Energy-minimized design in all-optical networks using unicast/multicast traffic grooming

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ABSTRACT

The increased bandwidth required by applications, tends to raise the amount of optical equipment, for this reason, it is essential to maintain a balance between the wavelength allocation, available capacity and number of optical devices to achieve the lowest power consumption. You could say that we propose a model that minimizes energy consumption, using unicast / multicast traffic grooming in optical networks.

Keywords: Optical Green, Traffic Grooming, Unicast, Multicast, Optical Networks.

1. INTRODUCTION

During the last decade, Internet traffic and new applications have grown at an annual rate of over 40%, allowing the bandwidth used in optical fiber deployed rapidly approaching its ceiling, giving the possibility of saturation capacity [1]. This growth is mainly due to the demand for high-definition video by end users accelerated by the mass of "Smartphone", tablets and mobile devices that allow consumers connection all the time and any place [1]. Additionally, end users are demanding services for storing large volumes of information on the web: cloud storage, which translates into an increase in demand for internet access. This new paradigm of consumption and storage is an opportunity for telecom service providers, however, requires new functionality into communication networks to provide the best experience for end users. Moreover, the problem with the increase in energy consumption becomes more serious. The energy saving and deployment of green technologies has become a major issue for the scientific community worldwide. Usage in the beginning of the network traffic day is greater, making the sites or companies providing telecommunications services requiring robustness in implementation of network equipment, increasing the economic cost significantly. It is therefore the task of research centers mitigate the effects of energy consumption in telecommunication networks and especially in optical networks. In recent years, the concept of green technology has been proposed as a tool for efficient and optimal deployment of optical devices. This paper first presents the improvement and energy minimization considering unicast traffic (a source to a destination) and multicast (source to several destinations) using traffic grooming in an optical network. Energy savings cost reduction and granularity in the optical is due to the convergence between IP network and optical network to support both low-speed data and high-speed optical transmission. The traffic grooming mechanism with optical technology allows us to discover that it is a viable solution by binding a lot of low-rate IP data into some high speed Lightpath. This greatly reduces power consumption in optical switches mitigating energy consumption [2]. The model energy minimization is a viable solution since it determines the number of splitters with minimum conversion wavelengths allowing checking the system's ability to reduce network costs. Based on our review, this paper proposes topics such as a network node model, virtual topology design, transit traffic matrix and uncertain matrix for energy saving and cost reduction. Also considering granularity optical network, with possible solutions and preliminary simulation results to guide future work.

2. ARCHITECTURE AND MODEL

The architecture for implementing an all-optical network unicast / multicast traffic grooming, offers high capacity and reliability for a data stream allowing the optimization of optical network resources and improved energy consumption. This section presents the architecture for a transparent network, where the switching is done in an all-optical half, allowing analyzing the behavior of energy consumption in the network.
2.1 Architecture for Traffic Grooming and Data Transport

Implementing a transparent network architecture, wherein the switching is performed in all-optical means, is shown in Figure 1. The optical splitter is used to replicate the signal to two or more output ports. These devices are located on the bank of optical amplifiers with an accompanied splitter (SAB) which allows extending the reach of the optical link. This architecture requires two optical switches, one for the basic switching unicast traffic splitter to the bank, and the other is used to switch the different replicas to its output ports. Furthermore, this switch allows multicast traffic. The architecture shown in Figure 1, distributes data and RF signals. Multicast traffic is carried in the wavelength $\lambda_2$. The first switch multicast routes the traffic to the first splitter bank, where they perform three replicas of the signal. The replicas enter the second switch, which sends two requests and copies to the output ports and the bag back to the node itself. Importantly, the architecture has no wavelength conversion. The implemented architecture (Transparent) is capable of routing both unicast and multicast traffic separately, however when performing Grooming with different traffic, some of these may reach unintended destinations with the idea of avoiding electronic optical conversions [3].

Figure 1. Architecture for all-optical network (transparent).

Given the previous analysis it was implemented as an US network topology, which has 14 nodes, where each node architecture applied as in Figure 2. This architecture allows Grooming assuming unicast and multicast traffic in the same light-tree (i.e. take a set of point to point links connected by a completely channel WDM optical network, and apply it to a set of point-to-multipoint) without optoelectronic conversions need. By incorporating these features bandwidth underutilization is reduced, achieving minimum number of wavelengths. It's good to know that this architecture takes advantage of both circuit switching technologies like packets [3].
Multicasting Traffic Grooming (MTG). The transport of traffic point-multipoint is achieved in an entirely optical length, therefore, by a virtual channel in a completely optical environment because to send the traffic is not an insignificant one and the solution may have a great impact on the cost of the network. TG is the ability given to a WDM network to combine several slow speed traffics (in the range of Mbps to a few Gbps, example: OC-1, OC-3) into one of greater speed (OC-192 or greater). To accomplish TG all of the nodes must have some special characteristics, more so if it is needed for multicast traffic. The network design problem that supports TG efficiently is not an insignificant one and the solution may have a great impact on the cost of the network. TG is ability to support unicast traffic has been widely researched. The routing of unicast traffic is accomplished using the concept of the Lightpath, which is a virtual channel in a completely optical environment between two nodes [8]. The intermediate nodes do not carry out OEO conversions for routing. The concept of the light-tree is employed in order to support Multicasting Traffic Grooming (MTG). The transport of traffic point-multipoint is achieved in an entirely optical transport architecture allows for traffic from one of the replicas acquired for multicast traffic. Additionally when capacity is available on a wavelength of one of the replicas it possible to add new traffic. All these processes are possible additions obtaining and implementing without using optical conversion electronics. Importantly, optical capabilities for information processing are available for transmission speeds of 2.5 Gbps and 10 Gbps [4]. The idea is to apply the routing architecture to transmit a number of sessions on the same wavelength; this is removed from a replica to send the link not established either unicast or multicast. When released capacity on the link traffic is sent with the last session implemented the process continues until fills the entire capacity of the system (nodes and fiber). This will optimize the use of wavelengths and saves on bank splitters, allowing minimum energy consumption.

Grooming algorithms, routing and wavelength assignment (GRWA) work with the assumption that all wavelengths in the optical media have the same characteristics of transmission of bits-no bit error [5]. However, the optical fiber presents some phenomena that impair the transmission quality of the light-trees. A physical phenomenon that may occur in the fiber is divided into two:

1. Linear optical effects: spontaneous amplification, spontaneous emission (ASE), polarization mode dispersion (PMD), chromatic dispersion.
2. Non-linear optical effects: Four-wave mixing (FWM), Self phase modulation (SPM), Cross-phase modulation (XPM), Stimulated Raman scattering (SRS).

Current work studying PMD, ASE, FWM algorithms applied to routing and wavelength assignment (without grooming), taking into account the effect of power, frequency, wavelength and length of the connection [6].

In this chapter, we propose a predictive model of allocation of wavelengths based on Markov chains. The model takes into account the residual dispersion in WDM networks with traffic grooming and supports unicast/multicast applications with Quality of Service (QoS) requirements.

New applications (both unicast and multicast) do not yet have the capacity provided by a wavelength, therefore, by allotting a wavelength in the range of Gbps to an application of a couple of Mbps one is underutilizing the full bandwidth available in one wavelength. To solve the underutilization problem researchers have proposed the concept of Traffic Grooming (TG). TG came about in order to improve the utilization of bandwidth and optimize OTN systems [7]. TG is the ability given to a WDM network to combine several slow speed traffics (in the range of Mbps to a few Gbps, example: OC-1, OC-3) into one of greater speed (OC-192 or greater). To accomplish TG all of the nodes must have some special characteristics, more so if it is needed for multicast traffic. The network design problem that supports TG efficiently is not an insignificant one and the solution may have a great impact on the cost of the network. TG is ability to support unicast traffic has been widely researched. The routing of unicast traffic is accomplished using the concept of the Lightpath, which is a virtual channel in a completely optical environment between two nodes [8]. The intermediate nodes do not carry out OEO conversions for routing. The concept of the light-tree is employed in order to support Multicasting Traffic Grooming (MTG). The transport of traffic point-multipoint is achieved in an entirely optical
medium (without OEO conversions). This kind of transmission is called transparent and it is possible to carry it out using optical cross-connect (OXC). The architecture for the support of light-trees is presented [9]. When light trees perform grooming of unicast and multicast traffic they can use a lot of bandwidth in routing unicast sessions toward unwanted destinations. This is done in order to avoid OEO conversions in information transmission which, from a transparency point of view, are very expensive. With the purpose of improving on the resources available (wavelength and available capacity) in an optical transport network and to accomplish this in a completely optical medium, [3] have proposed the Stop and Go (S/G) Light-tree architecture. S/G light-tree allows optimal routing and grooming of unicast and multicast sessions. Currently, there are different architectures for optical transport nodes that allow the optimal routing and/or traffic management unicast/multicast using the concept of Traffic Grooming in optical networks. However, grooming techniques and the assignment and routing algorithms proposed do not account for phenomena that can be provided in the optical fiber, which mitigate or add interference between the different wavelengths in WDM Networks.

2.2 Simulation Model

We analyze the performance of unicast and multicast traffic considering different measurement parameters, which will determine how the optimal network architecture is used. The number of wavelengths required, the system's capacity, optoelectronic conversions, optical splitter and the number of employees are factors that allow us to know that so much energy is minimized in an all-optical network with traffic grooming. The proposed architecture has components that are expensive and are currently under investigation. Is therefore of great interest to apply a cost model to verify that as feasible [10]. Our model takes into account various elements of the optical network, the architecture of the nodes and the number channels or wavelengths required for routing of sessions required at the time of the simulation. It should be noted that the length of the links is not taken into account because it is not supposed to require new fiber deployments.

The implementation model consists of three parts:

- **Considering cost wavelengths:**

  \[ \Gamma_1 = w \times \alpha \]

  Where \( w \) is the number of required wavelengths and \( \alpha \) the cost factor of a channel implementation. The variable \( w \) is one of the most important parameters in the design of an optical transport network; as such techniques are employed as traffic grooming to minimize the required amount. Besides this, there is a direct relationship between the number of wavelengths and the number of transceivers [11], namely to minimize the number of wavelengths minimizes the number of transmitters / receivers. The number of wavelengths is obtained by running an algorithm which is in charge of minimizing the number of wavelengths so as to efficiently use the available resources of the network.

- **Considering cost on a node:**

  \[ \Gamma_2 = n(\beta \times SAB + \varphi \times DS) \]

  Where \( n \) is the number of nodes with capacity S / G, \( \beta \) is the cost of a bank splitter and amplification required, \( \varphi \) is the cost factor of a detection system and the detection system number (DS). The teams that allow the transmission of information in all-optical half are under development, thus working at transmission speeds of 2.5 Gbps and 10 Gbps [12] and yet are costly. For this reason, these factors are the relevant parameters in the cost of the node.
• Cost considering a node without capacity:

\[ \Gamma_2 = m(\beta \times SAB + \varphi \times \rho) \]

It should be noted that nodes have the ability to work with multicast traffic. Where \( m \) is the number of nodes with no capabilities, \( \beta \) is the cost factor of a splitter and bench amplifier, \( SAB \) is the number of splitters and amplifiers required per bank and \( \rho \) is the cost factor of a transparent optical cross connector node without multicast capabilities. It is important to add a cost factor \( \rho \), basically to offset the cost of multicast-capable OXC Optical, (i.e. optical splitter) [12].

The total cost model is given by equation (A). The given parameters considered cost factors \( \rho \), \( \alpha \), \( \varphi \) and \( \beta \), for number of nodes \( n \) with capacities and \( m \) without capabilities.

\[ \Gamma = \Gamma_1 + \Gamma_2 + \Gamma_3 \]  \hspace{1cm} (A)

Table 1 shows an average value of the total consumption of the telecommunication network. The results were used for subsequent analysis methods and tools to reduce this consumption, and focusing on the access network and the core. The results were used for subsequent analysis methods and tools to reduce this consumption, focusing on the access network and the core [12].

According to the results in tables and shown in the various figures, a way of reducing the energy consumption of the network, is to reduce the ports of the equipment, but this will compromise the number of users to which can be serviced and network performance itself. The following sections, will analyze the methods and technologies currently being developed in order to achieve lower power consumption of the telecommunications network, without affecting parameters such as QoS and network capacity.

Table 1. Approximate energy consumption of the network

<table>
<thead>
<tr>
<th>Network Segment</th>
<th>Component</th>
<th>Energy Consumption by Team (W/h)</th>
<th>Total On Segment consumption (kW/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core</td>
<td>Core Router</td>
<td>10591</td>
<td>24.184</td>
</tr>
<tr>
<td></td>
<td>Optical Switched</td>
<td>2500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OXC</td>
<td>228</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WDM Transport System</td>
<td>10800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WDM Transponder</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDFA</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Metro</td>
<td>Border Router</td>
<td>4210</td>
<td>8.49</td>
</tr>
<tr>
<td></td>
<td>Network Gateway</td>
<td>1280</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ethernet Switch</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Border Router</td>
<td>4210</td>
<td>5.41</td>
</tr>
<tr>
<td></td>
<td>SONET ADM</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>OADM</td>
<td>450</td>
<td>0.450</td>
</tr>
<tr>
<td>Access</td>
<td>ONU</td>
<td>14</td>
<td>3.014</td>
</tr>
<tr>
<td></td>
<td>OLT</td>
<td>3000</td>
<td></td>
</tr>
<tr>
<td>Consumption Total Network</td>
<td></td>
<td></td>
<td>35.688</td>
</tr>
</tbody>
</table>
2.2.1 Energy Saving Method

This study analyzes the all Optical Network (AON). The aim is to implement a proposed methodology and compare consumption data obtained with those presented in these networks without applying any saving technique.

It stipulates that the energy consumption of the Network Unit (UN) in optical networks is based on two principles: If no data to send or not. When there is no data to send the network is in the state called idle.

The analysis presents three conditions in which the network can play:

- **Ideal**: All network components consume power at minimum levels, with no losses.
- **Poor**: all components consume power at maximum, showing losses in splitters and extra power is consumed due to the cooling of equipment.
- **Optimized**: These components are optimized to have better performance and lower energy consumption presented.

For analysis of the energy performance of networks researchers performed simulations in Matlab, by subjecting all three types of networks to various conditions, the results obtained are shown in Figure 3. Where the Optimized Case 1, Case 2 is worst and 3 is the case Ideal.

Posed technique for attaining significant energy savings in the UN connected to certain OLT is: When there is no data to send the OLT is put into sleep state. The user interface also enters sleep mode, the sleep period is set to 2 ms, after this automatically UN.

![Figure 3. Comparison of Energy Consumption in W/h of the UN, without Apply Savings Methods](http://proceedings.spiedigitallibrary.org/?doi=10.1140/epje/i2013-13220-0)
If the OLT receives the UN data in sleep state, the active OLT UN through GATE messages, which also allow a transmission time interval. The UN sends an acknowledgement (ACK) message confirming that the message received GATE and activated to receive data from the OLT, this scheme is shown in Figure 4. The results obtained in this study, shown in Figure 5, demonstrate that using the proposed technique, saving percentages are around 50% depending on the condition in which the network is located, (i.e., 21.99 consumption can be decreased to a consumption of 12.8).

3. SIMULATION

Two scenarios are considered in determining the design of the OTN. First considered a cost factor for SAB and DS, and the second lower values, considering that the technology will have matured, in the future. This will determine how effective was the energy consumption of network devices considering unicast and multicast traffic with traffic Grooming. Thus the variables to be analyzed are the number of splitters or SAB Banks, Number Detection Systems (DS), Wavelengths, capacity and cost. Simulations were performed considering NSFnet complimentary network in which the physical topology consists of 14 nodes with 21 bidirectional links. Certain nodes chosen randomly were considered as possible highest ranking nodes and nodes without capabilities had at least one neighbor capability available.
The algorithm randomly generates sessions taking into account that 40% of them are of type unicast. For multicast, sessions are randomly generated destinations. The capacity of each wavelength is equal to 48 and the traffic is equal to 12. In order to obtain an average, several simulations were run. Cost model parameters are assumed as defined by the European NOBEL project [13].

Figure 6: Model Output: Number of Bank splitter (a), Number Detection Systems (b).

For both scenarios the results for the bank of splitters, number of detection systems and wavelengths are the same. The number of bank routing splitters required for the sessions is shown in Figure (6, a). It is observed that the number of bank splitters with Light-tree architecture is slightly higher than the proposed model. Figure (6, b) shows that the number of systems required for optimum detection is very similar to the curve of the bank splitter. As the number of sessions increases, the number of detection systems increases linearly. This is because the number of detections is directly dependent on the number of bank splitters.
By analyzing the number of wavelengths, it is observed that the proposed architecture significantly optimizes the number of wavelengths, (Figure 7, a). As the number of sessions increases, the number of wavelengths tends to stabilize, otherwise as occurs with light-tree since it improves the utilization of wavelengths by 30%. Now to analyze the capability of the systems we can see that the proposed model shows a variable effective capacity with respect to Light-tree because as we increase the number of sessions the intensity does not diminish capacity as we see in figure (7, b).

**CONCLUSION**

We analyzed the classical architectures for routing unicast and multicast traffic in order to determine their limitations and benefits from energy consumption. We analyzed and found to light-tree significantly improves other techniques to efficiently manage the number of wavelengths and bandwidth, but at the same time the model may yield an improvement in wavelength and system capacity. This optimizes network resource consumption making optical devices and greatly reduces the system inefficiency. Through simulations campaigns there were certain drawbacks in the undesired traffic routing to different destinations when handling unicast and multicast together. This is to prevent optical-electrical conversions. Therefore it is proposed to improve traffic grooming using these types of routing. These results allow us to determine how feasible it is to implement the model routing architectures, allowing in the future to adapt these techniques to dynamic modeler **elastic optical networks**, to improve spectral efficiency and bandwidths, yielding speed rates on the order of terabits / second.
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