Power saving of IP over WDM: Coherent taxonomy, mechanism and technique: A review

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Abstract. In this survey, the comparison of highlights on the importance of energy saving in IP over WDM (IPoWDM) is presented and followed by the review on the existing related article by using systematically data review based inclusion and exclusion criteria. The adaptive clock frequency, sleeping mode, and hybrid grooming mechanism protection is the latest breakthrough in the IPoWDM mechanism. The researcher identifies trend of survivability is divided into three protections: link scheme, path protection and restoration. This paper focuses on the techniques and methods employed, and analyze the difference from the latest article review. The analysis based on the literature review indicates the development in the research trend and estimates the energy saving based on the techniques, mechanism and modeling and protection scheme by identifying the advantages and benefits for the next research. Results of obtained, we viewed from the ease and the great impact on power saving, the technology of sleep mode on the standby network is possible. The scheme that is carried with a protection mechanism is set to sleep and wake quickly. The easiness is a principal aspect that encourage to look into best protection strategies to save power in IPoWDM networks. Nevertheless, these does not prevent the possibility of development another mechanism. Finally, the potential for future research directions are also discussed.

1. Introduction

Nowadays, a router identifies the total capacity of traffic which is much smaller than the total capacity of an OXC carrier. The mechanism of IP router accumulates low-speed traffic flows and transfers the traffic over light paths provided by the optical layer. The IP node capacity reflects the largest share of the total power consumption as high as at 60% [1]. A power-efficient of IP over WDM network with network configuration provides higher energy savings with a slight increase in the consumption of power at optimization of light. This can be happening by using the implementation of the hybrid grooming [2] or by using intelligent traffic engineering and routing by utilizing sleep mode operation [3]. The goal for reducing electricity invoice due to energy consumption has become a crucial issue for all industries especially in the Information and Communication Technology (ICT) sector [4].

The objective of the studies is to minimize the total energy consumption by assigning corresponding technique base on topology for each router at different time based on traffic work prediction from the
existing research. This topic has been discussed from previous studies and manage to determine that the techniques and limitations of each implementation for each topology that has been done. They attempt meet in finding for similarities of both protection and restoration mechanisms for each layer in order to get a common technique strategy applied by combining network consumption of optical network infrastructures [5].

Through the information in current existence of simulations and research, the percentage of energy saving can be obtained from the diverse mechanism of energy functions by assuming at different levels considering the three areas configuration that allowed network equipment to save energy. These level are identifying as networks hardware components, network design and protocols design [6]. These is due to the perspectives in minimization the energy IP over WDM network which is a necessity to research problem. Some papers have research problem for energy efficiency to get the energy savings from the IP over WDM network. These approaches based on virtual-topology experiment and traffic grooming design to reduce network energy wasted.

The explanation of general IP over WDM architecture are related in section II. In section III, the principle of network energy consumption. The solution of power saving several of mechanism in previous articles in section IV. In section V resume to get classification and discussion of reviews paper. Finally, the conclusion the papers in VI.

2. IP over WDM network architecture
This area is a regulator IP over WDM architecture. In Figure 1 below introduces linear models of IP over WDM network [7]. The example using three nodes that are directly connected to the optic fibers. The basic structure on CIR (Core IP routers) preparation are from low-level traffic ingress of the package core network from other level access device routers. The CIR communicates through the Ethernet port to the muxponder OXC interface on the optical layer. The routers can specifically have divided into two structure layers, (i) the Basic Structure Device (BSD) and (ii) the Physical Structure Device (PSD). In this study it will be focus solely on the BSD. The BSD are a layer comprises of chassis device, switch fabric or control processor component, power supply device, fan devices, and Ethernet. BSD underpins the card in bidirectional transferring manner in between Line Card (LCard) / Slot Card (S-Card) / Port Card (P-Card) which are in steady state capacity. It can be more than one L-Card/SCard/P-Card installed in BSD. All type of cards can be in a fully utilized slots or empty slots. Each slot could be added or upgraded with L-Cards. There are combination numbers of SCards in each L-Card. S-Card is use to integrate media modules, which can support diverse capacity of port pluggable with difference light beam and interface (e.g., LAN port, 16/64/256 STM, 1 GE, 10 GE and 100 GE) [8]. The LCard, S-Card and P-Card are combined structure known as a physical interface.
Extended Long Haul (ELH) Muxponder devices. The principle uses in this architecture are a light path that need one Network-Side LC (NSLC) connecting in one Muxponder at every port to communicate with one port to another which is Optical-Electrical-Optical (OEO) conversion. Generally, the OEO conversion provides the signal restoration to performed before the signal quality reach the amount of degrading below the threshold limit which known as the 3R bidirectional structure (retiming, reshaping and re-amplification). The regenerator synchronously regenerates raw signals to WDM tunnel and fiber optic. These WDM tunnel and fiber optic interface connector are also known as Muxponder. This Muxponder, then combined with gain booster to become the Multiplexer. The Multiplexer will transfer to WDM terminal directly. In the other side, the De-multiplexer will have received a signaling and regenerated it in the preamplifier to become demuxponder [8,9]. At the same time, some additional electronics signals are simultaneously providing necessary gain to all wavelengths in both directions shown as flow “a” and “b” in the Figure 2. These “a” and “b” flow are also the optical transmission line which connecting two unidirectional fibers to the optical amplifiers [7].

The EO conversion are processed by traffic data over the optical transport until the destination. The other hand, the OE conversion is reassembled by merging the data become the electrical phase which is translated by the IP router. The transparent mode (linear line “b”, Figure 2) shows the OEO conversion in the intermediate router are incomplete stage which then will be filtered during electronic signal conversion at the destination router. The weakness of this basic technique is, if there is a physical damage to the signaling layer, this will interfere the signals transmission routing and automatically will proceed the transmission signal to the alternate routing which is longer en-route to the destination route. This will consume more time than the original design method en-route [10]. The opaque mode of OEO conversion processing in each transit node (linear line “a”, Figure2.), are allowing grooming to recover and control the packet delivery in each hop of optic wavelength. However, the process will take a lot of additional processing time, power consumption, and latency [4]. When compared to previous modes, the translucent mode is more saving for cost and energy in the IP domain on traffic regeneration in getting the effective bandwidth usability and decrease network fee [2].

Figure 2. Transformations modes in network layers: a: opaque, b: transparent [10].

3. Principles of network energy consumption
Each development’s attempt was constrained to major limited factor on the expenses of network device equipment. From the data in research [11], the amount of energy consumption on the Internet estimating to grow up by 1-2% per years. In 2017, the global power consumption prediction increase in telecommunication networks sector reach the amount of 220% compared to 2007. In according, the energy saving in the telecommunication sector is reasonable a challenge for the researcher reducing energy consumption become effective and efficient. The principal of light path technical scheme in backbone IP Over WDM networking divided into two strategies, either 1) making lightpath non-bypass
or 2) lightpath bypass in the connection between routers. In Zao et al [12], the connection of the router is depending on the strategies using a non-bypass network, shall there is any incident or network failure in the lightpath between the node networks it must be discontinued. Then, all data packets which carry by the lightpath will be stop and the router must be rerouting of the path. By this time, the data packet will be stuck on the IP layer intermediate routers. However, these strategies do not need the OEO exchange in the node, which passed by the routing path wherein there are additions of energy consumption used in optic ports layer. On the other side, if the bypass network strategies are held, then all data, which carried on the lightpaths forwarded to the optical, transmit in intermediate nodes until the packet arrives in the destination.

Beletsioti et al [13], presented the results in three comparisons of heuristic algorithms (ISLB, GF, and OVTC) obtaining power consumption on the IPoWDM optic by minimizing on the count of optical paths in the virtual architecture. The example of a small network topology consists of 11 links, which are connected to eight nodes virtually and the topology of Deutsche Telekom of 14 nodes and 23 links are compared. In Figure 3, the result of the experiment presented the lower limit level of the total power consumption by using ISLB, GF and OVTC algorithm. The number of random traffic sequentially from 20 Gbps to 120 Gbps, which the IP router is specifically as in need supporting device for power consumption and the smallest is optical amplifiers, asper indicated in Figure 4. Furthermore, the percentage details are 93% of energy consumption in the IP router, 6% in the WDM and 1% in the optical amplifiers (EDFAs).

![Figure 3. Power consumption in (a) Snode-net and (b) Deutsche Telekom [13].](image)

![Figure 4. Energy consumption distribution under the ISLB implementation [13].](image)

4. The solution of survivable in IP over WDM management

The efficiency in designing has saving many collections of different aspects of technology. The functionalities and requirements of telecommunication networking must be replied overall standardization aspects: (1) Scalability; (2) Resilience; (3) Quality of service; and (4) Service
management [4]. The main advantage of energy efficient integrated routing in backbone IPoWDM optical networks for improving bandwidth utilization or minimizing power consumption.

4.1. Requirement adaptive clock frequency mode protection scheme

In Zhao et al [12], it is suggested for energy efficiency by the management of clock frequency strategies on WDM networks. The adaptive clock frequency that merged with the lightpath bypass technique to concurrently producing number total consumption more efficiency in every of the router cards energize by an IP over WDM networking. The function as a lower limit implementation, the clock frequency and the power consumption of a router device can systematically be transformed and keep a direct connect with overhead steady. The global optimization design network based on formulating of the decomposed models wherein ideally determine the number of needed router devices and the clock frequency embraced by every router board in a time slot. The consequence of energy utilization situation is mentioned on Figure 5. The management fore see that without considering the adaptive clock frequency strategy, it can have looked without of remembering the adaptive clock frequency scheme and the number of energy utilization is doubled of that with clock frequency, moreover 14% higher than that the situation with the busy hour traffic request.

![Figure 5. Results of energy saving using by the adaptive router card clock frequency strategy in any topology.](image)

![Figure 6. Comparison of total power consumption between different designs by using sleeping method in (a) NSFNET and (b) USNET [7].](image)
4.2. Requirement sleeping mode protection scheme
Protection mechanisms are based on additional equipment to include backup resources in case of failure accident. The protection can be shared in three kind of protection: 1) life path switching, 2) span switching and 3) ring switching. The protection using scheme for backup resources are a standby scheme or in a state of sleep mode for allowing recovery of traffic when a failure appears in the resource end-to-end. In Ren et al [14], the IPoWDM networking planner, with some device of ports and IP router might need, wherein provided by various router devices. Therefore, due to the traffic activity requests among nodes various at different times, the condition can happen where every port on router device in low traffic situation. An essential status on router device sleep is not anyone device of the router ports contained the carry’s traffic. Sleep mode is explained as hibernation mode, where the resource can automatic active if the main link has failure in a short time. Main link of part are active mode and backup link are standby mode.

In Heddeghem et al [7], the summary on a various formulation method for degrading the energy utilization in core network is identified and discussed. Numerous factors have affected and provides an outline of the discrete energy saving methodologies. For ideal port on router designation, there is proposed of a blended router port distribution scheme called "mixed mode". As shown Figure 6, the interleaving similarity to get well step of the composite network consumption at the distinctive proportions are to choose that the lower utilization and the result relating to energy consumption and scheme can be downgraded the power consumption by over 40% compared with the non-sleeping mode under the lightpath bypass technique.

![Figure 7. (a) Power consumption of NSFNET and (b) power consumption of USNET [15].](image)

4.3. Requirement hybrid grooming mechanism protection scheme
The important solution for traffic grooming in the optical cross-connect allows full access to routing and switching. However, it cannot give a transparent mechanism for transmitting and receiving by time division multiplexing/ demultiplexing scheme. In Hou et al [2], another mechanism called the hybrid grooming system. The system has two important concepts: (a) the IP request in multiple layers by using the traffic grooming which is manipulated by lightpath in a high-capacity to get electrical mitigation on Transmission Ports (TPs). (b) The lightpaths on optical bypass guarantees the forming of an all-optical (OOO) single scheme and will not change Optical-Electrical-Optical (OEO) conversions on intermediate connection. As result, the consumption of power in each router ports connection to OEO operations is greatly reduced. In Chen et al [16], the switch node can be classified as an optical multi-hop partial grooming optical cross-connect (OXC) in any specific network scenario irrespectively. The interconnection of the optical layer, allows the pass through physical platforms (PP) to Reconfigurable Optical Add-Drop Multiplexers (ROADM). The ROADMs are responsible on physical fiber for
fulfilling and delimiting traffic schematic on the optic links and permitting in the intermediate transit node to bypass lightpath in physical platforms optic.

In Guo et al [17], the power efficiency on grooming survivable are optimized using the metric referred by power ratio. The power ratios have an estimation of energy consumption to establish rapport lightpath over degreasing with grooming as requirements to mitigate intemperate power utilization. Therefore, the incorporated multi-hop grooming will merge with the power survivable hybrid which more efficiency on the waveband port as energy saving. In Zhang et al [15], from the results of experiments indicate that the power ratio is comparison between the total power consumption and hybrid grooming methods in Figure 7. The power efficient of hybrid grooming method is recommended to upgrade network source advantage. From the energy model of IPoWDM hybrid, the decline of electrically lightpath conversion can be degraded because of power consumption.

5. Clarification and discussion
This paper reviews the classification and discussion of the feature on protection and reconfiguration in the related article. The general context of taxonomy under category was facilitated by being group grouping in reading material that has been done by previous researchers to develop algorithms or learning the techniques of power saving in IP-over-WDM apply. In recent years, many studies and researches have been performed for effort a power efficient in networking optimization, which can be referred in [4] and [18] as two comprehensive of survey standard. Most of the research in the literature focus on model to decrease the total power consumption or reduce the capacity of traffic density in optical transmission WDM and IP networks. We grouping at least in three large groups in the use of mechanism: based on switching on-off scheme [19,20] in components of the network or we call protection in link, the standby or sleeping mode [9] to protection the path routing of the traffic [21].

A traffic model of power consumption in routers is presented in three groups: 1. dynamic model [3,11], 2. static model [22,23] and 3. combined model [8,24]. The application developing on approach an ILP optimization International Technical Conference 2018 ITC2018 (4-6 Oct 2018, Semarang, Indonesia) 5 model [2,25] or heuristic based on algorithm [5,26] to minimize the power of the network, or practical in router board [1] and base on routing configuration scheme [27,28]. The mentioned three aspects of the problem survivability of power saving in this related paper is protected, restored and mathematical predicted model (as the performance metric and formulating). According to these protection aspects, we classify into two ways. In the first group, the protection in Link performance hop failure tolerance requirement. The second group, protection in path end-to-end traffic.

5.1. Performance measures

![Figure 8. Taxonomy of research literature on survivability power saving in IP over WDM.](image-url)
The approach of different validation and adoption of performance evaluation in the limited various studies have been tried to reviewed. The motivations of this work to help efficient performance in the same whereby the challenges and recommendations of the research have been in place to describe and innovate for better development of concepts. In this section, all of these parameters are discussed in Table 1 comparison of related work used in the reviewed papers. Table 1 presents various studies on IP over WDM to prove the energy saving classification, as well as a comprehensive survey related of various criteria and sub-criteria for evaluation. In Table 1, as illustrated by variations in the percentage saving of criteria among various method.

Table 1. Summaries of previous articles approaches and methods.

| Reference | Focus Mechanism | Modeling of Approach | Protection/Scheme |
|-----------|-----------------|----------------------|------------------|
| [2]       | ●               | ●                    | ●                |
| [3]       | ●               | ●                    | ●                |
| [5]       | ●               | ●                    | ●                |
| [9]       | ●               | ●                    | ●                |
| [10]      | ●               | ●                    | ●                |
| [11]      | ●               | ●                    | ●                |
| [12]      | ●               | ●                    | ●                |
| [13]      | ●               | ●                    | ●                |
| [14]      | ●               | ●                    | ●                |
| [17]      | ●               | ●                    | ●                |
| [19]      | ●               | ●                    | ●                |
| [20]      | ●               | ●                    | ●                |
| [21]      | ●               | ●                    | ●                |
| [22]      | ●               | ●                    | ●                |
| [23]      | ●               | ●                    | ●                |
| [28]      | ●               | ●                    | ●                |
| [24]      | ●               | ●                    | ●                |
| [25]      | ●               | ●                    | ●                |
| [26]      | ●               | ●                    | ●                |
| [27]      | ●               | ●                    | ●                |
| [29]      | ●               | ●                    | ●                |
| [30]      | ●               | ●                    | ●                |
| [31]      | ●               | ●                    | ●                |
| [32]      | ●               | ●                    | ●                |
| [33]      | ●               | ●                    | ●                |

Our review to perform evaluation of various classifiers of method in queries studies involved in; this aspect measures the effectiveness of focus mechanism, modeling approach, and protection scheme. In this section, all of these parameters are discussed in every chart comparison of related work used in the reviewed papers. The variance in the use of these criteria indicates an achievement in giving summary the power and capacity to specific next researcher.

5.2. Clarification: Objective function and traffic model
This study works to summarize the modern classification base Objective Fuction and Traffic Model in IPoWDM to know that how far the development of methods to get power saving. The focus of technique and method to compile the relevant for the literature is set as a basis of the indicate taxonomy. The taxonomy from literature is review the development in trend the research in specific area to show the advantage and benefit for the next research. Some of different article apply the subject from a basic
aspect, while other develop the technique and method efficiently. Some make contributes for advance and complexity to the real solution on the research.

![Figure 9. Summaries of previous articles Objective fuction and traffic model from reference.](image)

From the chart in Figure 9, the review of previous articles divided in two focus objective function: 1) focus on efficiency power and 2) focus for optimization in capacity. It is differenting aspect but analogous to get a minimizing power saving. Some of work show the result of attempt that the power effective relies on the total of active device. the disabling unused ports on a line card reduces the device power consumption. Developing of strategy on an IPoWDM architecture may require to discover the routing that reducing the quantity of utilized connections while optimizing all the demands. On the other hand, utilizing higher capacity of connection offers speed and capability more over optical capacity in every node. Furthermore, prediction of traffic models makes each research very interesting when they use or comparing the dynamic or static model. For example, in [21], traffic model indirectly effects the dynamic threshold on network power consumption by control of high DHT (Dynamic High Thresholds) and allowing for more efficient utilization of lightpath capacity. Therefore, the algorithm inspected is more evaluate of sampling in 100 experimentations that display diverse traffic based on the initial scramble.

5.3. Focus mechanism
The IPoWDM networks are referred to give guarantee for further generation networks of core architecture on resilience and the adjustments ability by proposing the controlling on IP protocols and feature at optical layers e.g. substantial bandwidth provision, reasonable latency, minimum error of bit rate, and others [29]. The challenging aspect of researcher for reconfiguring designing efficient power-saving strategies as a new paradigm of resource energy saving has been proposed for more proportional on the energy consumption and amount of the traffic executed.

![Figure 10. Summaries of previous articles in focus mechanism.](image)

Based on the graph in Figure10, the focus mechanism to get the best power saving changes from the link scheme to the path protection. This is felt good where the path protection will produce a balance in transferring data from source to destination. There is two group in survivability mechanisms: 1. focus
in path protection and 2. focus in link scheme. Path protection is improvement scheme for planned failure, whilst link scheme is manual improvement restoration carried out after or during a failure. According to research [30] the weakness of survivability based on restoration scheme is less then dependable and require more time to restored, then the path protection is more normally utilized by administrators.

5.4. Modeling approach

![Modeling Approach](image1.png)

**Figure 11.** Summaries of previous articles in modelling approach.

In this systematically review, there are four approaches adopted: 1) approaches for design in MILP, 2) approaches for design heuristic method, 3) approaches for design routing base, and 4) Math-model. All approaches adopted aim to getting the power saving in the IP Over WDM network.

In modeling approaches, the ILP approaches and Heuristic approaches are always used from year to year. ILP approach is intended as a linear mathematical calculation method in obtaining optimal solutions to the scheme by maximizing or minimizing objective functions. Whereas the Heuristic Method approach aims to solve simple problems based on samples. This technique can be further investigated into more complex problems.

5.5. Protection / scheme

Finally, these are comparison between protection and scheme. Some of research that has been done, focuses on these two fields. on the 5.c, it has been alluded that the protection in this case tends to prioritize the concept of survivability (DPP or SPP) and migration (restoration metrics) while the link scheme is more inclined to physical concepts.

![Protection / Scheme](image2.png)

**Figure 12.** Summaries of previous articles in protection/scheme.

In Figure12, Migration techniques that are often used of researcher. These technique has two ways in general, namely Migration (upgrading devices / relocation) or setting routing metrics (link failure protection). In the subjective author, we have a tendency of view researching in the sleep mode scheme to reduce power consumption on network devices. We notice that the internal factors of the existing scheme cannot be changed pragmatically and sleep mode can follow the existing scheme.
6. Conclusion
In this paper review the general view in terms of techniques research to get the energy saving estimates, which is one of methods to approximation the total of energy consumption. The increase of the energy consumption is substantial responsibility and a lot on strategies for energy saving in telecommunication aspect. We group the metadata for comparing techniques on reducing energy consumption from previous work in the development of IP over WDM technology. This is due to the development of various telecommunication technologies by researchers with diverse background to achieve knowledge requisite at diverse phase of implementation. Finally, the mechanism, protection scheme, capacity and power values appropriate is solution survivability technologies as well as energy saving by researcher as a global issue in the telecommunication networking.

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