Load Adaptive Optical-Bypassing for Reducing Core Network
Energy Consumption

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Abstract

We study dynamic reconfiguration of a core IP/MPLS-over-WDM network for adaption to traffic patterns changing during the course of the day. Our approach tries to route the traffic preferably in the optical layer and deactivates unused IP router ports. Our results show up to 57% reduction of power consumption in low-load periods by load adaptive optical-bypassing and deactivation of network element subsystems.

1 Introduction

Energy consumption of photonic data transport networks has been attracting more and more interest over the past years. The reasons are twofold. First, energy consumption already causes a significant portion of the operational expenditures (OPEX). Thus, improving energy efficiency will also reduce the costs of network operation. Second, the power consumption of the Internet already adds up to 0.75% of the entire energy consumption of a typical OECD nation [1]. This may appear to be a small fraction, however, as growth rates in the Internet (especially of data traffic) are still very high with approximately 50% per year also the power consumption will rise proportionally in the future, if no countermeasures are taken. Currently, most (>90%) of the power consumption in data transport is created in the access area. The customer modem or optical network units (ONU) alone contribute to more than 65% of the total power consumption in access networks, with the DSL modem of each subscriber consuming approximately 5–10 W [2]. Even for higher access data rates and new technologies (e.g. fiber to the home, FTTH) the power consumption of the network termination equipment will not change significantly. In the industrialized world the number of subscribers will not climb a lot anymore, and most people are already connected to the Internet. Thus the energy consumption in network access will only rise slowly in the forthcoming years due to increased backhaul capacity. However, data traffic volume is expected to continue its exponential increase. The energy consumption of the core network has a stronger correlation with the transported traffic. This is why the energy consumption of the network core will become dominant in the future, if access data rates are higher than 100 Mb/s [2]. Research efforts should consequently try to improve core network energy efficiency.

Core networks are designed for peak traffic demands [3]. However, it can be observed that the traffic load shows diurnal variations ranging from approximately 25% in the early morning to peak values in the evening [4]. Components and devices following these traffic load variations potentially enable reduction of the energy consumption. In this paper we investigate the energy saving potential of a European core network assuming optical-bypassing and deactivation of net-
work element subsystems during low load periods. We show that 57% of energy can be saved for a network load of 25% compared to the peak network load.

2 Investigated network and demand model

For our investigations we have selected the COST266 European core reference topology shown in Fig. 1. The network consists of 28 nodes and 41 bidirectional edges in a mesh topology. As most 80 channel systems are only used partially we also assume only 40 wavelengths per link with a bit rate of 40 Gbit/s per wavelength.

![Fig. 1. COST266 European core reference network](image)

In our studies – as a first step – we assume that all components in the optical layer remain active all the time (fixed optical layer) and that all unused (IP router) line cards and chassis are switched off, if they become unused (flexible IP layer). Currently, the deactivation of port groups or line cards is only possible via a local craft terminal or an element management system [5]. For automatic deactivation based on the traffic load an interface to the network management system must be implemented. Various system vendors are working on this functionality. Furthermore, it is desirable that the startup times are reduced, which are currently lasting up to some minutes.

We assume that each node is equipped with a core router (e.g. Cisco CRS-1 IP router) configured in such a way that the peak load of all incoming links can be processed. The energy consumption of the router and optical layer components is summarized in [6].

In Fig. 2 the diurnal traffic load of the DE-CIX node in Frankfurt/Main, Germany, is depicted. The red curve (top) depicts the peak traffic (in bit/s), whereas the underlying yellow curve depicts the average traffic (averaged over 15 min intervals). It can be seen that the minimum average traffic is roughly 25% of the maximum traffic. The above numbers can also be used as a good indicator for the change of the traffic load in the core network [4]. In our studies we investigated four different network loads ranging from 25% to 100% of the peak load.

![Fig. 2. Daily usage statistics of DE-CIX node](image)
3 Heuristic approach to reduce core network energy consumption

In the initial state of our simulation the network is totally opaque meaning that the optical connections are terminated at each node, and all demands are processed by an IP router. For routing of the demands with a minimum number of hops we used a 3-shortest (link-disjoint) paths algorithm. As the IP router is the network element with the highest contribution to the total energy consumption optical bypassing (and deactivation of unused subsystems) of IP routers is a promising option to reduce the total power consumption.

To investigate the impact of optical bypasses we successively added transparent connections to the initially opaque network. For these transparent connections we chose a length of three links. The reason is that for the investigated topology the average number of hops of a connection is approximately three. Furthermore, for this choice the maximum transparent reach of a 40 Gb/s optical signal – which is roughly between 1000 and 1500 km – is not exceeded. To select the optical bypasses to be added we used the following heuristic approach. We analyzed 50 random demand realizations for a given traffic load and generated a list of all occurring continuous link tuples of length three. The tuples are sorted by utilization (defined as the product of number of connections times the usage time). The tuple utilized most is added first as an optical bypass to the graph, then the second and so on. The exact position and the ranking of the different optical bypasses is shown in Table 1. We assume that existing connections cannot be switched to an optical bypass (e.g. due to a service level agreement requiring uninterruptable connections). In the following we always used the bypasses determined for a traffic load of 140 Erlang and in the order as shown in Fig. 3.

In the optical layer transparent bypasses can be created by deploying optical cross-connects (OXC)s at the intermediate nodes, and bypasses may be loaded up to the total number of (continuous) wavelengths available (here: 40). We assume that the optical bypasses use the same infrastructure as the original opaque network so no additional capacity is added to the network. We furthermore assumed that it is not possible to shut down an IP node entirely because there is always local traffic at each node.

4 Results

With the above assumptions a minimum power consumption of the entire network comprising both IP routers and optical layer equipment can be calculated based on the data provided in [6]. For the investigated network the standby power consumption is 0.82 MW. The results for different network traffic loads are summarized in Table 2.

For the peak network load a maximum power consumption of 2.77 MW has been determined. It is obvious that the energy consumption is highest for the opaque case with no optical bypasses.

Table 1. Nodes connected by optical bypasses of length 3.

<table>
<thead>
<tr>
<th>Name</th>
<th>Connected nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Paris - Milan</td>
</tr>
<tr>
<td>B</td>
<td>Lyon - Munich</td>
</tr>
<tr>
<td>C</td>
<td>Amsterdam – Munich</td>
</tr>
<tr>
<td>D</td>
<td>Milan – Barcelona</td>
</tr>
<tr>
<td>E</td>
<td>Munich – Barcelona</td>
</tr>
<tr>
<td>F</td>
<td>Lyon – Rome</td>
</tr>
<tr>
<td>G</td>
<td>Rom – Budapest</td>
</tr>
<tr>
<td>H</td>
<td>Munich – Rome</td>
</tr>
<tr>
<td>I</td>
<td>Paris – Barcelona</td>
</tr>
<tr>
<td>J</td>
<td>Berlin - Brussels</td>
</tr>
</tbody>
</table>

Table 2. Reduction of the total power consumption for different traffic loads (standby power consumption: 0.81678 MW)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>140</td>
<td>1.27511</td>
<td>1.18696</td>
<td>6.91</td>
<td>19.23</td>
</tr>
<tr>
<td>280</td>
<td>1.7457</td>
<td>1.57327</td>
<td>9.88</td>
<td>18.56</td>
</tr>
<tr>
<td>420</td>
<td>2.2793</td>
<td>2.00999</td>
<td>12.21</td>
<td>19.03</td>
</tr>
<tr>
<td>560</td>
<td>2.7719</td>
<td>2.46233</td>
<td>11.17</td>
<td>15.84</td>
</tr>
</tbody>
</table>

Fig. 3. Determination of optical bypasses by highest usage determined for a network load of 140 Erlang.
By adding 10 optical bypasses the total energy consumption is decreased by approximately 11% in the case of peak network load (Fig. 4, Table 2). If only the variable power consumption (power consumption above standby, which can actually be influenced by optical bypassing of IP routers) is regarded, this part is decreased by 15.8%.

For loads lower than the peak capacity the maximum power consumption (which occurs for the totally opaque network scenario with no bypasses) is reduced due to the fact that only line cards and chassis are powered up when needed (Fig. 5, Table 2). In the case of 25% network load (equivalent to 140 Erlang in our studies) a maximum power consumption of 1.28 MW has been calculated. By adding 10 optical bypasses this number can be reduced by another 6.9% (or 19.2%, if only the dynamic portion of the energy consumption is referred to). This leads to a total reduction of the power consumption of 57% compared to the peak network load.

From Table 2 it can also be observed that the reduction of the dynamic portion of the power consumption is approximately 19% for network loads of 140 to 420 Erlang when adding 10 optical bypasses. In the case of peak network load (560 Erlang), however, the reduction of the dynamic portion of the power consumption is reduced to 15.8%. This can be attributed to the fact that some links (especially in the center of the network) may be fully loaded and detours to these routes have to be taken leading to a lower utilization of the (statically predetermined) optical bypasses. Also the use of optical bypasses may be limited due to the unavailability of free network resources.

5 Conclusion

We have presented a study of the energy consumption of an optical core network. The use of ten optical bypasses can decrease the dynamic portion of the power consumption by approximately 19% compared to an opaque network. We have shown that the total power consumption of a network can be decreased by 57% during low load periods by optical bypasses in combination with deactivation of unused IP node subsystems.

6 References

