Minimizing Power Consumption Through Brute Force Algorithm in Elastic Optical Network

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2023 IEEE 14th Latin America Symposium on Circuits and Systems (LASCAS) | 978-1-6654-5705-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/LASCAS56464.2023.10108288

***Abstract*—Elastic optical networks are possible solutions to the growing demand of users for all types of Internet services due to the flexibility of network parameters different from traditional networks. Despite the great advantages, the power consumption problem remains crucial. This manuscript aims to introduce a new form to minimize the power consumption in elastic optical networks through the brutal force algorithm. We have also deployed a new optical topology based on Acarape and Redencao cities. After dimensioning the network, the power consumption is calculated. Finally, numerical results were compared with the traditional techniques in the literature in which the proposed algorithm outperforms in all scenarios.**

Keywords—Elastic Optical Network, Energy Consumption, Network Topology.

I. INTRODUCTION

The use of Internet services has become a great necessity since most work activities are being performed remotely during the pandemic. The report of the Organization for Economic Cooperation and Development (OECD) points out that during the COVID-19 health emergency, the use of the Internet had a 120% increase in videoconference traffic and a 30% increase in online games the same as in the cloud [1,2]. The connection via optical fiber is one of the solutions to this growing demand from users for different types of services. The use of fiber optic connection is justified by the various benefits it offers concerning other technologies, among which we can mention its greater data transmission capacity, less signal degradation, immunity to electromagnetic interference, etc. Despite this, it has some limitations that affect its effectiveness. The advent of Elastic Optical Networks (EONs) was a revolution in optical networks significantly improving the efficiency of traditional optical core networks based on Wavelength Dense Multiplexing (WDM) and addressed the disadvantages of WDM. On the one hand, WDM suffers from rigid resource allocation for which optical resources, i.e., wavelengths are separated by 50 or 100 GHz. This occurs while the spectrum in EON is divided into bandwidth granularity resources thinner, called frequency slots (FSs), with the size of 12.5 or even 6.25 GHz. Therefore, EON assigns subchannels and super-channels to requests based on their requirements. On the other hand, EON provides a high data rate in transmissions and flexible modulation formats based on network requirements. Therefore, resources are efficiently allocated to incoming requests, and wasted resources are avoided [3]

Power consumption increases as the amount of data on optical networks increases. Several solutions are proposed among which we can mention the efficiency of Information and Communication Technology (ICT) solutions, which undoubtedly include the Internet of Energy (IoE) and autonomous energy systems supported by fifth-generation (5G) wireless networks that allow fast bidirectional response and feedback.

In elastic optical networks, energy consumption can be significantly reduced through some new features such as optical traffic “cleaning” and optical layer bypass. Compared to traditional optical networks, elastic optical networks offer the lowest probability of blocking [3,4] and, therefore, can accept larger volumes of traffic. This is a big benefit in terms of energy efficiency, as deploying additional network elements would not increase the cost but would increase energy consumption. Some of the possible approaches that can reduce power consumption include putting some of the network elements into sleep mode when traffic is below a certain threshold, or at a network level, consider changing routes during periods of low traffic [5]. These two approaches decrease the quality of service (QoS) and the transmission Quality of Transmission (QoT).

Power consumption can be reduced as long as the QoS performance remains within the Service Level Agreement (SLA), one of the goals of this project. Through a brutal force algorithm, every lightpath is chosen according to their power consumption metric differently from the proposals in the literature in which the lightpath is chosen according to the physical distance. The selected lightpath must have an uncommon node with other lightpaths. Thus, the network survival is ensured against failure. Additionally, the modulation format is allocated dynamically. A new optical topology is introduced considering the cities of Acarape and Redencao, in Ceara State in Brazil.

Section II depicts the power consumption. Section III shows the proposed algorithm, while Section IV presents a performance study of the introduced methods. Section V concludes with the research.

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II. POWER CONSUMPTION MODEL

In the literature, there is a lack of detailed information regarding power consumption models of traditional optical networks (those that use WDM technology) [6] and adapted for EON networks [7-9]. Therefore, in this work, the power consumption model used in this work will establish relationships between the devices used in the physical layer and their power consumption. In this study, models of optical layer equipment and devices will be used to enable a broader and more flexible investigation in order to explore possible energy efficiency bottlenecks. The model used can be used together with models that establish consumption in the layers above or that consider the power consumption of support equipment such as air conditioning, coolers, among others [6][10].

In this context, the power consumed by the optical layer will be given by:

$$P_{optic} = P_{\frac{TX}{RX}} + P_{sw} + P_{amps} \quad (1)$$

where $P_{\frac{TX}{RX}}$, P_{sw} and P_{amps} are the power consumed by transmitters/receivers (BV-OTP), optical cross-connects (BV-WXCs), and amplifiers, respectively.

The way to compute all the power consumption parameters is detailed explained in [11][12].

The consumed power by the transmitter and receveir is $P_{\frac{TX}{RX}} = P_{TX} + P_{RX}$, then the consumed power in the transmitters is:

$$P_{TX}(W) = P_{DSP} + (E_{driver} + E_{laser} + E_{CW})R \quad (2)$$

where P_{DSP} is the consumed power by the DSP, E_{driver} is the energy consumed by the laser driver circuit, E_{laser} is the energy consumed by the laser, E_{CW} is the consumed energy by the continued laser and R the transmission rate. The receivers used are composed of electronic circuits and EDFA amplifiers in pre-amplifier configuration. In this way, the power consumed in the receivers is given by [13]:

$$P_{RX}(W) = P_{DSP} + P_{amp} + P_{LO} + E_{Re\,c}R \quad (3)$$

where P_{amp} is the power consumed by the EDFA preamplifier and P_{LO} is the power consumed by the local oscillator and $E_{Re\,c}$ is the energy consumed by the photodetector. If a transimpedance amplifier receiver is used, the term (P_{amp}) will be disregarded. The BV-WXC considered in this work is based on an architecture composed of Wavelength Selective Switch (WSS) with Micro-Electro-Mechanical Systems Switches (MEMs) and Liquid Crystal on Silicon (LCoS) [14], in addition to transmitters/receivers for adding and removing channels, as illustrated in Fig. 1. On the other hand, BV consumption -WXC can be set to compose only MEMs or LCoS. Therefore, for this type of optical switch, the power consumed is given by:

$$P_{SW} = \sum P_{LCOS} + \sum P_{MEMS} + \sum P_{\frac{TX}{RX}} \quad (4)$$

with P_{LCOS} being the power consumed by WSS based on LCoS, P_{MEMS} the power consumed by WSS based on MEMs and $P_{\frac{TX}{RX}}$ the power consumed by the added channels and withdrawn at the BV-WXC. The power consumed by MEMs is approximately 107mW per port and the power consumed by LCoS is 4 W per device with a 9 x 1 ratio [15].

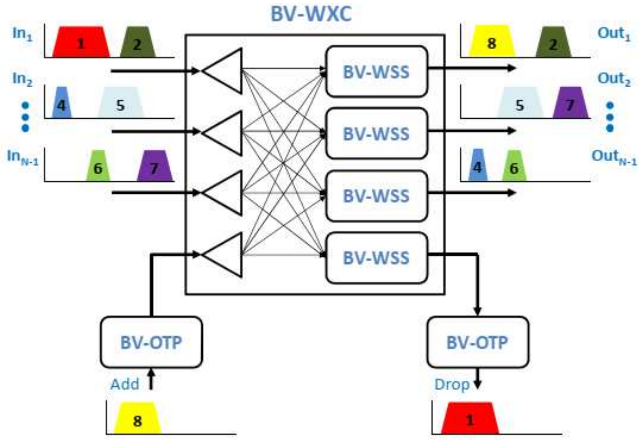

Fig.1. BV-WXC Arquitecture.

In optical transmission systems, linear and non-linear effects cannot be ignored since they introduce some impairments on the physical layer, reducing the QoT of the system. However, Klekamp et al. have deployed an empirical equation for coherent systems in which non-linear effects have been considered to calculate the maximum optical distance, D_{imax}, considering that [16]:

$$D(Km)[-804.3 \times ln(T_R) + 5584.6]_{imax} \quad (5)$$

III. POWER CONSUMPTION BRUTAL FORCE ALGORITHM

In this section, we introduce the power consumption brutal force algorithm (PC-BFA) which is explained in the following lines. Initially, for a connection request, two nodes are selected one as the origin node (O_N) and the other as the destination node (D_N). Through brutal force algorithm a list of all the possible lightpath among (O_N) and node (D_N) is randomly defined with uncommon nodes ie each lightpath must not have any node in common with others. Those lightpaths with any common node are discarded. When two lightpaths have a common node the PC-BFA selects the one with the physical shorter distance. This ensures protection in the network again failure. The lightpaths with uncommon nodes among(O_N) and node (D_N) are saved in a buffer (U_L). To meet the SLA requirement, each (U_L) is compared with the distance criterion approached by the authors in [22] (in this the modulation format is allocated adaptively according to the frequency slot). Only the lightpaths which meet the above criterion are selected referred as (L_S). The power consumption of each (L_S) is computed and the lowest among them is selected (L_{PC}). The process is repeated until all the connection requests have been attended ($N_i = N_{\max}$). The output of the PC-BFA is a random lightpath meeting QoS and QoT requirements with minimal power consumption. Figure 2 highlight the flowchart of the proposed algorithm.

As previously reported, the algorithm fulfills the QoS and QoT requirements because the allocation of the modulation format in the optical paths is done dynamically according to the physical distance. For example, for physical distance between 314km to 640km 16QAM modulation should be adopted while for a physical distance greater than or equal to 1700km BPSK is allocated. Table I summarizes the allocation of modulation formats according to their maximum distance reaches [16]. This flexible allocation process improves spectral efficiency and consequently the power consumption as shown by the results.

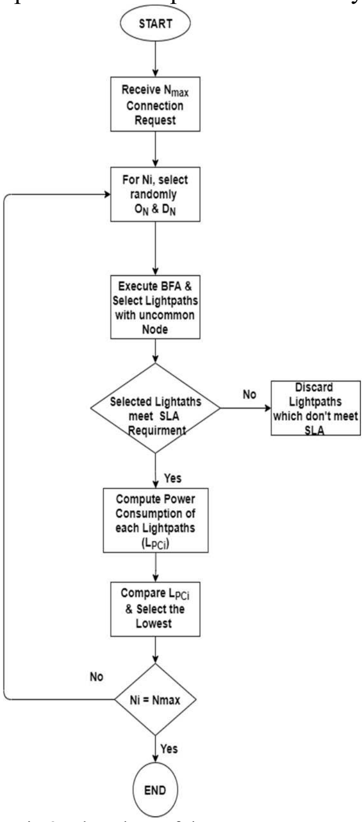

Fig.2. Flowchart of the Power Consumption Brutal Force Algorithm.

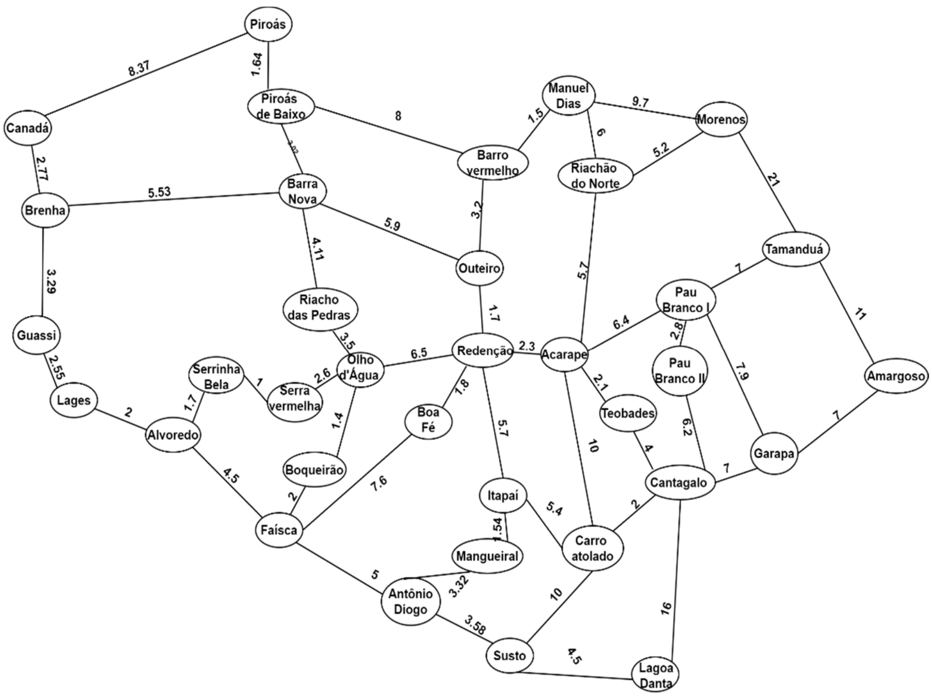

Fig. 3. Acarape-Redencao Network Topology Consisting of 35 Nodes.

IV. Results and Discussion

To evaluate the effectiveness of the proposed AM-EE algorithm, extensive simulations were conducted using Acarape – Redencao network topology as shown in Fig 3. Redencao and Acarape are Brazilian municipalities in the state of Ceará. They are located at an altitude of 88 meters above sea level and 55 km away from Fortaleza. It is part of the Serra de Guaramiranga pole. The topology is done following the geographic map of the region. The network topology consists of 35 nodes and 70 bidirectional links. The nodes represent the different communities, districts, and urban centers of the aforementioned cities. The links represent the paths that interconnect the different regions. The numbers between cities represent physical kilometer distances. We deployed the network topology considering that the optic fiber must traverse every community of both cities. To establish a connection, two nodes are chosen, one as the source node and the other as the destination.

TABLE I. Modulation Formats And Their Maximum Distance.

Modulation	Maximum distance (Km)
BPSK	1776
QPSK	1219
8PSK	893
16QAM	662
32QAM	483
64QAM	336

To create a dynamic scenario, the connection requests arrive one by one, following a Poisson process, with an average arrival rate λ . The holding time is negative exponentially distributed.

Fig. 4 shows the power consumption versus number of connection requests in which we have considered both a traditional technique (with modulation fix and referred to as M-STATIC) and the PB-BFA (variable modulation format). We can see that the power consumption is decreased by adapting the modulation format one of the goals of our developed algorithm PC-BFA.

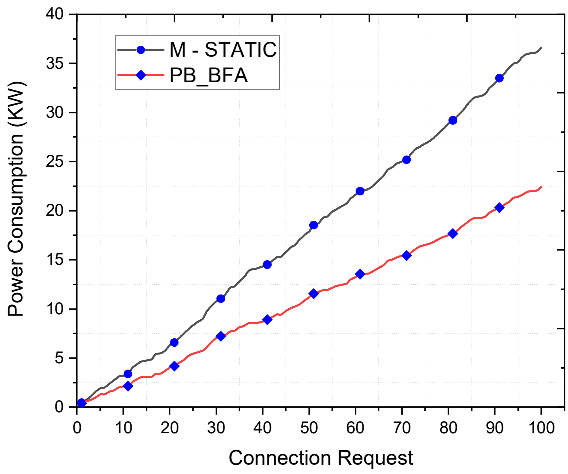

Fig.4. Power Consumption per Connection Request.

Fig 5 highlights the power consumption per bandwidth in which three different routes have been considered. Table II resumes the three routes showing the origin and destination nodes and their physical distance. For each route, both static and variable modulation have been considered. We can appreciate that the power consumption increases in all the scenarios by the growth of the bandwidth despite this, the power consumption is lower when the proposed algorithm is employed. This may be explained by the proposed algorithm's introduction of better conditions by allocating the appropriate required bandwidth and modulation format M.

TABLE II. THREE SELECTED ROUTES RANDOMLY.

Origin	Destination	Route	Distance(Km)
Redencao	Lagoa Danta	R1	16
Garapa	Barra Nova	R2	11
Faisca	Carro Atolado	R3	10

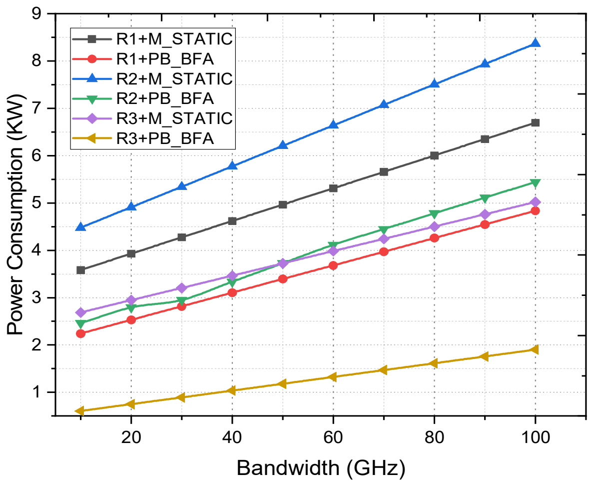

Fig. 5 Power Consumption per Bandwidth for Three different Routes.

V. CONCLUSIONS

A new approach to improve the power consumption in elastic optical networks has been proposed in this manuscript. The proposal is referred to as Power Consumption Brutal Force Algorithm (PC-BFA). The performance of the PC-BFA algorithm has been evaluated in terms of power consumption as a function of a connection request and the use of available bandwidth. The results have been compared with those of the traditional case in which the modulation format is static, and, in all scenarios, our proposed PC-BFA outperforms it.

ACKNOWLEDGMENT

This work was supported by CAPES, CNPq, FAPEM and UNILAB.

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