Green Networks: An energy-oriented model for IP Over WDM Optical Networks

G. A. Beletsioti
Dept. of Informatics
Aristotle University of Thessaloniki, GR-54124
gmpelets@csd.auth.gr

C. A. Kyriakopoulos
Dept. of Informatics
Aristotle University of Thessaloniki, GR-54124
kyriak@csd.auth.gr

G. I. Papadimitriou[1]
Dept. of Informatics
Aristotle University of Thessaloniki, GR-54124
gp@csd.auth.gr

P. Nicopolitidis[1]
Dept. of Informatics
Aristotle University of Thessaloniki, GR-54124
petros@csd.auth.gr

E. Varvarigos[1]
Dept. of Comp. Eng. & Inform.
University of Patras
Rion, GR-26500
manos@ceid.upatras.gr

[1]Senior Member IEEE

Abstract—**The rapid spread of the Internet has brought a significant increase in energy consumption of network equipment. Since the energy crisis and environmental protection are of increasing concern in recent years, many research efforts are in use to save energy. In this context, the present research focuses on reducing the energy consumption of an IP over WDM backbone network using the lightpath bypass strategy. Schemes based on lightpath bypass strategy were previously proposed aimed at reducing energy consumption. Although these approaches, which perform aggregation of traffic, can increase the overall power saving, they suffer from low reuse of lightpaths. To overcome the above drawback this paper proposes a new efficient heuristic called Intelligent Search Lightpath Bypass (ISLB) which will focus on energy efficiency issues related to the planning phase of a WDM optical network. This model is based on traditional traffic grooming designs and aims to increase the number of reusable lightpaths. The proposed scheme, which uses intelligent search methods to find all possible lightpaths that could be reused in the virtual topology, can significantly reduce the energy consumption of an IP over WDM network. As a result more node pairs share common lightpaths and thus less power is consumed in the network. Extensive simulation results indicate that the proposed heuristic algorithm manages to achieve a percentage of power saving, by up to 8%, compared to similar proposed techniques for energy-saving.**

Keywords—Energy consumption; IP over WDM, lightpath bypass, energy efficient optical networks.

I. INTRODUCTION

The enormous spread of the Internet applications is one of the main causes of the growing demand for capacity in telecommunication networks. The continuous increase in the number of Internet users [1] and the increasing demands of network applications, such as voice over IP (VoIP) and video-on-demand [2], makes the growth rate stable for several years. It is estimated that the global IP traffic will grow at dramatic rates during the next few years [3]. In this development effort the cost of network equipment is the main limiting factor. Nevertheless, the energy consumption of the devices in the network tends to be an equally, if not a more important limiting factor.

The energy consumption of network equipment is occupying a significant part of power consumption worldwide and this part is expected to grow over the years. Nowadays the total energy consumption of the Internet accounts for 1-2 % comparing with the global power consumption and it is predicted that the energy consumption growth (by percentage) of telecom networks will reach the amount of 220% in 2017 [4]. Thus, saving power in telecom networks is becoming an important challenge. As a result many research efforts have been made in recent years in the direction of reducing energy consumption. The purpose of the releted research is to create energy-efficient network architectures. Reduced energy consumption makes Internet use more environmentally friendly due to the reduction of the emissions of carbon dioxide (CO_2) and also more economical due to lower operating expenses.

This paper focuses on the energy efficiency of optical networking technologies. Optical technology uses the optical fiber as a transmission medium and combined with the wavelength division multiplexing (WDM) technology appears to be the key factor in satisfying the high speed and large capacity demands. This paper focuses on the optical backbone network, which significantly contributes to the total network power consumption due to the popularity of bandwidth-intensive applications.

Many different approaches have been proposed in the literature to reduce the energy consumption in backbone networks. The proposed approaches can be divided into two categories. The first category consists of selectively disabling the inactive network elements [5, 6, 7] when the traffic load is reduced, while maintaining the vital functions of the network to accommodate the residual circulation. The second category concerns the construction of energy efficient structures during the design of the optical network [8], creating efficient algorithms that aim to minimize the energy consumption of the network elements.

In the present research the second approach is adopted, by designing an efficient heuristic, which reduces the power consumption of the IP Over WDM optical network. The backbone IP Over WDM networks can be implemented in two ways, either using lightpath non-bypass or using lightpath bypass [2, 9]. If there is no bypass capability in the network (lightpath non-bypass) all the lightpaths incident to a node of the network should be terminated, meaning that all data which are carried by the lightpaths are processed and forwarded by intermediate IP routers in the IP layer. This method implies Optical/Electronic/Optical conversions in every node which require major energy consumption due to the extensive use of

IP router ports. On the other hand, if the lightpath bypass approach is implemented, all data which are carried by the lightpaths simply bypass all the intermediate nodes until they reach the destination node, avoiding the Optical/Electronic/Optical conversions since the signal remains exclusively on optical domain.

The above-described procedures have been proposed in [10], where the authors present two heuristics using lightpath bypass strategy, named Direct-Bypass and Multihop-Bypass respectively, to reduce energy consumption. The differences between these two architectures concern the capabilities of performing aggregation of traffic [11, 12]. The Direct-Bypass architecture does not provide grooming properties, while the Multihop-Bypass architecture does. Despite the fact that the Multihop-Bypass performs better than the Direct-Bypass approach reducing the total power consumption of the backbone network, it does not provide the maximum number of the lightpaths that could be reused in the virtual topology.

The present research proposes a new power-aware heuristic scheme (ISLB) to combat the above drawback. This scheme is mainly based on intelligent search methods to increase the number of reusable lightpaths used in the virtual topology in order to ameliorate the percentage of energy saving of the IP Over WDM network. Extensive simulation results indicate that the proposed scheme performs better than the Multihop-Bypass approach implemented in [10], improving the total energy consumption with a percentage of power saving ranging from 4.5% to 8%.

The rest of the paper is structured as follows. Section II provides background about the model of the IP Over WDM backbone network and explains the concept of the lightpath bypass strategy. Section III describes the design of the Intelligent Search Lightpath Bypass scheme that further reduces energy consumption in the backbone optical network. Finally extensive simulation results concerning the total energy consumption are presented in section IV.

II. BACKGROUND

This Section presents background knowledge for this work that concerns the topology of the examined IP Over WDM backbone transport network. Additionally each network device that is used in this study is discussed as well as the basic concept of the Multihop-Bypass method implemented in [10].

A. *IP Over WDM BackboneNetworks*

The IP Over WDM network consists of two layers, the IP and the optical layer, as shown in Figure 1. In the IP layer, a core IP router which gathers all traffic from peripheral access routers is connected via appropriate interfaces with an optical switching node, which is a dumb optical patch panel. In the optical layer, optical switching nodes are interconnected with physical fiber links. For every fiber there is a pair of optical multiplexers and demultiplexers. In-line Erbium Doped Fiber Amplifiers (EDFAs) are placed every 80 km over the fiber so that the optical signal can travel over long distances. Moreover on each optical fiber a post-EDFA (booster) is placed at the multiplexer output and a pre-EDFA is placed at the input of the demultiplexer . Each optical fiber can multiplex no more than 16 wavelengths, with a transmission capacity of 40 Gb/s each. Finally a pair of transponders capable of full wavelength conversion corresponds at each wavelength.

B. *Lightpath Bypass Strategy*

With the lightpath bypass method, all lightpaths incident to a node of the network which is not the destination node of the lightpath, directly bypass the intermediate node and move forward until they reach the destination node. To be able to achieve this approach all the optical switching nodes must enable the lightpath bypass stage. In this way, significantly reduced use of the IP router ports is achieved.

During the lightpath bypass method, lightpaths are created between all nodes in the network, the capacity of which should be sufficient to accommodate all the data flows between nodes. Furthermore in the optical layer the routing of the virtual links is based on the shortest path routing algorithm which can minimize the total number of required WDM transponders and EDFAs. The lightpath bypass approach is based on traditional traffic grooming designs, which means that this method allows different pairs of nodes to share a common lightpath with a unique constraint not to exceed the maximum capacity of the wavelength, which is assumed to be 40 Gb/s. This strategy improves the wavelength capacity utilization of the medium as it requires the establishment of fewer lightpaths and thus achieves lower energy consumption, since it uses a smaller number of IP router ports, WDM transponders and EDFAs.

III. REDUCING ENERGY CONSUMPTION VIA INTELLIGENT SEARCH LIGHTPATH BYPASS

A. *Power Consumption Figure*

The approach that will be studied focuses on reducing the overall energy consumption resulting from the various network elements, such as EDFAs, IP router ports and WDM transponders. Additionally the set of variables used in the proposed heuristic is given below.

G	physical topology G=(N,E), which consists of N nodes and E links.
m, n	indexes of the nodes in the physical topology (optical layer).
i, j	indexes of the nodes in the virtual topology (IP layer).
C_{ij}	number of wavelengths between node i and node j.
W_{mn}	number of used wavelengths between node m and node n.
A_{mn}	number of EDFAs on each physical link between nodes m and n.
f_{mn}	number of optical fibers between nodes m and n.
E_r, E_t, E_e	average energy consumption of an IP router port, a WDM transponder and an EDFA respectively.
L_{mn}	physical distance between nodes m and n.
Δ_i	the number of ports used to collect traffic from peripheral access routers at node i.
[λ]	traffic demand matrix which indicates traffic between each node pair. The traffic demand between each node

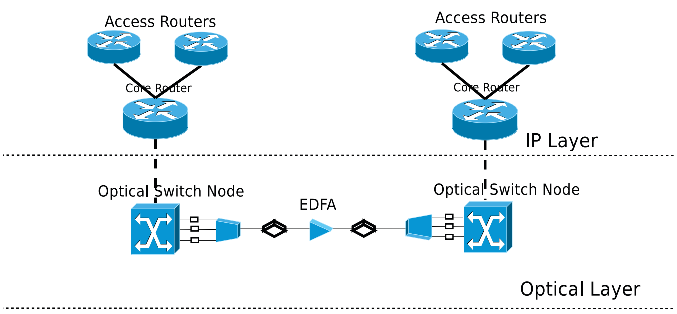


Figure 1: IP Over WDM Architecture.

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}.

Mathematically, the overall power consumption is computed by the energy model (1) as:

$$\sum_{i\in N} Er \times \left(\Delta i + \sum_{j\in N:i\neq j} Cij\right) + \sum_{m\in N}\sum_{n\in Nm} Et \times Wmn + \sum_{m\in N}\sum_{n\in Nm} Ee \times Amn \times fmn \qquad (1)$$

The term $\sum_{i\in N} \boldsymbol{Er} \times (\boldsymbol{\Delta i} + \sum_{j\in N:i\neq j} \boldsymbol{Cij})$ refers to the energy consumption in the IP layer computing the power consumption of the IP router ports, while the terms $\sum_{m\in N}\sum_{n\in Nm} \boldsymbol{Et} \times \boldsymbol{Wmn}$ and $\sum_{m\in N}\sum_{n\in Nm} \boldsymbol{Ee} \times \boldsymbol{Amn} \times \boldsymbol{fmn}$ refer to the evaluation of power consumption of the WDM transponders and EDFAs respectively.

B. Intelligent Search Lightpath Bypass

The ISLB scheme examines the requests for lightpath establishment upon their arrival one by one in a serial fashion, starting from the highest traffic demand to the lowest. By skipping the first step of the algorithm, which sorts the nodes according to their traffic demand, the proposed algorithm can be also used as an on-line operation algorithm, which dynamically handles lightpath establishment. This scheme uses search methods to successfully increase the number of reusable lightpaths of the network's virtual topology. The main function of the proposed architecture is that for every examined request, all *previous* requests are examined again in multiple ways in order to reuse the lightpaths in a more efficient way. The total number of operations performed by the end of the algorithm (when all the requests have examined) is calculated by the equation (2) as :

$$\sum_{i=1}^{NodePairs}(i)\ x\ (i+1) \qquad (2)$$

where the variable NodePairs indicates the total number of node pairs which are created in the examined network.

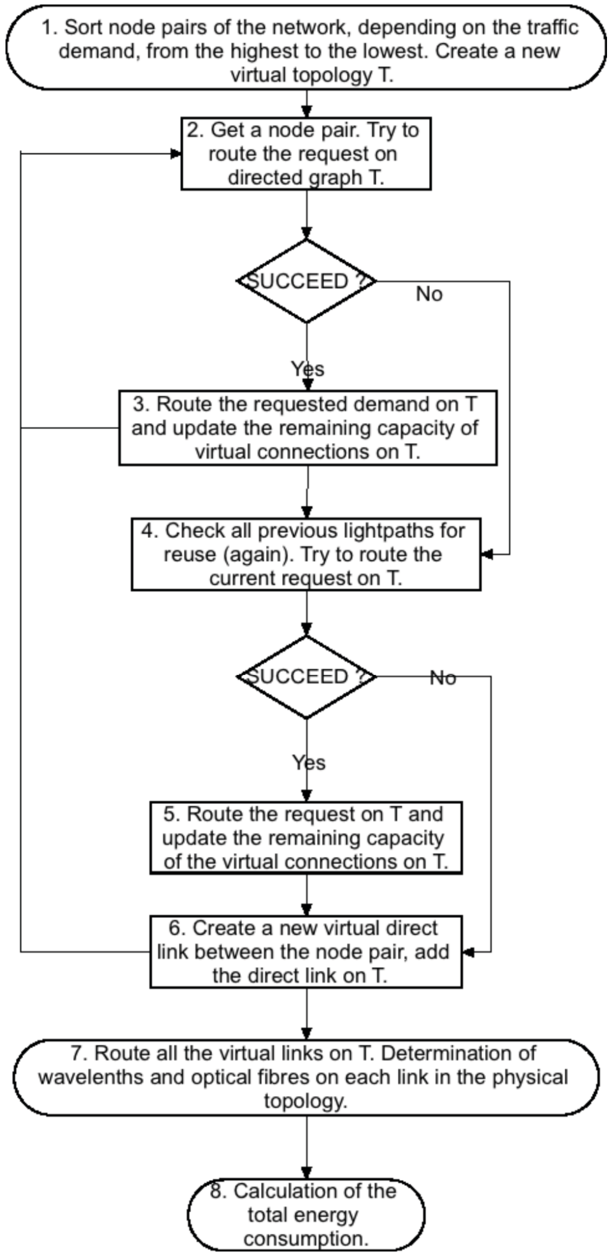


Figure 2: Flowchart of the Intelligent Search Lightpath Bypass (ISLB).

Figure 2 shows the flowchart of the heuristic (ISLB). The algorithm begins by sorting all the node pairs of the network depending on their traffic demand, from the highest to the lowest. A new virtual topology T is created (step 1). Then it gets a node pair (step 2) and tries to route the requested traffic demand over the directed graph T. If there is enough free capacity to accommodate the requested traffic demand, the algorithm routes the request over T and updates the remaining capacity of virtual connections over T (step 3). After that, the algorithm checks again (step 4) all previous requests for reuse and tries to route the current request over the directed graph T. If there is not enough capacity to accommodate the request the algorithm goes to step 4. If there is enough free capacity to accommodate the current requested traffic demand, the

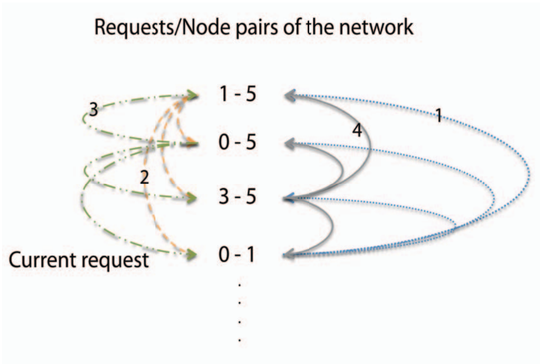


Figure 3: Lightpaths' examination order.

algorithm routes the request over T and updates the remaining capacity of virtual connections over T. Otherwise a new direct virtual (step 6) link between the node pair is created and added in T. Step 2 is repeated until all the requests have been examined. After that all the requests are routed based on the shortest path routing. Finally in step 8 the number of wavelengths and optical fibers on each link in the physical topology are determined and the amount of total energy consumption of the IP router ports, WDM transponders and EDFAs is calculated.

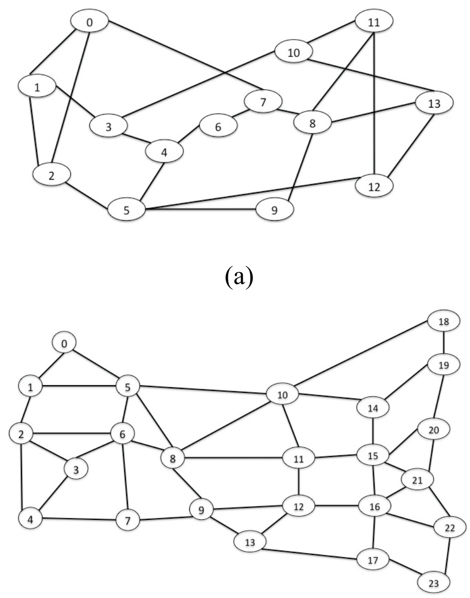
Figure 3 illustrates schematically the operation of ISLB. It is assumed that the current request is the forth (0-1) and all the requests have a traffic demand of 10Gb/s as shown in Figure 3. Applying the Multihop-Bypass approach [10], the algorithm examines the previous requests once to find a combination of lightpaths to accommodate the current request. In this case, there is no such combination and thus, there are not any lightpaths to be reused. On the other hand, via ISLB, all previous requests are examined again in order to increase the number of the reusable lightpaths. In this example, it can be seen that the second request (0-5) can be routed via the first (1-5) and the forth (0-1) lightpath. Thus, the total number of established lightpaths is decreased and as a result the total energy consumption is lower.

IV. Performance Evaluation

A. *Study Cases*

The proposed scheme described above can be used on any topology, however on this study it is examined on two different sized networks. The first network is the National Science Foundation Network (NSFNET) which consists of 14 nodes and 21 links as shown in Figure 4(a) and the second network is the IP backbone network of the United States of America (USNET), consists of 24 nodes and 43 links (Figure 4(b)).

Also, it is assumed that the average energy consumption for each router port is at 1000 W according to Cisco 8-slot CRS-1 data sheet [13], each WDM transponder consumes about 73 W according to Alcatel-Lucent WaveStar OLS 1.6T ultra-long-haul systems [14] and each EDFA consumes 8 W according to the Cisco ONS 15501 [15].



(a)

(b)

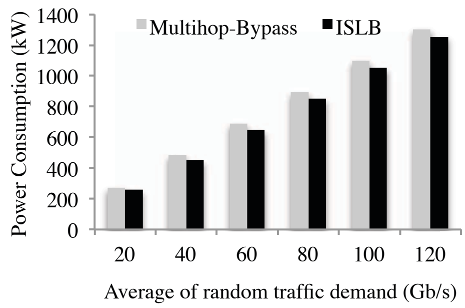
Figure 4: Test networks: (a) NSFNET, (b) USNET.

B. *Total Energy Consumption*

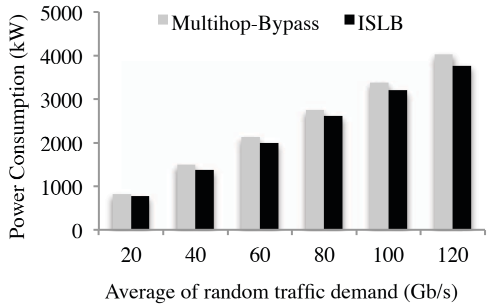
Figure 5 illustrates the amount of total energy consumption in kW for the Multihop-Bypass approach implemented in [10] and the proposed Intelligent Search Lightpath Bypass heuristic when the average traffic demand fluctuates from 20 Gb/s to 120 Gb/s per node pair. The comparisons of the different schemes are shown in Figures 5(a) and 5(b) for the networks NSFNET and USNET respectively. The energy consumption of both above methods show a similar trend, with both methods gradually increasing consumption in the same way from an average traffic demand of 20 Gb/s/node pair to 120 Gb/s/node pair. However, beginning from a common value for low loads the energy consumption of Multihop-Bypass remains always higher compared with that of the proposed approach. Regarding the USNET network it is worthy to note that at 120 Gb/s the power consumption of Multihop-Bypass stands at 4025,7 kW, while for ISLB is 265,57 kW lower.

C. *Number Of Reusable Lightpaths*

It is interesting to observe how the average number of reused lightpaths in the virtual topology differs when the Multihop-Bypass approach implemented in [10] is compared with ISLB approach. Figure 6 represents the average number of reused lightpaths in NSFNET and USNET networks. Via the proposed heuristic it is noticed that the number of the lightpaths that can be reused is significantly greater compared to the Multihop-Bypass architecture. More precisely charts located above (for each network topology) reflect the absolute number of reusable lightpaths as changing the traffic demand. Multihop-Bypass follows a downward trend while the Intelligent Search Lightpath Bypass scheme follows a slight increase in both networks when the average traffic demand is increased from 20Gb/s per node pair to 120Gb/s per node pair.



(a)



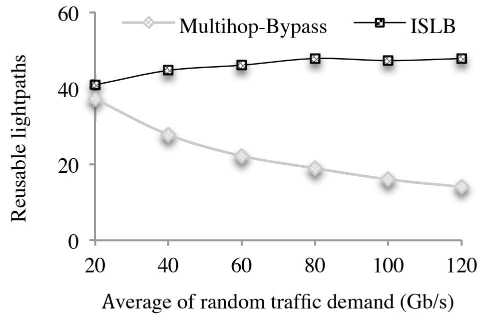
(b)

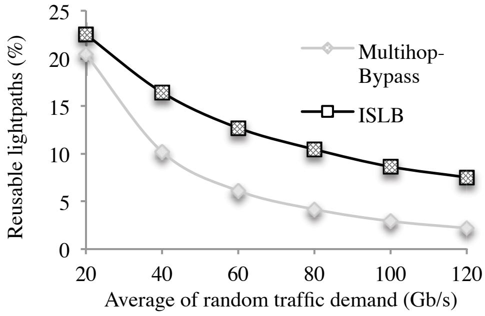
Figure 5: Comparison of total power consumption between different designs in (a) NSFNET and (b) USNET.

This is due to the fact that Multihop-Bypass has no control over any requests with average traffic demand over 40Gb/s. Observations are verified on the charts shown in Figure 6 (for each network topology), which report the percentage of reusable lightpaths. The percentage of reused lightpaths is clearly higher when the Intelligent Search Lightpath Bypass method is used. However, both schemes show a fall in the rate due to the dramatic increase in the number of lightpaths as the average traffic demand is increased. Specifically by using the Multihop-Bypass approach, the percentage of reused lightpaths drops sharply from 20Gb/s to 40Gb/s and continues with a gradually decline from 40Gb/s to 120Gb/s, while the Intelligent Search Lightpath Bypass approach shows a steady decrease.

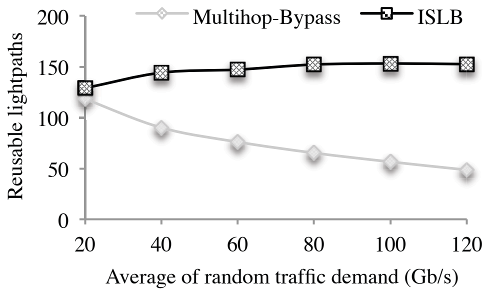
D. Power Consumption Saving

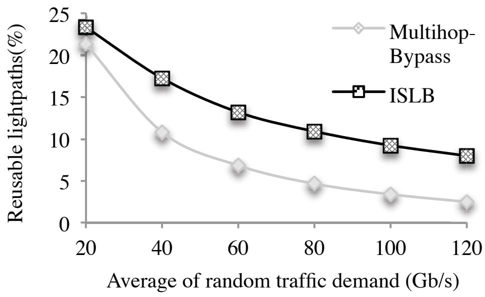
In addition to the total energy consumption and the average number of the reused lightpaths, two line graphs are presented (7(a) and 7(b) for the networks NSFNET and USNET respectively) indicating the percentage of power saving when ISLB is compared with the previous implementation. These graphs show the extent over which the ISLB strategy performs better than the previous one. Simulation results denote that ISLB can increase the percentage of power saving, ranging from 4.5% to 8%. Comparing the results of the two different-size networks it is noted that the percentage of power saving is increasing with the increase of network size, owning to the flexibility of the former to find more combinations of lightpaths to route the current request. The highest percentage of power saving in the first network reaches about 6.5%, while





(a)





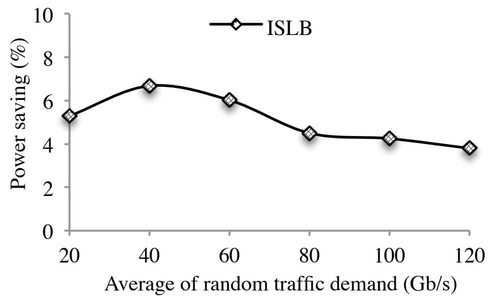
(b)

Figure 6: Average number of reusable lightpaths between different design schemes in (a) NSFNET and (b) USNET networks.

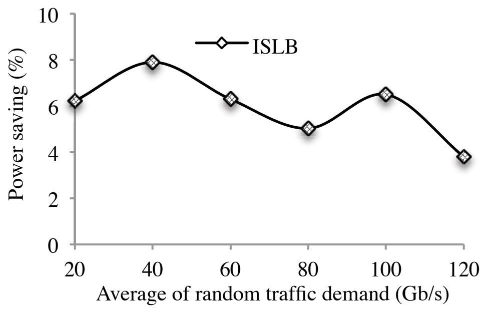
the highest power saving in the second network reaches the amount of 8%.

E. Distribution Of Energy Consumption In The IP Over WDM Network

Figure 8 shows the distribution of power consumption of each component in the IP Over WDM optical network when applying the ISLB scheme. It can be seen that IP routers



(a)



(b)

Figure 7: Power Consumption saving in (a) NSFNET and (b) USNET.

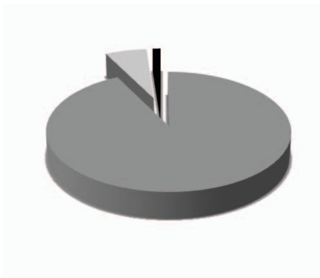


Figure 8: Distribution of energy consumption on each component.

accounted for the majority of the power consumption while the EDFAs accounted for the minority for any value of the traffic demand in any network topology. In detail, IP routers consumes about 92% of the total power while WDM transponders occupy about 6% and EDFAs consume about 1%.

V. CONCLUSION

Core network energy consumption is increasing at an alarming rate. It is necessary for researchers to turn into new network architectures in order to improve the energy efficiency of backbone networks. This paper presents an energy efficient model which aims to reduce the total power consumption of an IP Over WDM Backbone Transport Network. Architectures based on lightpath bypass strategy were previously proposed aimed at reducing energy consumption of the IP Over WDM network. Despite the fact that these architectures reduce the total power consumption of these networks, they do not take into account the number of the lightpaths that could be reused in the virtual topology. To combat the above drawback a new efficient heuristic, named Intelligent Search Lightpath Bypass (ISLB), which is based on traditional traffic grooming capabilities is proposed. This model uses search methods to maximize the number of the reusable lightpaths in the virtual topology. Therefore more node pairs share common lightpaths and so less energy is consumed in the network. Extensive simulation results indicate that the proposed scheme can increase the percentage of power saving by up to 8%, comparing with the existing implementations.

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