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Energy Efficient Partition-Lightpath Scheme for IP over WDM Core Networks

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Abstract

In this paper, the research focus on the development of energy saving schemes with roots in sleep modes that support the evolution of greener core optical IP networks. The cornerstone of the adopted strategy is partition-lightpath schemes underpinned by the hibernation state implemented through a modification of the intelligent control plane, in particular for transparent network architectures under different scenarios. An enhanced multi-level operational hibernation mode through partition-lightpath was defined including functionality, structure considering its implementation issues. Through the use of appropriate design parameters the impact on blocking probability, wavelengths assignment, LSP connection requests, degree of node connectivity and network utilization can be minimized while also achieving energy savings. Evaluation of this scheme indicates potential reduction in power consumption from 9% up to 17% at the expense of reduced network performance.

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Keywords: Energy Efficiency, IP over WDM networks, Power Consumption, OXC, GMPLS, Partion-Lightpath

1. Introduction

Recent development on power consumption in core telecommunication networks is still expanding. Correspondingly, the global amount of Internet Protocol (IP) traffic is growing every year. While this growth is

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gradually slowing down from an earlier Compound Annual Growth Rate (CAGR) of 100% (about 10 years ago) to estimated CAGR of around 20% to 30% at present, this reduced growth still outperforms the annual 13% efficiency increase of new telecommunication equipment in core networks[1]. Accordingly, the sleep mode is the most known energy saving techniques mechanism in core networks.

The key distinction between the sleep mode and hibernation mode is that in the former energy savings are performed manually, for instance by pre-setting configuration or through the manual selection of switch off states for nodes, whilst the latter is a dynamic approach where network equipment or links are placed into sleep modes automatically governed by the state of the traffic flows within the network. Furthermore, previous research has not developed / evaluated hibernation mode techniques for power conservation in core optical IP networks under wavelength continuity. Hibernation modes are proposed based on partition-lightpath schemes to invoke a family of energy conservation options.

Partition-Lightpath hibernation mode relying on balancing energy consumption across network while maintaining wavelength connectivity was proposed and evaluated. The approach lowers power consumption at the expense of a slight increase in blocking probability; maintaining network performance by enhanced traffic utilisation through efficient lightpath establishment.

2. Network Energy Model

In our approach in order to evaluate overall network power consumption and consumed energy per a data bit we used so called equivalent network energy model (see Figure 1) based on multilayer Internet Protocol / Generalized Multi-Protocol Label Switching (IP/GMPLS) over optical layers. In this model, a network carrier bandwidth of OC-192 and average energy consumption of 1019nJ per bit was assumed following[2,3,4].

The parameter G_n denotes a Router's dissipated power of 10kW within its energy consumption of 1000nJ/bit. X_n represents Optical Cross-Connect (OXC) dissipating 100W and consumes 10nJ/bit. W_n denotes Wavelength Division Multiplexing (WDM) part of the node with dissipating power of 120W and energy consumption of 12nJ/bit. A_n represents the consumption owing to Erbium-Doped Fibre Amplifiers (EDFA) within connection spans placed at 70 km intervals, the power consumption is estimated to be 1W with energy of 0.1nJ/bit.

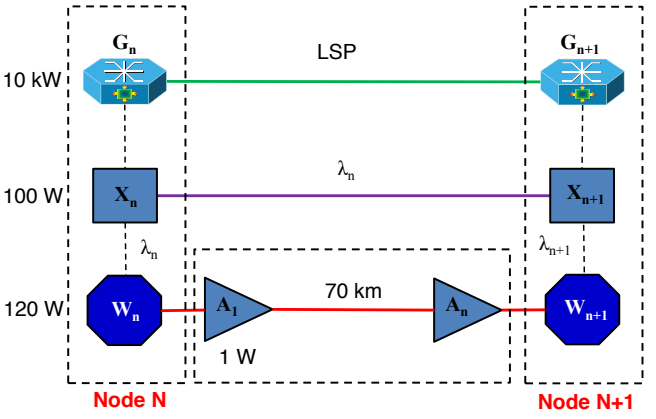

Fig. 1. An Energy Model Design for IP over WDM Networks.

2.1. Energy per Bit

We define energy per bit consumed by the node as $E_b = P_T / C$ where P_T represents the node total power consumption and C is the bandwidth offered by the network link.

2.2. Energy Consumption

The total energy consumption in IP over WDM networks calculated per data bit E_{bit} in order to support the network offered load can be defined as:

$$\sum_{k=0}^{\infty} E_{\text{BIT}} = \left[\frac{\sum_{k=0}^{n-1} \Delta p_{\text{CONTROL PLANE}}}{C} \right]_{\text{IP LAYER}} + \left[\sum_{k=0}^{n-1} \Delta p_{\text{WDM}} + \frac{\sum_{k=0}^{n-1} \Delta p_{\text{TRANSPONDERS}}}{C} \right]_{\text{OPTICAL LAYER}} + \left[\sum_{k=0}^{n-1} \Delta e_{EDFA} + (\alpha+1) \sum_{k=0}^{n-1} \Delta e_{OXC} \right]_{\text{OPTICAL LAYER}} + \left[\beta \right]_{\text{CONSTANT}} \quad (1)$$

where Δe_{EDFA} is the energy consumed by EDFA; Δe_{OXC} is the energy consumed by the node's OXC; β represent the noise factor associated with the Bit Error Rate (BER) and a heat transfer rate in network equipments; and finally, α is number of hops

3. Hibernation Mode: Partition-Lightpath Scheme

The Partition-Lightpath scheme within the hibernation mode strategy is illustrated in Figure 2. In this architecture, the node consisting of a core router and OXC is connected by optical fibre links and a control plane is responsible for managing the delivery of IP-based messages, through OSPF-TE routing and RSVP-TE signalling. Full wavelength conversion is employed at all OXC nodes to manage the wavelength-continuity constraint and more efficient use of the wavelength resource. In this scheme, power consumption is reduced by link re-routing, traffic engineering and traffic grooming.

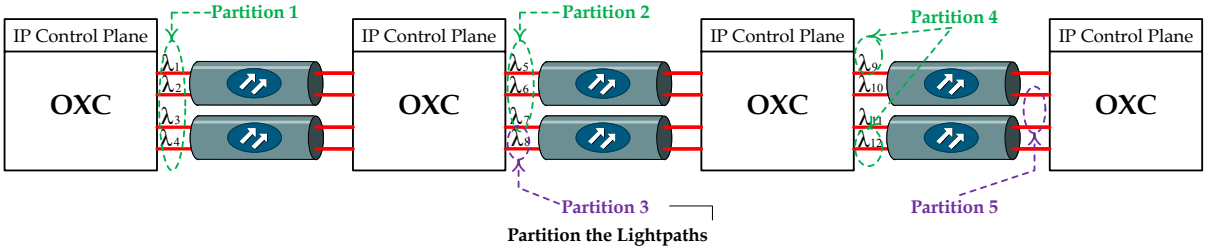

Fig. 2. Partition-Lightpath Hibernation Mode.

The light path set and parameters are given in Table 1; each light path connection is assigned appropriate wavelengths within a fibre link. Table 2 presents the partitioning setting of the hibernation mode in relation to light path establishment.

Table 1. Lightpath set and parameters.

Lightpath	*Wavelength*
1	$\lambda_1, \lambda_5, \lambda_9$
2	$\lambda_2, \lambda_6, \lambda_{10}$
3	$\lambda_3, \lambda_7, \lambda_{11}$
4	$\lambda_4, \lambda_8, \lambda_{12}$

Table 2. Lightpath set and parameters.

Partition	*Lightpath*	*Wavelength per Node*	*Link*
1	1, 2, 3, 4	$\lambda_1, \lambda_2, \lambda_3, \lambda_4$	1, 2
2	1, 2, 3	$\lambda_5, \lambda_6, \lambda_7$	3, 4
3	4	λ_8	4
4	1, 4	λ_9, λ_{12}	5, 6
5	2, 3	$\lambda_{10}, \lambda_{11}$	5, 6

Although, light paths and fibre links for network partitioning result in network topology changes, this mechanism can lead to significantly reduced power consumption.

4. Efficient Optical Connections (Light path Establishment)

Messaging initiation and termination can be described by a sequence diagram. Figure 3 illustrates the messages sequence diagram for the transition from the ON to the OFF state assuming that the network is a full mesh topology (complete network topology connections are not shown for simplicity). For end-to-end provisioning from ingress to egress node with wavelength conversion, after mapping the available resources the wavelength are reserved by signalling.

Consider the optical fibre connection from ingress to egress node traverses links with light path 1= {λ1, λ5, λ9, λ13}, light path 2= {λ2, λ6, λ10, λ14}, light path 3= {λ3, λ7, λ11, λ15} and light path 4= {λ4, λ8, λ12, λ16}. Dynamic wavelength provisioning assigns particular wavelengths to light paths on fibre links between adjacent nodes and can be bundled for hibernation to form Partition 1 and Partition 2. The former consists of a set of active wavelengths (λ1, λ2, λ3, λ4, λ9, λ10, λ11, λ12) forming a light path whilst the latter comprises a set of idle wavelengths (λ7, λ8, λ15, λ16) and active wavelengths (λ5, λ6, λ13, λ14). The Control plane receives hibernation notification messages indicating that idle wavelengths (λ7, λ8) of light path 3 and light path 4 respectively on partition 2 on fibre links between node 2 and node 3. At Node 3, after the hold-off timer expires, hibernation notification messages are transmitted back to the ingress node to release the reserved wavelengths. The loopback LSP *Resv_Confirm_Lightpath* message propagates back along the link until it arrives at the ingress node to request the inactive wavelengths. If however, Node 3 receives a LSP setup request message to place the node in an *OFF* state, a *Resv_Err* message is sent to acknowledge the ingress node that wavelengths (λ7, λ8) are in power-down state. As a result, the network updates the routing table, local updated wavelength availability information and network topology into TED. The ingress node releases a LSP by propagating a *Path_Tear* message to tear down the connection to idle wavelengths.

If no idle wavelengths are available along the path, then Node 3 will check for similar light path ID and partition ID to place the link into sleep. Node 3 will then propagate messages to adjacent nodes to check available light paths. In this case, the control plane detects other inactive wavelengths (λ15, λ16) on the fibre linking Node 4 and Node 5. Again, a similar process as previously described at Node 5 is initiated, after the hold-off timer expires, with hibernation notification messages transmitted back to the node to release the reserved wavelengths. A loopback LSP *Resv_Confirm_Lightpath* message propagates back along the link until Node 4 to request the suspension of the idle wavelengths. Based on this information, the shortest path distance to re-route the selected light path (in this case light path 3 and light path 4) and re-configure the idle wavelengths to power-down partition 2 (under-utilized capacity) and to assign (move) the light paths on available wavelengths on partition 1.

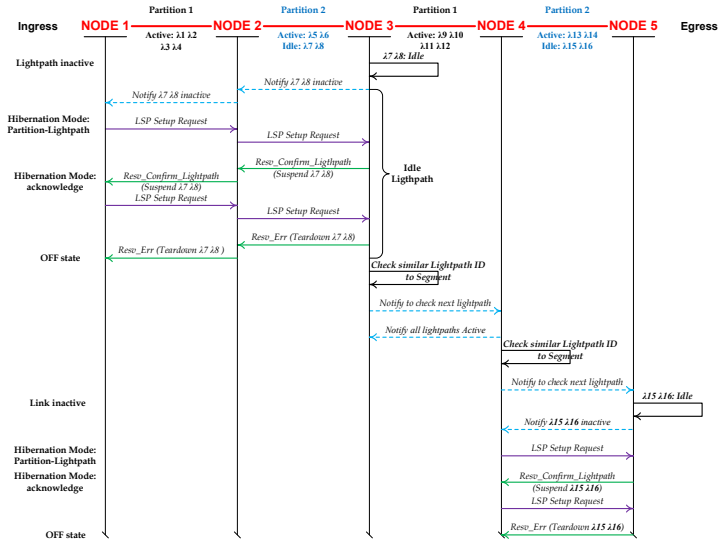

Fig. 3. Message Sequence Diagram for transition from ON to OFF of Partition-Lightpath Scheme.

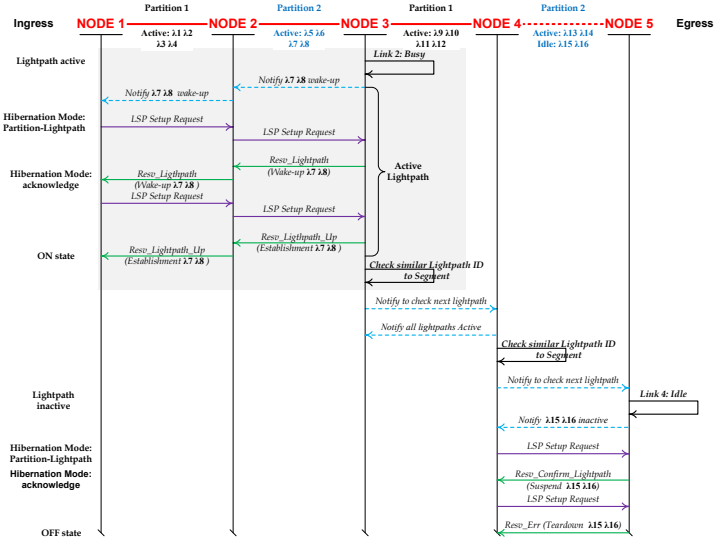

Fig. 4. Message Sequence Diagram for transition from the OFF to the ON state for the Partition-Lightpath Scheme.

Figure 4 presents an example messages sequence diagram for the transition from the OFF to the ON state. Node 3 detects traffic on wavelengths (λ7, λ8) and changes its state to BUSY (active state) and full power operation is resumed. It then transmits the confirmed notify message to inform the adjacent node that it is in the process of powering-up. A *Resv_Lightpath* message is sent to the ingress node to notify that the node is powering up, switching to the ON state. The node issues requests for the establishment of a light path connection to adjacent nodes; the control plane propagates the signalling and routing messages to corresponding nodes. Lightpaths re-route to the shortest path and the control plane sends messages to update the topology information into TED. Similar actions

occur in Node 4 and Node 5. If any inactive wavelengths are changing to active state, then the wake-up notifications will be sent back along each section of the path to establish all reserved wavelengths. All light paths return to active and full power consumption is resumed.

4. Simulation Results

The network topology which is being utilised by the European Optical Network (EON network). The EON network has a Full Mesh Network Topology with 9 nodes and 20 bidirectional fibre links[6,7]. The IP/GMPLS nodes are linked by bidirectional pairs of single mode fibres. The EON network topology was used in our simulations and was based on a discrete event modelling tool known as OMNet++ (Object Modular Network Tested in C++). It has been assumed that all links are equal in terms of number of wavelengths (eight), that the message length is fixed at 256 bytes, and a nodal processing delay is 20ms. All EON network Nodes are capable to maintain information on their total power consumption as well as energy per bit consumed. Wherein, the standard GMPLS signalling and routing protocols are implemented following the Internet Engineering Task Force (IETF) standard[8,9].

The performance metrics takes into account the average power consumption, blocking probability and average request blocking[10,11,12,13]. We also assumed that lightpath requests are uniformly distributed. Note that, the inter-arrival connection requests are independent Poisson processes with an arrival rate of α and the queue lengths exponentially distributed with the expected service rate time of $1/\mu$ measured in seconds. Therefore, the network offered load is α/μ.

The proposed Hibernation concept was verified on described EON by implementing segmentation-link schemes. These nodes/links are then put into "hibernation" or an "SLEEP state", in which nodes have suspended their unused functionalities (e.g. unused ports / interfaces, Mux/DeMux capabilities, signalling gates, unused wavelengths, etc.) and keep only the minimum network operation activities.

Figure 5 presents the power consumption difference from the 'ON' mode compared to partition-lightpath scheme for a node as a function of offered network load; the results show a noteworthy improvement in power consumption of ~0.25kW. The power consumption follows an approximately linear relationship with network traffic demand. This is because the networks employ traffic grooming and optical bypass; the former creates an aggregation of low-rate IP traffic (data) in IP layer into a few of high speed light paths in optical layer thus reducing the number of active electrical ports. The latter balances the traffic load and manages the power distribution amongst nodes.

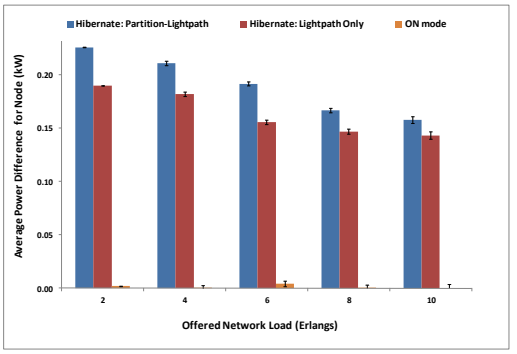

Fig. 5. Average power difference between the ON state and different Partition-Lightpath Schemes as a function of offered load.

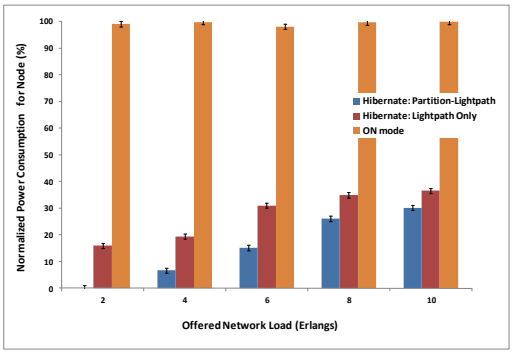

Fig. 6. Normalized power consumption for different Partition-Lightpath schemes as a function of offered network load.

Figure 6 shows the normalized power consumption of different hibernation schemes to the case of the reference "ON mode" state as a function of offered network load. Results show that the partition-lightpath scheme can achieve a power saving of 74% at 8 Erlangs compared to the lightpath only scheme (63%);the previous work claims that achieved a 40% power saving[14] using green routing technique. Figure 7 presents the power efficiency ratio between the Optical domain and IP domain network equipment. The Power ratio is defined as the ratio of the number of

segment-link connections over the number of the active (ON state) network equipment. Results show that for both the partition-lightpath scheme and the lightpath only scheme, a power saving of 66% and 60% respectively at a network load 8 Erlangs can be achieved.

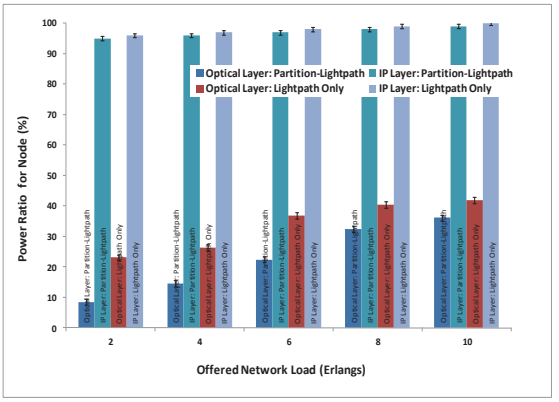

Fig. 7. The power ratio between the Optical layer and IP layer for partition-lightpath schemes as a function of offered network load.

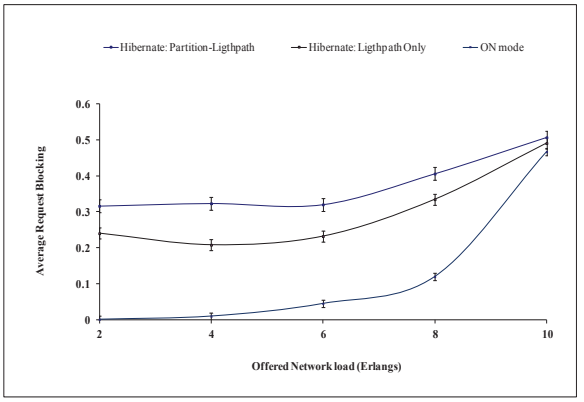

Fig. 8. Request blocking for different Partition-Lightpath Scheme as a function of offered network load

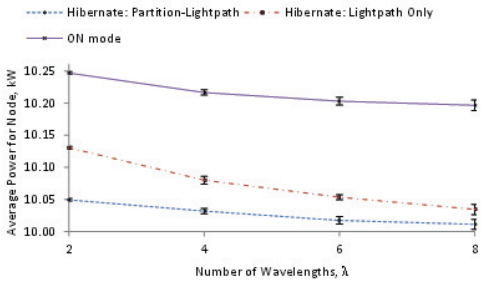

Fig. 9. Link power consumption as a function of the number of wavelengths for peak and minimum traffic loads for Partition-Lightpath Schemes.

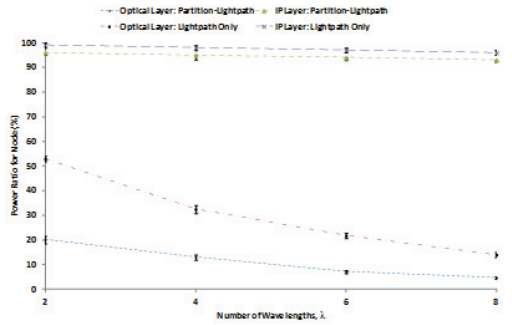

Fig. 10. Power ratio as a function of the number of wavelengths for peak and minimum traffic loads for Partition-Lightpath Schemes.

Figure 8 presents the impact on the blocking probability for partition-lightpath and lightpath only schemes. For the 'lightpath only scheme', the probability of blocking falls below ~23% thus delivering a better network performance but the power reduction/savings are minimal at 0.18kW (Figure 5). However, when segment-link scheme is set the blocking probability falls to ~32% and offers 0.25kW (Figure 5) of power saving. Here, the OXC makes use of all-optical wavelength converters to reduce blocking probability. The results show that the hibernation modes approach permits power savings at low loads.

Figure 9 presents link power consumption as a function of the number of wavelengths; results show similar trends for all λ. Energy consumption improves when the partition-lightpath scheme is applied, from 10.05kW to 10.01kW at the expense of a higher probability of blocking. The OSPF-TE advertises LSA messages to all fibre links and draws decisions on the most energy efficient way to re-route to connections with the minimum number of light paths; light path requests are updated by TED followed by path computation. In the extreme, a single fibre link can support all traffic while all other fibre links can be powered down.

Figure 10 shows the optical layer and IP layer power ratio as a function of the number of wavelengths. The power ratio is defined as the power dissipated by nodes of selected light path against the number of wavelengths within the entire set of active light paths. In the optical domain the partition-lightpath scheme yields a higher power saving ratio (~80%) than lightpath only scheme (~48%).

4. Conclusions

The energy savings owing to partition-lightpath schemes on the European Optical Network (EON) full mesh topology was evaluated. Partition-lightpath optimises energy consumption by tearing down all idle light paths within node link(s) and by sub-clustering based on network activity status. The impact of a proposed approach on energy consumption as a function of the number of wavelengths, the degree of network connectivity, the number of nodes and connection requests was analysed. The proposed path provisioning strategy reduces network power consumption by forming network topologies through the selective partitioning of the wavelength within connections to enable a hierarchy of "suspended" states. The impact of the approach on blocking probability was also investigated. Results show that, the hibernation mode exhibits a trades-off between energy savings and crucial network performance parameters. The mechanism minimizes power consumption in both the optical and IP domains. The former provides energy savings through optical bypass at intermediate OXCs, control of wavelength converters, traffic engineering and lightpath re-routing. The latter provides energy savings through traffic grooming and low-rate traffic aggregation, traffic engineering and routing.

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