to lay a fibre along an already used duct than to use a new duct". Like the path transformation, the duct transformation also works in the electrical and in the optical layer. Furthermore, there is a *wavelength assignment transformation* that is pure heuristically. The task of this transformation is to allocate wavelengths so that the number of fibres in the whole network is minimized. Finally, the *transition transformation*, which is also heuristically, tries to multiplex electrical paths into the optical layer.

5. Results

We investigate the dependency of optimization results from network parameters by an example network comprising 6 endnodes and 6 hybrid switching nodes. With the cost function of an electrical switching node $c_{el}(V)$ and the cost function of an optical switching node $c_{op}(V)$ (the argument V describes the traffic volume through a switching node) we define a point of intersection (PoI). This is a result of the assumption, that electrical switching costs are lower than optical switching costs for low traffic volume ($c_{el}(V) < c_{op}(V)$ if $V < PoI$), and that electrical switching costs are higher than optical switching costs for high traffic volume ($c_{el}(V) > c_{op}(V)$ if $V > PoI$). PoI denotes the traffic volume for which the functions c_{el} and c_{op} are equal. Furthermore, we postulate that the maximum data rate of a WP in the optical layer corresponds to the maximum data rate of an entire fibre in the electrical layer (i.e. we assume optical point-to-point transmission on a single wavelength in the electrical layer).With these assumptions we investigate the network by changing two parameters, namely the PoI parameter and the "fibre costs per length" parameter. Every pixel in figure 5 represents the network topology with the lowest total costs our planning tool found. If PoI is increased, less and less traffic passes into the optical layer. If fibre costs are increased, more and more traffic passes into the optical layer, because the influence of the switching costs to the total costs decreases. The question how many fibres must lie in the network becomes more importance. Because in our example WDM is used only in the optical layer, the maximum data rate of a fibre in the electrical layer is lower than the maximum data rate of a fibre in the optical layer. Due to the possibility to minimize the entire number of fibres in the network, there is a benefit of carrying traffic within the optical layer

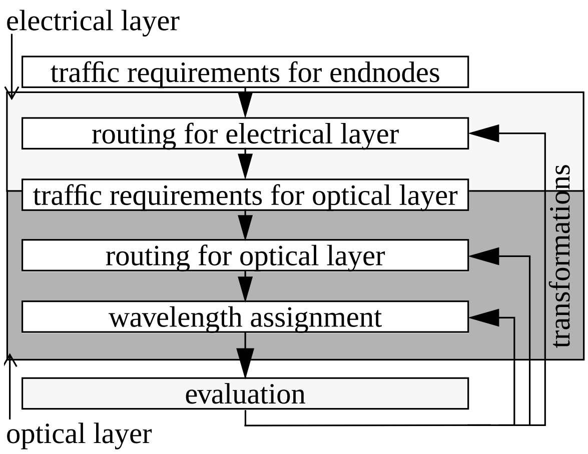

Figure 4: Layering structure

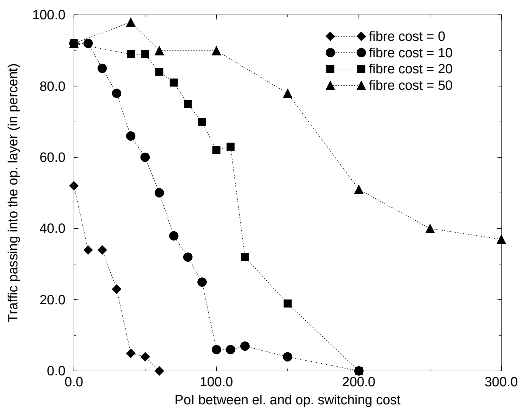

Figure 5: Optimization results

6. Conclusion

In this work we have presented an approach for a flexible and modular software structure for a photonic network planning tool that considers also an electrical path layer. Because many planning parameters are unknown today, a planning tool must be flexible in order to make redesign easier. The algorithms are embedded as modules in a framework based on SA. Thus, the planning tool is adaptable to special problems by exchanging particular algorithms.

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