Approaches for the migration of optical backbone networks towards Carrier Ethernet

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Abstract - This paper describes migration strategies in optical networks. It is expected that the conversion of current transport networks (IP/MPLS over SDH) into more packet oriented (IP/MPLS over Ethernet) technologies will result in significant cost savings for network operators. The state space of a migrating network can be modeled as an directed graph. To find the optimal migration path within this state oriented graph, several approaches, such as the Incremental Migration and the All-Period Migration can be used. Current research results regarding cost development and resource utilization in layer 1 and layer 3 are presented in this work. The effects of several planning techniques within such uncertain environment, like routing and grooming, on the total cost development are discussed, too.

Index Terms - Transport networks, network planning, migration modeling, CAPEX/OPEX costs

I. INTRODUCTION

The traffic demand in optical backbone networks is expected to increase rapidly in the next years. Also the income of network providers is constantly decreasing due to shrinking tariffs for end users. This perspective makes opportunities for any cost reduction imperative. This paper describes how network operators can cope with the increase of backbone traffic in the next years.

Network migration describes a technical process for the upgrade and the exchange of existing hardware/software (infrastructure) to other network devices that generate calculable cost savings for its owner. The shift of classical SDH services towards cost efficient Ethernet services is currently under way, i.e. for high data rate Internet access or global interconnection of company locations [7]. The introduction of Carrier Ethernet services is heavily investigated by most providers, since it promises significant cost savings and a simplification in terms of administration and maintenance.

There are two possible scenarios on the hardware level for the migration towards Carrier-Ethernet [7]. Firstly line cards with MPLS-TP switching capability can be directly added to an existing node, if the node is a so called Multi Service Provisioning Platform (MSPP). In this case, existing and new demands can be mapped to old and new hardware via the Network Management System (NMS). The second possibility is the migration via an overlay, which means that the new hardware will be added to the existing infrastructures in parallel. New demands will then be transmitted only on the new hardware and the old hardware will be upgraded slowly, or even totally replaced in the future. In this paper we investigate the first approach.

The remaining paper is structured as follows. In the second section modeling techniques are described, that are necessary to implement a migration algorithm. The third part is dedicated to migration approaches that have to be considered for a realistic calculation. Section IV is presenting first calculation results and in the last chapter a short conclusion is given.

II. MODEL DESCRIPTION

A. System model

The architectural basis of the migration approach is an actual IP/MPLS/SDH/DWDM network (Fig 1). A possible future scenario and migration approach is illustrated in Fig 2 (IP/MPLS/ETH/DWDM). The target architecture consists of an intelligent optical layer using optical cross connects (OXC) [11, 6] and using an improved Layer 2 using MPLS-TP capable Ethernet switches.

Because exact information about installed hardware in
optical backbone networks is extremely rare the system model has to be abstracted using a simplified model. Many device models for IP routers (IPR), Ethernet switches and OXC’s have been proposed and developed within the NOBEL-2 project [11]. This work is based on the results of NOBEL-2 presented in 2008.

The example presented in Fig 3 shows the basic structure of an IP router core node with several slots. These slots contain slot cards and those can hold several port cards. In the same way the structure of Ethernet switches has been defined. On optical layer the DWDM line is modeled with multiplexers, amplifiers and dispersion compensating fibers (DCF). OXC’s are described by using the Wavelength Selective Switch (WSS) architecture [6, 5, 11]. This broadcast and drop OXC has the advantage of linear scaling costs, but it is only suitable for smaller add-drop-ratios.

The implemented cost model consists of different parts:
- Capital Expenditures (CAPEX) for basic device costs
- Implementation Expenditures (IMPEX) for the installation of devices
- Operational Expenditures (OPEX)

1) CAPEX
For our purposes CAPEX represents the purchase cost of the different devices that are used during the migration. These costs were also proposed in the NOBEL-2 project. The final device costs are calculated by summing up their component costs (slot cards, port cards and basic node), as formulated in equation 1. The component costs are normalized to a 10Gigabit WDM Transponder and therefore, they give a very realistic basis for the optimization of the migration problem.

$$C_{IP-router} = C_{basic-Node} + C_{Slotcard} \cdot N_{Slots} + \sum_{k} C_{Port}^k \cdot N_{Port}^k$$  \hspace{1cm} (1)

Where:
- $C_{IP-router}$: cost of the IP router
- $C_{basic-Node}$: cost of the IP router basic node
- $C_{Slotcard}$: cost of an IP slot card
- $N_{Slots}$: number of used slots in the IP router
- $C_{Port}^k$: cost of a port card with granularity k
- $N_{Port}^k$: number of used port cards in the IP router

2) IMPEX
IMPEX consist of travel cost for employees, extra charges and penalty fees for implementation failures, [9]. Because these costs are extremely uncertain, they have been modeled as a part (20%) of the initial CAPEX, plus an annual increase of 10% (modeling increase of salary, inflation, etc.), as shown in equation 2. Additionally an upper bound for every node has been defined to model the fact that installations at the node benefit the total installation costs.

$$C_{IMPEX}^y = 0.2 \cdot C_{CAPEX} \cdot 1.1^y$$  \hspace{1cm} (2)

Where:
- $C_{IMPEX}^y$: overall IMPEX costs of an device in year $y$
- $C_{CAPEX}$: initial CAPEX cost of an device
- $y$: year used for calculation $\in N$

3) OPEX
The operating cost for the network (or OPEX) has been considered as 10% of the initial IMPEX of a node, since complicated calculations are also very unrealistic due to costs for energy, cooling, security personal and Point of Presence (PoP) rental. The models for OPEX and IMPEX are very simplified, since the main focus of this work is algorithmic research. Existing models can be easily replaced in the future.

C. Traffic model
Because information about realistic traffic flows in optical networks is difficult to obtain, assumptions regarding traffic sources and traffic sinks had to be made. The German 17-node backbone of the Deutsche Telekom AG (DTAG), presented in Fig 4, is used as reference network in this work.

The population density of the German states sharing a backbone PoP is used to calculate this node’s backbone traffic factor. For instance the state of Saxony has 4.23 million inhabitants, by also serving partial traffic of the states Brandenburg (0.86 mil), Saxony Anhalt (0.84 mil) and Thuringia (0.58 mil) a total population for Saxony (node Leipzig) of 6.51 million is assumed. Divided by the reference node Munich (serves 9.62 mil) Saxony has a source traffic factor of about 0.67. Thus Munich has source traffic of 500 Gb/s, and Leipzig produces about 335 Gb/s.

Traffic direction factors were assumed by respecting the geographic location of the nodes. The node Frankfurt, for instance, shall receive one fifth of Germany’s produced traffic and has therefore a very high sink factor of 0.2, since it has connections to France, GB, USA, etc. Other important border nodes like Cologne, Berlin or Hamburg received a sink factor of 0.08. The overall distribution is shown in Fig 5.

Forecasts [15] reveal that the overall backbone traffic in the next years will increase about 40% per year. Since the migration problem is strongly time dependent, this value is used in our investigated model.
The used traffic flows are all emerging from IP layer. Since most emerging traffic coming from metro networks is capsulated in Ethernet frames, a traffic-shift-model towards an Ethernet layer has to be implemented. Because this work focuses on the presentation of a migration in layer 1 and layer 3, this is not shown here.

III. MIGRATION APPROACHES

Network migration can be realized using different planning techniques. Our goal is to find the optimal resource utilization over a certain time scale and therefore the optimal cost scenario.

Firstly, it has to be differentiated between single-layer migration and multi-layer migration. Single layer migration focuses on changes in one layer (i.e. adding OXC’s). Multi-layer migration algorithms will discuss the effects that result from changes in two or more layers (i.e. layer 1 and layer 2). This work is related to the single layer migration, whose results emerge from changes in the optical layer and the IP layer.

Secondly an incremental migration and an all-period migration have to be distinguished. Incremental migration describes a transition from one migration step to the next while only considering possible traffic changes within the next time step. In an all-period approach all time steps are influencing today’s planning result. These planning techniques are discussed in detail in [10]. Basically this work uses the incremental planning idea, which means that only a traffic forecast to the next step is used. Generally, it would be better to make an all-period migration and to make a global traffic forecast over the whole migration period, because system changes can be adapted much more effective in terms of total migration cost. This discussion is scheduled for further work in the project.

The basic steps of the implemented migration algorithm are described by the flowchart in Fig 6. Firstly, a reference network has to be created (section III.A). We then calculate a routing which is kept for all migration steps and the resulting IP transit traffic (IPTT) per node. For every migration step, the IP and optical capacity for every node is checked. If this capacity would be exceeded, a hardware insertion/migration has to take place. In our case, there are five options to insert hardware (devices):

- Insert a fully equipped 640G IP-Router (also an option without migration)
- Insert a 40G IP slot card (also an option without migration)
- Insert a 640G IP-Router with one 40G slot card
- Insert a 1280G IP-Router with one 40G slot card
- Insert an OXC (with assumed capacity of 2 TBit/s and 5 ports)

There are much more options possible which will be implemented later, these five options were chosen to develop a common starting point for the incremental algorithm.

After each step, the IP traffic increases according to the given traffic model. Finally, insertion results are saved (StepMAX defines the maximum number of planned migration steps). Some important parts of the algorithm, such as routing and hardware insertion, are described in further sections.
A. Reference network generation

To create a reference network as starting and end point for the migration, a Greenfield planning has to be made. Therefore, we use Integer Linear Programming (ILP) to describe the planning problem [1, 4, 14]. CPLEX is used to solve the granularities at the different nodes. As described in section II.A the initial network structure is an IP/MPLS/SDH/DWDM network. The criterion to find the optimal initial network is the cost function that has to accumulate all costs of the network (equation 3: partial cost function for a reference network). Conditions that have to guarantee the routing (flow constraints) and the correct granularity of the devices are the constraints for CPLEX. In equation 4, two example constraints for the generation of a reference network are described. The first one describes that the number of incoming channels has to be smaller than or equal to the available WDM capacity of a node (therefore all WDM granularities are accumulated). The second constraint describes that the capacity of different slot cards in a node limits the usable ports in the node.

\[ C_{\text{NET}} = \sum_{k \in \text{OXC nodes}} \sum_{n} y^{k}_{n} c_{\text{OXC}} + \sum_{k \in \text{WDM nodes}} \sum_{n} (w^{k}_{n,\text{in}} + w^{k}_{n,\text{out}}) c_{\text{WDM}} \]
\[ + \sum_{i,j \in \text{links}} \left( l_{i,j} f_{i,j} c_{\text{FIB}} + \left( l_{i,j} f_{i,j} c_{\text{OLA}} + l_{i,j} f_{i,j} c_{\text{DGE}} + \frac{l_{i,j}}{\text{DCF}_{\max}} c_{\text{DCF}} \right) \right) \]
\[ + \sum_{n} a_{n} c_{\text{AMP}} + \cdots \]

\[ y^{k}_{n} \quad \text{amount of OXC's in node } n \text{ of granularity } k \]
\[ k \quad \text{granularity of a device} \]
\[ K_{\text{OXC}} \quad \text{amount of OXC granularities} \]
\[ K_{\text{WDM}} \quad \text{amount of WDM terminal granularities} \]
\[ n \quad \text{node number} \]
\[ N \quad \text{amount of nodes} \]
\[ w^{k}_{n,\text{in}} \quad \text{amount of WDM demux in node } n \text{ of granularity } k \]
\[ w^{k}_{n,\text{out}} \quad \text{amount of WDM mux in node } n \text{ of granularity } k \]
\[ a_{n} \quad \text{amount of amplifiers in node } n \]
\[ l_{i,j} \quad \text{start/end node number of a link} \]
\[ f_{i,j} \quad \text{amount of fibers between } i \text{ and } j \]
\[ c_{\text{FIB}} \quad \text{length dependent fiber costs} \]
\[ c_{\text{OLA}} \quad \text{quantitative costs of an Optical Line Amplifier (OLA)} \]
\[ c_{\text{DGE}} \quad \text{quantitative costs of a Dynamic Gain Equalizer (DGE)} \]
\[ c_{\text{DCF}} \quad \text{quantitative costs of a Dispersion Compensating Fiber (DCF)} \]
\[ l_{\text{OLA}} \quad \text{maximum reach of a OLA in km (in [11]: 80 km)} \]
\[ l_{\text{DGE}} \quad \text{maximum reach of a DGE in km (in [11]: 320 km)} \]
\[ l_{\text{DCF}} \quad \text{maximum reach of a DCF in km (in [11]: 750 km)} \]

\[ \forall n \quad c_{\text{ch}_{n,\text{in}}} \leq \sum_{k \in \text{WDM nodes}} w^{k}_{n,\text{in}} c_{\text{cap}_{\text{WDM}}} \]
\[ \forall n \quad p_{n,\text{ip}}^{\text{in}} \leq \sum_{k \in \text{RS}} s^{k}_{n,\text{ip}} c_{\text{cap}_{\text{G}}} \]

\[ c_{\text{ch}_{n,\text{in}}} \quad \text{usable incoming channels in node } n \]
\[ c_{\text{cap}_{\text{WDM}}} \quad \text{available channel capacity of WDM Terminal with granularity} \]
\[ K_{n} \quad \text{amount slot card granularities} \]
\[ P_{n,\text{ip}}^{\text{in}} \quad \text{amount of useable IP ports in node } n \]

B. Routing

The routing discipline, which may differ from the ILP solution, plays a key role for the discovery of nodes with the most IP transit traffic. To achieve a detailed view on a network routing, algorithms have to implement grooming approaches. Therefore, different grooming algorithms (link-by-link-, end-to-end-, traffic-grooming [8]) are under investigation to discover their influence on the resource utilization in optical backbone networks and thus on the overall migration costs. A basic conclusion [13] is that link-by-link grooming will save hardware on layer 1 but it will consume a lot of IP port cards. End-to-end-grooming will save layer 3 equipment, but will use more wavelengths and requires (photonic) OXC’s. Traffic-grooming can achieve cost savings in both layers but it uses more expensive hybrid OXC’s.

In our implementation, only capacities on layer 1 and layer 3 are considered, which is equal to an assumption of perfect traffic grooming. The given demands are routed with a load-distributed Dijkstra algorithm, which means that the capacity of the next node and next link is analyzed and it is only added to the temporary tree if it is capable to handle the traffic of the current demand. This means that the shortest connection to the target node is not always used. It also prevents the migration algorithm from adding hardware too greedily.

After the routing, the IP transit traffic for each node is calculated by accumulating all passing IP demands. Every node is checked if it has enough capacity on layer 1 and/or layer 3. If the traffic cannot be transmitted, a hardware insertion at this node is necessary (alternatively a rerouting could be started).

C. Hardware insertion

As explained before, there are currently five types of hardware insertions. If a node was declared as potentially problematic, it enters the hardware insertion procedure (Fig 7).

Depending on the situation at the node, different layers are upgraded. If the traffic through the OXC \( T_{\text{OXC}} \) is smaller than its capacity \( C_{\text{OXC}} \) and if the IP traffic \( T_{\text{IP}} \) (starting and terminating) is bigger than the nodes IP capacity \( C_{\text{IP}} \), IP equipment has to be added. In this case, it is checked if there are free IP slots at the node and, if available, just slot cards are purchased. If this is not the case, a random IP basic node is added (full 640G, basic 640G, and basic 1280G). In the other cases, the insertion of an OXC is suitable to route the probably high transit traffic \( T_{\text{IP}} \) at the node. This OXC will be added in a standard configuration.

After serving all problematic nodes, the network should be able to fulfill the routing requirements for the next migration step. As mentioned in section II.C, the traffic of all demands will be increased and the next migration step takes place.

The whole algorithm can be restarted to find an optimum regarding the costs of all migration steps, until a maximum time value is reached. To improve this randomized approach, different heuristic ideas are under investigation. For the
optimal placement of new hardware the Greedy Randomized Adaptive Search Procedure (GRASP) can be used [3]. Another option is the consideration of the migration task as Shortest Path Problem (SPP), where the huge search space is limited and an optimal path through the state graph is calculated.

![Image](Fig 7. Hardware insertion discipline)

IV. RESULTS

The first results of this work shall be the information which devices have to be added, where and when. Therefore, the structure of the output has been defined as follows:

<table>
<thead>
<tr>
<th>STEP</th>
<th>NODE</th>
<th>EDGE</th>
<th>TYPE</th>
<th>AMOUNT</th>
<th>COSTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
<td>OXC</td>
<td>5 [Ports]</td>
<td>37 [CU]</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>0</td>
<td>IPR</td>
<td>16 [Slots]</td>
<td>124 [CU]</td>
</tr>
</tbody>
</table>

The costs during the current migration approach can then be accumulated and separated by the different cost and device types. The presented results were produced by using the incremental migration approach for the German 17 node DTAG backbone network and are differentiated by the two options to insert only IP routers (Fig 8-9) and to insert IP routers and optical cross connects (Fig 10-11). As migration time frame five years were chosen. The figures are labeled with OPEX, IMPEX and CAPEX (described in section II.B) as well as IPPC (IP port card), IPBN (IP basic node) and OPBN (optical basic node). It can be seen that the most CAPEX costs are related to IP port card equipment, which can only be avoided by migration towards Carrier Ethernet. Also IMPEX costs play a key role for the migration, which leads to the conclusion that these costs have to be modeled in more detail in the future.

An important advantage of the direct incremental migration algorithm is its scalability. Since only problematic nodes have to be investigated it scales with $O(n)$ in comparison to GRASP with $O(0.021e^{0.312n})$ for the vertical migration process (which is equal to the application of GRASP to the whole time frame and not just for the determination of the hardware placement in one migration step).

V. CONCLUSION

The approaches of this paper, like the modeling of the different cost components, demand a careful evaluation and improvement. But the presented results show that the research in the area of network migration can save significant costs for the network providers. Our current research focus is the development of a suitable all-period migration as well as on an improvement of the currently implemented OPEX an IMPEX model. Furthermore the theoretical approaches of GRASP and the SPP will be adapted to the practical migration task.

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REFERENCES

Resource Utilization: Only IP router
Migration timeframe: 5 years

Fig 8. Summarized costs for incremental insertion of IP routers to satisfy increasing IP traffic (German 17 node backbone network, yearly timescale)

Resource Utilization: IP router and OXC’s
Migration timeframe: 5 years

Fig 10. Summarized costs for incremental insertion of IP routers and OXC’s to satisfy increasing IP traffic (German 17 node backbone network, yearly timescale)

Fig 9. Differentiated CAPEX costs for incremental insertion of IP routers to satisfy increasing IP traffic (German 17 node backbone network, yearly timescale); IPPC: IP port cards; IPBN: IP basic nodes; OPBN: Optical basic nodes

Fig 11. Differentiated CAPEX costs for incremental insertion of IP routers and OXC’s to satisfy increasing IP traffic (German 17 node backbone network, yearly timescale); IPPC: IP port cards; IPBN: IP basic nodes; OPBN: Optical basic nodes