Energy Efficient Virtual Topology Configuration Algorithm for IP Over WDM optical Networks

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ABSTRACT

Until recently the main limitation to the development of networks was the cost of equipment and transmission. Today the main problem is the increasing energy consumption. A number of studies estimate the energy consumption of ICT in a range of 2%-10% of global power usage with telecommunication networks occupying a large part of this proportion. For this reason, in recent years considerable efforts are made in order to create energy efficient networks architectures. In this context, this paper focuses on reducing the energy consumption of an IP Over WDM backbone network using lightpath bypass and traffic grooming capabilities. Although previously proposed schemes based on lightpath bypass and grooming strategies can reduce the overall energy consumption on a network they do not take into account the minimization of the number of the lightpaths that should be established in the virtual topology. To overcome the above mentioned drawback a novel power-aware heuristic, called Online Virtual Topology Configuration (OVTC), which will focus on energy efficiency issues related to the operation phase of a WDM optical network is proposed. This model which is mainly based on lightpath bypass and grooming capabilities, reduces the number of lightpaths that should be established in the virtual topology, disabling and reusing lightpaths which data could be routed via alternative pre-established lightpaths and thus reduces the overall power consumption. Simulation results indicate that the proposed architecture manages to achieve a percentage of power saving by up to 6%, compared to similar proposed techniques for energy-saving.

KEYWORDS

Energy consumption; IP over WDM, lightpath bypass, traffic grooming, energy efficiency.

1 INTRODUCTION

Information and Communications Technology (ICT) is responsible of a percentage which varies from 2% to 10% of the world’s power consumption. ICT sector produces some 2% to 3% of total emissions of greenhouse gases. Moreover, it is estimated that this percentage might double in the next decade. An important part of these emissions, about the one sixth, is attributed to telecommunication networks [1]. Researchers have estimated that the ICT industry, which comprises Internet and cloud services, discharges more than 830 million tons of carbon dioxide every year [2].

In recent years the energy efficiency of communication networks has received a lot of research attention. Energy is becoming the issue of our future because energy consumption is causing dramatic climate changes. Worldwide the growth rate of Internet users is about 20% per year, while in the developing countries this growth is closer to 40-50% [3]. The need for a “green” eco-friendly Internet becomes more and more urgent.

This paper focuses on the energy efficiency of optical networking technologies. Current optical networks are mainly implemented with WDM technology which offers greater bandwidth, faster connections and generally more reliable networks. As the traffic load increases the cost and the power consumption of the network increase too. The power consumption in an optical network is mostly due to the devices placed at the nodes and the links of the network.

This work studies optical networks for backbone transport of traffic. The backbone networks are composed of multiple nodes which
are connected in ring or mesh topologies. Links between these nodes consists of optical fibers and typically use wavelength division multiplexing to serve the network requests. In typically large core networks each fiber consists of 40 to 80 wavelengths, while each wavelength may have a capacity of 1, 2, 5, 10, 40 and 100 Gbps. The major energy consumption is mainly in the IP layer of WDM networks where high capacity routers and electrical components (electrical devices in which the optical signal is converted into electrical and visa versa) are the most important source of energy consumption. The total energy consumed in a core network is the sum of the energy consumed by the links and the nodes in the network. More precisely, about 10% of the total energy is consumed in the links while the remaining 90% is consumed in the IP routers.

From the network design perspective an IP Over WDM network may be implemented in two ways, namely lightpath bypass and lightpath non-bypass. The differences between these two architectures concern capabilities of optical switching. Under the lightpath bypass strategy the signal remains exclusively in the optical domain, bypassing the processing of IP packets in the intermediate nodes and thus avoiding the Optical/Electronic/Optical conversions. In contrast, under the lightpath non-bypass strategy, all lightpaths incident to a node of the network should be terminated, processed (OEO conversions) and forwarded by intermediate IP routers in the IP layer.

A set of published papers have considered energy efficiency in the design of IP Over WDM networks. Authors in [4] and [5] make comparisons between heuristics which either providing grooming capabilities or not. It is noticed that heuristics based on grooming techniques always perform better in terms of energy consumption compared to those which do not. Despite this fact, these techniques do not take into consideration the reduction of the number of lightpaths that should be established in the virtual topology. The term virtual topology (VT) describes the actual routing of the signals (lightpaths) between the network nodes.

To combat the above-mentioned drawback a novel power-aware heuristic called Online Virtual Topology Configuration (OVTC) is proposed. In [6] the so-called ISLB model focuses on energy efficiency issues related to the planning phase of a WDM optical network. With respect to [6], OVTC scheme is an enhanced version of the ISLB and is applied during the operation phase of the network. OVTC reduces the number of lightpaths that should be established in the virtual topology, by disabling and reusing lightpaths which data can be routed via alternative lightpaths and thus decreases the overall energy consumption. Extensive simulation results indicate that the proposed scheme performs better than the Multihop-Bypass approach when applied in the operation phase improving the total energy consumption with a percentage of power saving by up to 6%.
2 NETWORK MODEL

2.1 IP Over WDM Architecture

The network scenario that is considered in this work consists of two layers, the IP layer and the optical layer, so that raw IP packets can transmit directly over the optical layer, as shown in Figure 1. Specifically, in the IP layer, each core IP router is connected to an optical switching node via short-reach interfaces, while collecting IP traffic from peripheral access routers. In the optical layer, the optical switching nodes are interconnected by optical fiber links that carry a maximum number of wavelengths. WDM transponders perform EO and OE signal conversion needed for transmitting (or receiving) signals towards (or coming from) WDM links. For multiplexing/demultiplexing of the optical signals at the output/input ports of the switching node, a pair of optical passive multiplexer/demultiplexer are used for each fiber link. In order to enable the optical information to traverse long distances, In-line Erbium Doped fiber Amplifiers (EDFAs) are placed at regular distances. Moreover, two more EDFAs are used at the multiplexer output (booster) and at the input of the demultiplexer (pre - EDFA) on each fiber link.

2.2 Traffic Grooming on Lightpath Bypass Technique

Through the Lightpath Bypass strategy, virtual links are created between all nodes of the network, with a capacity which ought to be adequate to support the entire traffic load traversing the nodes. The main characteristic of this method is that all lightpaths incident to a node which is not the actual destination node, straight avoid the intermediate node and move forward until they reach the destination node. This method implies that for each node pair a virtual link must be established no matter how much traffic demand is actually required. Most of the times this could lead to low capacity utilization of the medium.

Introducing traffic grooming capabilities [7, 8] on Lightpath Bypass strategy, different pairs of nodes are allowed to share common lightpaths with a unique constraint not to exceed the maximum capacity of the wavelength. Although this approach, which performs aggregation of traffic, uses pre-established lightpaths to route some requests and as a result increases the overall power saving of the network, implies the OEO conversion at the intermediate nodes on the virtual topology.

Figure 2 illustrates schematically the operation of the lightpath bypass strategy using aggregation of traffic in a 4-node network (nodes A, B, C and D) with two existing lightpaths, named ac and cd. Considering this figure the overall power consumption of a new-coming connections ad carried by the pre-established lightpaths ac and cd using traffic grooming is also examined. When ad connection arrives at the network the appropriate procedures of the OEO conversions are taking place in order for the former to be multiplexed on the existing connection ac (grooming phase). The signal is then transmitted via the WDM transponder, amplified by the optical amplifiers (EDFAs) and finally received by a WDM transponder at node C. The appropriate OEO conversions are repeated so for ad connection to be multiplexed on cd (grooming phase). A compatible WDM transponder transmits the signal which is amplified by the EDFAs until it reaches the destination node D and received by a WDM transponder.

3 POWER CONSUMPTION ANALYSIS

3.1 Energy Consumption Contribution

In this study the main components which can influence the total power consumption of an IP Over WDM network are the IP routers, the WDM transponders and the optical amplifiers (EDFAs). They can be analyzed as :

**IP routers:** This contribution arises when traffic is electronically processed by IP routers in the intermediate nodes, when the traffic grooming method is enable in order to accomplish grooming or degrooming of traffic...
TABLE 1  
VARIABLES & PARAMETERS FOR THE STUDY

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>physical topology G=(N,E), which consists of N nodes and E links</td>
</tr>
<tr>
<td>m, n</td>
<td>indexes of the nodes in the physical topology</td>
</tr>
<tr>
<td>i, j</td>
<td>indexes of the nodes in the virtual topology</td>
</tr>
<tr>
<td>C_{ij}</td>
<td>number of wavelengths between node i and node j</td>
</tr>
<tr>
<td>W_{mn}</td>
<td>number of used wavelengths between node m and node n</td>
</tr>
<tr>
<td>A_{mn}</td>
<td>number of EDFAs used on each physical link between nodes m and n</td>
</tr>
<tr>
<td>f_{mn}</td>
<td>number of optical fibers between nodes m and n</td>
</tr>
<tr>
<td>E_r, E_t, E_e</td>
<td>energy consumption of an IP router port, a WDM transponder and an Edfa respectively</td>
</tr>
<tr>
<td>L_{mn}</td>
<td>physical distance between nodes m and n</td>
</tr>
<tr>
<td>\Delta_i</td>
<td>the number of ports used to collect traffic from peripheral access routers at node i</td>
</tr>
<tr>
<td>[\lambda]</td>
<td>traffic demand matrix which indicates traffic between each node pair. The traffic demand between each node pair is generated by a random function uniformly distributed within the range [10, 2X-10] Gb/s where X{20, 40, 60, 80, 100, 120]</td>
</tr>
</tbody>
</table>

where the variables and the parameters used in (1) are defined as shown in Table 1.

4 ONLINE VIRTUAL TOPOLOGY CONFIGURATION

4.1 Problem Definition

The Online Virtual Topology Configuration (OVTC) heuristic is defined as:

Given:
1) A network topology G = (N,E)  
2) A set of unknown connections (dynamic scenario)  
3) Power consumption of each component

Goal:  
Disable or Reuse pre-established lightpaths on the Virtual Topology in order to decrease the number of the established lightpaths to reduce the total energy consumption

4.2 Heuristic Approach

The main idea of the proposed scheme is that for every examined request, all previously served requests are examined again in order to disable a number of pre-established lightpaths from the Virtual Topology to save energy, as shown in Figure 4.

Assuming that ac is the new coming connection and the four previous connections are already established lightpaths. Applying the OVTC scheme, all previous request are examined again in multiple ways in order to delete (if this is possible) lightpaths from the
virtual topology. In this example, the third request (ab) can be routed via the first (aw) and the forth (wb) lightpath. Thus, the total number of the established lightpaths on the virtual topology are four (aw, pq, wb and ac) instead of five (aw, pq, ab, wb and ac) and as a result the total energy consumption is lower. Specifically, the request ab becomes inactive and its data is transferred through the requests aw and wb. The important difference between the OVTC and the Multihop Bypass scheme is that the latter algorithm checks the previous requests once to find a combination of lightpaths to accommodate the new-coming connection. In this example, there is no such combination and thus, there is not any lightpath to be reused. The pseudocode shown in Figure 3 depicts the exact operation of the proposed algorithm.

4.3 Algorithm Description

The OVTC is an online algorithm which examines and serves the requests for lightpath establishment upon their arrival one by one in a serial fashion.

The proposed scheme is divided in two main phases. The first phase consists of the actual configuration of the current virtual topology by deleting or reusing pre-established lightpaths and the second phase consists of the power consumption computation of the established lightpaths on the virtual topology.

Figure 5 illustrates the flowchart of the heuristic. The algorithm begins by retrieving a node pair from the unknown set of connections, to be examined and served in following steps, and tries to route it on the virtual topology via pre-established lightpaths. At this point the algorithm enters the configuration phase.
If there is a combination of lightpaths whose capacity is sufficient to accommodate the examined request, the algorithm routes the request over VT and updates the remaining capacity of virtual connections used by the request (reusage of lightpaths). After that, all previous requests are checked again in an effort to decrease the number of established lightpaths. If there is enough free capacity to accommodate the current (again checked) requested traffic demand, the algorithm routes the request over VT, updates the remaining capacity of the virtual connections used by the request and deletes the current request (deletion of a lightpath). On the other hand, if there is not enough capacity to accommodate the examined request, the algorithm checks again all previous requests in order to disable and update, if needed, lightpaths and virtual links’ capacity on VT. Then a new direct virtual link for the initial (examined) request is created and added on VT. By the end of this phase, it is ensured that there are not any other combinations of lightpaths to accommodate the entire bandwidth of a request.

During the second phase of the algorithm the total power consumption of the served connections on current configured VT is calculated. The two phases of the algorithm are repeated until all connections have been examined and served.

5 NUMERICAL RESULTS

5.1 Case Study

In this study two networks were considered. The first network, consists of 6 nodes and 8 links (6node-net) as shown in Figure 6(a) and the second network, called NSFNET (National Science Foundation Network) consists of 14 nodes and 21 links as shown in Figure 6(b).

5.2 Cumulative Power Consumption

The estimates for the energy consumption as comes from the Multihop Bypass approach implemented in [4] and the proposed Online Virtual Topology Configuration heuristic are given in Figure 7. More precisely bar charts in Figures 7(a) and 7(b) show the comparisons of the above mentioned schemes in 6node-net and NSFNET networks respectively.

In both methods the total energy consumption when the average traffic demand varies from 20 Gbps to 120 Gbps per node pair is calculated as the sum of the energy consumed on each configured virtual topology for each new incoming request. In both networks it is noticed better energy performance of the proposed OVTC design compared to the reference model of Multihop Bypass approach [4]. These results are translated into profit by up to 5,5% and 6% in terms of energy savings as shown in Figures 8(a) and 8(b) for 6node-net and NSFNET networks respectively.

5.3 Number of reused/disabled lightpaths

In addition to the cumulative energy consumption and the percentage of power saving, two graphs are presented indicating the actual number of reused (Multihop Bypass, OVTC methods) or disabled (OVTC method) lightpaths between different design schemes in
Figure 6. (a) 6node-net and (b) NSFNET.

Figure 7. Cumulative power consumption in (a) 6node-net and (b) NSFNET.

Figure 8. Percentage of power saving (%) in (a) 6node-net and (b) NSFNET.

graphs show the extent over which the OVTC architecture performs better than the Multihop Bypass strategy.

It can be seen that the absolute number of the reused or deleted lightpaths, when the Multihop strategy is applied presents a significant drop, while the OVTC scheme follows an upward trend in both test networks when the average traffic demand is increased from 20 Gbps to 120 Gbps per node pair. This is due to the fact that the Online Virtual Topology Configuration method can process connections which traffic demand is over the 40 Gbps, while the Multihop Bypass method does not. More precisely in NSFNET for an average traffic demand of 40 Gbps, the Multihop Bypass approach reuses only about 18 lightpaths, while the OVTC model reuses and disables about 46 lightpaths from a total number of 274 lightpaths that should be established on the virtual topology.

Figure 9 (9(a) and 9(b) for the networks 6node-net and NSFNET respectively). These line
Figure 9. Number of reused/disabled lightpaths between different design schemes in (a) 6node-net and (b) NSFNET.

6 CONCLUSION

As backbone network energy consumption is increasing at an alarming rate, this study focuses on the reduction of the power consumption of an IP Over WDM core transport network. A new power-aware model is proposed in order to reduce the number of lightpaths that should be created in the virtual topology during the operation phase of the network. The proposed scheme disables or reuses lightpaths which data could be routed via alternative lightpaths and thus reduces the overall energy consumption. Extensive simulation results indicate that this model can increase the percentage of power saving by up to 6% comparing with existing implementations.

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