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Energy Consumption-sensitive Intentional Rerouting of Protected Connections in Elastic Optical Networks

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Abstract: The reduction of energy consumption in elastic optical networks is of major interest to the research community. As a result, several methods for solving this problem in combination with existing classical problems have been proposed. Elastic optical networks are subject to disturbance phenomena that degrade their quality and performance. To optimize resources, operators must recalculate new routes and plan the displacement of established connections towards these new routes to cope with these phenomena, it's the reconfiguration. The problem addressed in this article is to reconfigure a set of unicast protected connections without interruption to a new routing calculated during the process. Knowing that the use of backup paths solves the interruption problem, but has an impact on the overall energy consumption, the goal is to find a good compromise between the two sub-problems when switching from old routes to new ones. To the best of our knowledge, there is no work on reconfiguration that uses energy-aware backup paths. In this work, we proposed an energy-aware EERA_EON rerouting algorithm using the backup paths. Simulations have shown the performance of this approach in terms of energy consumption compared to the work of our predecessors. Subsequently, we proposed a classical BRA_EON rerouting algorithm in elastic optical networks. Simulation results show that we perform BRA_EON in terms of the number of steps.

Index Terms: Energy Consumption, Connections Protection, Rerouting Intentional, Elastic Optical Networks.

1. Introduction

The data explosion due to new information and communication technologies and the development of new applications using the network infrastructure are forcing telecom operators and internet service providers to deploy optic fiber networks. Wavelength Division Multiplexing (WDM) is the technology developed in existing optical networks to meet these requirements. The limitations of WDM optical networks have motivated the development of elastic optical networks [1-2]. In this new technology, the increasing demand of applications leads to an increase in energy consumption [3].

A study [4] has shown that the overall energy consumption in communication networks will reach 1.5 TW (13,140 Twh/year) in 2025 if no planning is done to reduce energy consumption. The amount of information and data carried by an optic fiber and the disturbance phenomena that degrade network performance have led to the development of protection technics which is an important issue in these networks. Connection protection by backup paths increases energy consumption [5]. Energy consumption is a crucial factor in the performance of elastic optical networks. It depends jointly on the network components and the traffic carried in the network [6]. The reduction of energy consumption in elastic optical networks has become an issue in recent years. Consequently, many studies have been conducted in this direction. Most of the work concerning efficient energy management is done in routing and spectrum resource allocation. Optical networks are subject to phenomena that degrade their performance and quality of service.

Reconfiguration is one of the means used by the research community to optimize network resources and energy consumption [7]. In some studies, reconfiguration requires knowledge of the initial and final paths. The problem is to know how to switch from the initial to the final paths while respecting certain optimality criteria. Another variant is the calculation of the final routing during the reconfiguration process [8]. In this case, the interruption problem is handled by using backup paths. Let us consider a set of protected connections with backup paths. The question that could be asked is how to reduce the energy consumption during the reconfiguration process of the protected connections while guaranteeing the continuity of the traffic and the speed of the process? The aim of this work is to propose a method to reduce the overall energy consumption during the rerouting process in a static context, i.e. to respond to the disturbance phenomena that generate it, for a better network performance. This process must be fast in terms of the number of steps while guaranteeing continuity of flow (no interruption during the rerouting process).

In this work, the final path is calculated as we go along. This ensures that sufficient resources are available at each stage to satisfy the establishment of the connection on the new path.

In section 2 we present the related works and the problem formulation in section 3. The presentation of our approach is done in section 4 and finally the analysis of the results in section 5.

2. Related Works

2.1. Reconfiguration Algorithm Calculating the Final Paths During the Process

Work has been done in the literature on the calculation of the final path during the reconfiguration process. This approach is referred to as paths rerouting. The authors in [9] proposed a rerouting approach by minimizing disturbances under dynamic traffic. Connections arrive and depart randomly. Given the wavelength continuity constraint along the optical path, some existing resources will have to be reorganized (reconfigured) to obtain wavelength continuous optical paths to satisfy the establishment of new requests. These connections are rerouted over existing optical paths. This is a passive rerouting approach to support the establishment of new connection requests. Thus, connections are moved to other wavelengths on the same existing optical path. In this respect, a study in [10] showed that there are two variants of rerouting, intentional rerouting which is performed during the lifetime of the connection while limiting disruptions to improve network performance or achieve good load balancing. Passive rerouting promotes the establishment of new connection requests and reduces the probability of network blocking. In this work, it is shown that when there is wavelength conversion, passive rerouting gives better performance. Without wavelength conversion, intentional rerouting shows better performance. Some authors [11] propose a rerouting algorithm with optical path admission methods. This approach calculates a new optical path for an established connection in the network. In this approach, the resources of the selected path are released before the calculation of the new optical path to establish the new request. This method therefore causes a flow interruption. Another variant in [12] is to reroute a set of lightpaths according to a number of new requests by setting a predefined threshold. The rerouting is then done periodically. The calculation of the new paths is done with the k-shortest path algorithm considering the length of the links and the resources available after the update of the link weights at each calculation period. This work is done in the context of passive rerouting to support the establishment of a new connection. In [8] the authors propose an intentional rerouting that improves the performance of the network during disturbance phenomena.

The previous work does not consider the energy consumption in the rerouting process. The following section will be devoted to work that takes the energy consumption problem into account.

2.2. Energy Efficient Algorithm in Elastic Optical Networks

Number Several authors have worked on energy consumption in elastic optical networks. In [5] the authors proposed a model for managing energy consumption in elastic optical networks for protection systems. In this work, a comparison of energy efficiency for fault tolerant networks using connection protection (use of backup paths) between WDM and elastic optical networks was made. It was shown that elastic optical networks are more energy efficient. Network equipment has a considerable impact on the overall energy consumption. Several works in the field of energy management and network performance optimization have been carried out. This work uses connection protection. The reduction of the blocking probability with respect to the modulation format is often managed by inserting regenerators. However, the introduction of regenerators has an impact on the overall energy consumption. In [13] the authors proposed a new traffic optimization scheme to minimize energy consumption by using an auxiliary graph to take into account all transmission options. A study in [14] was proposed to improve the energy efficiency of the network by configuring the optical transponders and applying the traffic bundling policy. In [15] the authors propose an energy minimization algorithm based on traffic bundling by classifying connections according to priority level to also reduce the blocking probability. The authors in [16] proposed a method for protecting connections in Elastic Optical Networks (EON) by placing regenerators. This method considers the QoS requirements of connection requests while minimizing energy consumption. Two types of connections were studied. Critical connections that need to be protected end-to-end by dedicated protection and non-critical connections using shared protection. The power consumption formulas for each component as a function of data rate and modulation format are presented in this work. The authors of [17-18] proposed a study of power consumption in elastic optical networks based on the physical architecture of a type of flexible transponder with variable bandwidth. To reduce the energy consumption, a mixed integer linear scheme for efficient resource allocation (lightpaths and spectrum) was implemented for small networks. For large networks, a resource allocation algorithm using the traffic bundling technique is proposed. The algorithm considers the modulation formats to allocate the spectrum resources appropriately. Simulation results show the performance of this approach. A study in [19] showed that the routing and allocation of spectral resources generates energy consumption that continues to grow. In addition to this, there is the power consumption of components such as optical amplifiers. An optical amplifier operates when an optical signal passes through the optic fiber. In a multiple fiber context, the optical paths must be collectively amplified. In this work, the authors proposed a static routing and spectral resource allocation method that reduces the overall power consumption by establishing the optical paths in an appropriate way while reducing the spectral resources (the bandwidth demand). The work consisted in jointly minimizing the bandwidth and power consumption at the optical amplifiers by finding a good compromise. An integer linear program is proposed and a heuristic favoring this compromise has been developed by making a good allocation of resources. Furthermore, in the same logic, the authors of [20] present a resource allocation system that takes into account certain failures by jointly minimizing the waste of spectral resources (bandwidth) and the energy consumption of certain equipment in a single fiber context. An analytical linear program for small network instances and a low-complexity heuristic are proposed for large networks. Numerical results show that by appropriately allocating optical paths, modulation format and frequency slots to each connection request, this approach significantly increases spectral efficiency and reduces power consumption in networks with variable traffic volumes. To reduce energy consumption, some authors propose a method of deactivating under-used links. The authors in [21] propose a new energy-aware algorithm (SOLA), which selectively disables network links in low-use scenarios that support energy efficiency. The deactivation is based on a threshold value defined by an empirical formula defining the link utilization rate. This approach reduces the total energy consumption, while maintaining a low blocking probability for dynamic traffic. In [22] the authors proposed a modulation format-based resource allocation approach to improve energy efficiency. For each connection, the optical path with low energy consumption is selected. A study in [23] selects the optical path employing an average number of regenerators while minimizing the spectral resources reducing the blocking probability and improving the energy efficiency. The authors in [24] use a penalty-based solving method in the spectral resource optimization framework. Paths with very long lengths use the regenerators efficiently. The authors of [25] have proposed a modulation format-aware routing and spectrum allocation algorithm that reduces power consumption. They base the power consumption of a subcarrier on the subcarrier rate and the amount of transmission data. In contrast to other works that limit themselves to the power consumed in Watt, in this work they evaluate the energy in Joule. The classical reconfiguration determines the new paths according to the network before the actual reconfiguration (migration from initial to final paths). But some works such as [8] and authors of [10-11] determine the final paths of connections during the migration process as justified above. These works only consider the reduction of blocking probability and/or process time and the reduction of spectral resources to determine the final paths. Knowing that energy reduction is crucial for the survival of optical networks, in this work, in addition to the criteria used in the literature, we will consider the energy criterion. Thus, the problem will be to propose an intentional rerouting technique that reduces the overall energy consumption by considering the number of active links on the path in addition to the optical path length and the modulation format. The algorithm should consider the speed of the process in terms of the number of steps. It is on this problem that we will focus. In the following section, we present our problem formulation.

3. Network and Energy Models

3.1. Network Modelling and Architecture

Let the network be modelled by an undirected graph $G=(N,L,B)$ with N the set of nodes in the network, L the set of links l representing the optical fibers as $l=(n,m)$ with $n,m\in$. B the set of frequency slot blocks, $B=\{b_k^l : k\in\{1,...,n\}\}$ where b_k^l is the block k of the link l. $|b_k|$ the block size k representing the number of contiguous slots in the block.

A connection request is defined by the quadruplet (s,d,w,q). Let C be the set of connections established in the network. $c_i=(s_i,d_i,w_i,q_i)$ the $i^{ème}$ connection request from source s_i and destination d_i with a bandwidth w_i $|w_i|=nbr(c_i)$ the number of slots and q_i the amount or data capacity of the information transmitted by the connection i .

3.2. Energy Consumption Model

The energy consumption is caused by the components of the elastic optical network, namely the bandwidth-variable transponders (BVT), the bandwidth-variable optical switches (OXC_BV) and the optical amplifier (AO) [26]. The power consumption of the BVT transponder depends on the number of slots allocated to the connection and the modulation format. The power consumption of the optical switch (OXC_BV) depends on its degree. The power consumption at the amplifiers depends on the width of the spectrum to be amplified. The equations below are detailed in [21] and the authors of [27-28].

A. The Power Consumption of Variable Bandwidth Transponders (BVT)

The power consumption of a transponder is defined according to (1) below

$$P_{BVT}^{i}=\alpha D+\beta \tag{1}$$

P_{BVT}^{i} The power of a transponder in modulation format i

α The power of a unit of bitrate.

β an additive constant representing 20% of the overall power consumption of a transponder.

D The transmission rate in Gb/s with a suitable modulation format M

We have (2):

$$D=nbr(c_i)\times M\times T \tag{2}$$

$nbr(c_i)$ the number of slots in connection i, M the modulation format defined in the table below and T the capacity of a slot in the standard modulation format $T=12.5Gb/s$. A transponder BVT will be represented by (α,β) . According to the literature [21,26] $\alpha=1.683$ and $\beta=91.333$.

The power consumption of the transponders on the path is defined by the following (3):

$$P_{BVT}(ch)=2\times P_{BVT}^{i} \tag{3}$$

B. The Power of Optical Amplifiers

According to the work of [16,20-21], knowing that an optical amplifier is placed every 100 km to regenerate the signal, the consumption of an optical amplifier is defined as follows (4):

$$P_{AO}=0,0075F=30W \tag{4}$$

F is the bandwidth of the spectrum to be amplified. In the optical path, the power consumed by the optical amplifiers is defined by (5) and (6):

$$P_{AO}(ch)=\sum_{(n,m)\in ch}\varphi(n,m)\times P_{AO} \tag{5}$$

$$\varphi(n,m) = \begin{cases} 0, \; if \;\; \dfrac{L}{d_{AO}} \le 1 \\ \left\lceil \dfrac{L}{d_{AO}} \right\rceil, otherwise \end{cases} \tag{6}$$

$\lceil . \rceil$ returns the lower integer value is the number of amplifiers. L the length of the link between the source and the destination.

C. Power Consumption of Variable Bandwidth Optical Switches (OXC_BV).

The power consumption of an optical switch is presented in (7) defined as follows [26] :

$$P_{OXC_{BV}}(ch) = 85 \times \deg + 100 \times \delta + 150 \tag{7}$$

$\deg$ number of active links connected to the switch, δ channels that can be inserted or deleted. We assume that there are no additive channels $(\delta = 0)$.

The power of the optical switches on the connection path is defined in (8):

$$P_{OXC_{BV}}(ch) = (n_{ch} + 1) \times P_{OXC_{BV}} \tag{8}$$

n_{ch} is the number of links on the optical path.

The power consumption of an optical path is defined from (3), (5) and (8) by (9) and (10).

$$P(ch) = 2P_{BVT}^{i} + \sum_{(n,m)\in ch} \varphi(n,m) \times P_{AO} + (n_{ch} + 1) \times P_{OXC_{BV}} \tag{9}$$

$$P(ch) = 2P_{BVT}^{i} + 30 \times \sum_{(n,m)\in ch} \varphi(n,m) + 320 \times n_{ch} + 150 \tag{10}$$

The calculation of energy in Joule according to the work of [25] defined in (11) below:

$$Energ = P \times \frac{1}{B_r} \times V \tag{11}$$

With P the power consumed by a subcarrier according to the modulation format, B_r the rate of a frequency slot adapted to the modulation format and V the amount of information transmitted from a source to a destination of a connection request.

The energy consumed in Joule of connection request is defined by (12) below:

$$En = \frac{P(ch)}{D} \times Q \tag{12}$$

$P(ch)$, D and Q are respectively the power, the transmission rate and the data capacity of information transmitted expressed in bytes of the connection from a source to a destination.

3.3. Eligibility Criteria for an Optical Path

Let be the k-shortest paths determined by the Dijkstra algorithm. The set of candidate paths must have the minimum resources to satisfy the connection demand. The set of candidate paths is defined by (13) as follows:

$$ch(c_i) = \left\{ ch_j : \exists b \in B(ch_j); |b| \ge nbr(c_i) : j \ge 1 \right\} \tag{13}$$

$ch(c_i)$ Set of candidate paths for a given c_i connection request.

$B(ch_j)$ Set of frequency slot blocks on path j

$nbr(c_i)$ the number of slots required to establish the connection request c_i .

The eligible path of the connection request is defined by (14) below:

$$ch_{el}(c_i) = ch_k : En(ch_k) \leq En(ch_j) \, and \, ch_k \in ch(c_i) \quad (14)$$

$ch_{el}(c_i)$ is the eligible path of the connection request c_i .

$En(ch_k)$ and $En(ch_j)$ respectively, the energy consumption of the paths ch_k and ch_j . $ch(c_i)$ the set of candidate paths of the connection c_i .

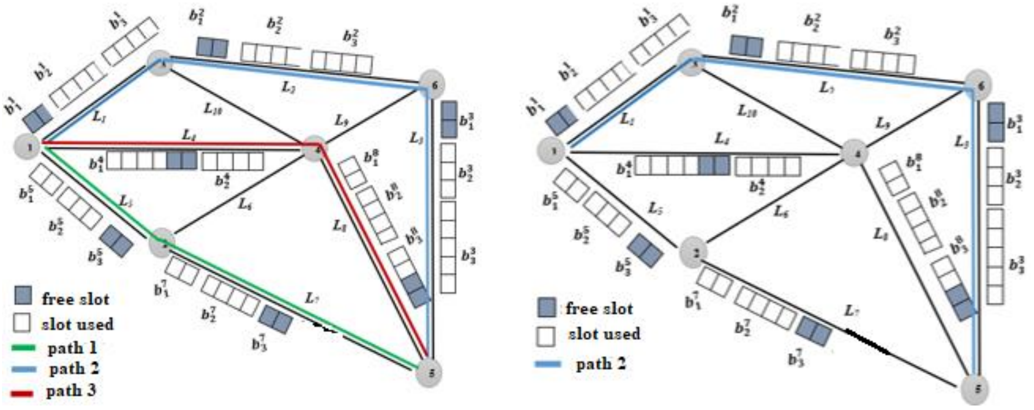

Fig.1. Illustration of eligible path determination

The calculation of the energy consumption, depending on the modulation formats, is defined in the table below.

Table 1. Energy model of a subcarrier as a function of the modulation format [5]

Modulation format	Range [km]	Single subcarrier throughput (Gb/s)	Power consumption of a single subcarrier (W)
BPSK	4000	12,5	112,374
QPSK	2000	25	133,16
8 - QAM	1000	37,5	154,457
16 - QAM	500	50	175,498
32 - QAM	250	62,5	196,539
64 - QAM	125	75	217,581

4. Reconfiguration with Power Consumption-sensitive Rerouting

4.1. Classical Rerouting Algorithm in Elastic Optical Networks

In this section we propose an algorithm for intentional rerouting in elastic optical networks. According to the studies of [10,12] In this section, we propose the Basic Rerouting Algorithm in Elastic Optical Networks (BRA_EON), rerouting algorithm, an intentional rerouting algorithm that computes new paths to improve performance and plans any route changes for connections in case of disturbance phenomena, degrading the network state. The pseudo-algorithm is defined as follows:

Algorithm 1: Classic path rerouting algorithm (BRA_EON)

Input: P^{old} Set of optical paths, $P = \{ \}$

Output: P^{new} Set of new optical paths

Begin

While P^{old} ***not empty do***

Choose the path $p(s,d)$ *from* P^{old} // Choose an established optical path

calculate the paths $p_1(s,d), p_2(s,d),..., p_k(s,d) \neq p(s,d) \, with \, k \geq 1$

***if* path is found**

***for* i = 1 to k**

if $p_i(s,d)$ **has sufficient resources**

$P = P \cup p_i(s,d)$
end if
end for
end if
if P **is not empty**
select a path $p \in P$
$P^{new} = P^{new} \cup p$ // Establish the connection on the new path that has available resources
end if
$P^{old} = P^{old} - \{p\}$ // delete path p from the initial set of paths
end While
end

In this algorithm, P^{old} is set of optical paths, for each optical path in the initial set of optical paths, we calculate the k-shortest optical paths for a source and destination node for selected optical path, the new optical path with sufficient resources among these calculated paths is retained. We reroute the connection to the new path and the resources of the old path are released before the next connection is chosen. We iterate the process until there are no more connections to reroute in set of P^{old}.

In the next section, we propose an energy-sensitive rerouting algorithm. The previous algorithm reroutes sequentially connection by connection to respond to the phenomenon that triggered it.

4.2. Energy Consumption-sensitive Rerouting Algorithm

In this section we present our algorithmic approach. This approach is called Energy Efficient Routing Algorithm (EERA_EON). Consider a network in which connections are established with backup paths. The backup paths are shared (several primary paths use the same resources on the backup paths). The final paths are calculated as they are established. The algorithm selects the energy-optimal path for each connection.

Algorithm 2: Energy Efficient Routing Algorithm (EERA_EON)

Input: $G = (N, L, B)$ with B the capacity of the links in terms of the number of slots $c_i = (s_i, d_i, w_i)$ all the initial paths $b_i = (s_i, d_i, w_i)$ the backup paths.

Output: Energy-optimal reconfiguration sequence.

BEGIN
// Construct the auxiliary graph G_a with b_i
for i= 1 to $|b_i|$
$G_a = G_a + n_i$ // adding nodes n_i in graph G_a
end for
for i = 1 to $|b_i|$ **- 1**
for j = i+1 to $|b_i|$
if (bi and bj share a link or resource) // sharing links or resources in both paths
$G_a = G_a + link(n_i, n_j)$ // adding link in G_a when corresponding paths share link
end if
end for
end for
for n_i ***in*** G_a
$G_c = G_c + color(n_i)$ // run algorithm for coloring nodes of G_a
end for
for* each color *col in G_c
***for* each node n in** G_c
***if* n has a color col**
$set\_group(col) = set\_group(col) \cup \{n\}$
end if
end for
$\pi = \pi \cup set\_Group(col)$
end for
While π is not empty

```
25.        select a set  π* ∈ π                    // choose a group of π's in order of increasing index
26.            establish simultaneously all connections of  π*  on their backup path respectively
27.            Free up resources from the π_t group's former primary paths
28.        for each connection c in  π*
29.            calculate the k-shortest path  p_1(c), p_2(c),..., p_k(c)
30.              if path found
31.                 Select eligible path with (14)
32.             Establish connection c on eligible path
33.             Free up resources of c  backup path
34.              end if
35.        end for
36.        Update  π
37.    end While
38. END
```

Our algorithm takes as input the network topology, the set of connections, their initial paths C_i with their backup paths b_i. The goal is to calculate during the reconfiguration process the final paths that are not known in advance. The final paths obtained must minimize the overall energy consumption. In **line 3 – line 5**, we calculate the auxiliary graph G_a from the backup paths**.** In the auxiliary graph the nodes represent the backup paths of the connections - an edge between two nodes in the graph means that the backup paths share resources we see that in **line 6 – line 12**. The construction of this graph is specified in the work of [8]. In **line 13 – line 15**, the $Color(\,)$ algorithm for coloring the nodes of the graph G_a was inspired by the work developed in [29-30] which is one of the references in the literature although being an old method, it is still used. In this step, the nodes of the graph G_a are colored with the minimum number of colors possible. No two adjacent nodes have the same color. Result of coloring graph nodes is defined in graph G_c**.** According to G_c a set of connections groups are formed in π to **line 19** by using $Set\_Group(\,)$ algorithm on G_c**.** We have drawn on the work of [8] to define this algorithm. That allows us to know which connections have independent backup paths (i.e., do not share resources or links). This allows us to form the set π of groups of connections that can be simultaneously reconfigured according to the optimality criteria. From **line 24 – line 37**, we iterate until the set π is empty, the operations of simultaneous switching of the connections of each group on the backup paths, the release of the resources of the old primary paths, the calculation of the k-shortest paths for each connection of the current group. Then the eligible path of each connection reducing energy consumption is determined from the k-shortest candidate paths. In **line 27** After determining the eligible path for each connection of the current group, we simultaneously establish the connections on their calculated final paths. In **line 33,** we release the resources of the backup paths of the connections in the reconfigured current group b_k^m and move to the next not-yet-reconfigured group in the π-set. In **line 36,** the set π is updated and the process resumes until there are no more connections to reconfigure.

5. Simulations and Analysis of Results

In this section, we present the results of our simulations. The performance metrics of our approach are the energy consumption and the duration in terms of number of steps during the reconfiguration process. We analyse the results of our approach with one of the reconfiguration algorithms that calculates the final paths in the process using the backup paths from the literature. To the best of our knowledge, algorithms that compute the final paths using the backup paths in our context are not obvious to find.

Each link has 320 frequency slots, 5 modulation formats are defined depending on the communication range. The k-shortest path algorithm is used to calculate the candidate paths that have the necessary spectral resources to satisfy the connection demand. Here we arbitrarily set k=3 due to contiguity and frequency slot continuity constraints. We progressively generate lightpaths ranging from 10 connections to 300 connections for the primary paths for a source and a destination with the Dijkstra algorithm. Tables 2 and 3 below present the summary of the simulation metrics and parameters respectively. The spectral resources of the primary paths are removed before the calculation of the backup paths for the same connections (source - destination). The backup paths under these conditions can use the same physical links as the primary paths by using different spectral resources. Thus, we distinguish the virtual topology from the physical topology. We compare ourselves to [8] in terms of overall energy consumption and the classical rerouting algorithm in elastic optical networks based on the work of [10, 12] in terms of the number of steps. By steps we mean any change in the virtual topology during the process (optical path change). Each change in the virtual topology consists of pre-establishing the connection, establishing the connection on another optical path (primary or backup) and releasing the resources on the old optical path. The transition from one path to the backup path and from the backup path to the new path are two steps. At each switch, the virtual topology is modified. We observe the performance of our approach in the PAN EUROPEAN topology with 28 nodes and 44 links and the USA BACKBONE topology with 24 nodes and 41 links.

Table 2. Simulation metrics

Metrics	Expression
Execution duration	Number of steps
Energy consumption	Energy expressed in Joule
Number of interruptions	Binary variable

Table 3. Simulation parameters

Parameters	Values
Simulator	flexgridsim
Topologies	Pan_European and Usa_Backbone
Modulation format	5
Number of slots per link	320
Instances of execution	500

We find that in terms of overall energy consumption we achieve a good performance compared to Connection Group Reconfiguration Algorithm (CGRA) approach of Xin et al. Fig. 2 shows this through the two topologies used in the literature in the field of elastic optical networks. This performance is since in the calculation of the final optical paths we consider the energy consumption of all the links constituting the optical path. We have shown using equations (10) and (11) that the energy consumption depends on three parameters, namely the link length, the number of links in the path and the modulation format. In contrast to the work of our predecessors, who only consider the modulation format and the link length, which also influences the length of the selected optical path. A path can be short but if it contains more links the energy consumption of the path will be high. The algorithm of Xin et al. only considers the link length of the path which results in high energy consumption for paths that use enough links. Also, the fixed nature of the spectrum resources is a cause of this high consumption. With the EUROPEAN PAN topology, as shown in Figure 2, the energy consumption is lower in relation to the link lengths, which are very short, in contrast to the USA BACKBONE. However, both follow the same trend in terms of performance. This is because in the calculation of the new paths we consider a third parameter which is the number of active links on the selected path in addition to the other two parameters such as the path length and the modulation format. The consideration of this third parameter is crucial in that an optical path, although short if it contains more links may consume more energy than a path that uses fewer links. Taking this third parameter into account has allowed us to reduce the overall energy consumption in both topologies. The consumption is even more accentuated in the USA BACKBONE topology because of the length of the links, which are longer than in the EUROPEAN PAN topology.

In terms of the number of steps in the process, we are on par with the CGRA approach of Xin et al. The number of steps is related in both approaches to the number of connection groups based on the computation of the auxiliary graph generated through the shared backup paths. We compared ourselves to a rerouting algorithm in elastic optical networks which we adapted for the purpose. Fig. 3 shows the results of our simulations in the two previous topologies. This performance is because we simultaneously reroute a set of optical paths belonging to the same group using the auxiliary graph, which allows the optical paths to be grouped together, as opposed to conventional rerouting, which carries out the operation by considering the optical paths individually. When the number of connections is high, the performance of our approach is evident in contrast to the classical rerouting algorithm in elastic optical networks. In the classical algorithm, rerouting is performed by selecting an initially established optical path at each step of the process. The calculation of the new path considers the availability of resources and the updated link length after each step. This approach ensures that sufficient resources are available to establish the connection on the new path. It also guarantees the continuity of the flow during the process. We note that our approach guarantees the continuity of the flow also due to the use of backup paths and the use of old optical paths whose resources have been previously released.

The following tables (Table 4, 5) show the results of the simulations.

Table 4. Overall consumption table during the energy rerouting process (KJ)

Algorithms	Pan_European	Usa_Backbone
EERA_EON	462.54	570.6
CGRA	582.55	670.55

Table 5. Process duration in terms of number of steps

Algorithms	Pan_European	Usa_Backbone
EERA_EON	112	112
BRA_EON	300	300

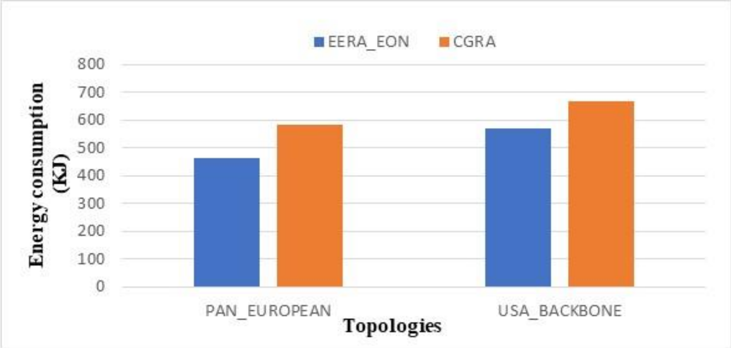

Fig.2. Overall energy consumption

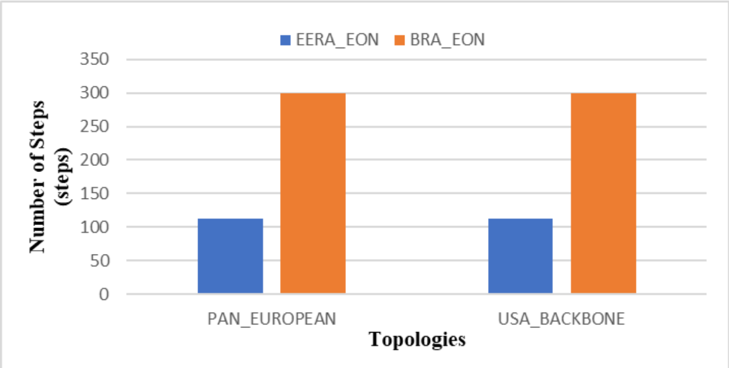

Fig.3. Number of rerouting steps

6. Conclusions

In this work, we have presented a reconfiguration approach using backup paths. It is an approach to rerouting protected connections in elastic optical networks. We proposed a rerouting algorithm sensitive to the overall energy consumption called **EERA_EON**. The algorithm has shown its performance with respect to the overall energy consumption compared to the work of Xin et al. Subsequently, we proposed a **BRA_EON** rerouting algorithm based on the literature. This work proposes a rerouting algorithm that allows the establishment of new connection requests, which is referred to as passive rerouting. We proposed the BRA_EON, an intentional rerouting algorithm that calculates new paths to improve performance and plans a change of route for connections in case of phenomena degrading the network state. We compared ourselves with this algorithm in terms of the number of steps in the process. We also observed a good performance because we perform the rerouting in a much lower number of steps than the **BRA_EON** algorithm.

This work has several application areas such as medicine, secure exchanges between political figures, point-to-point communications, etc. Let's take the case of a remote surgery, the slightest disturbance of the communication during the remote surgeon's orientations can have serious consequences, namely the death of the patient. To solve such a problem, a rerouting (calculation of the new path according to an optimality criterion) is necessary, this operation must be done without interruption of the flow with a speed of the process with a lower energy consumption.

Another area of application could be banking transactions and all disruption-sensitive communications. Disruption during the transaction between the bank and the customer could cancel the transaction or cause an update problem if the customer just managed to withdraw or deposit money just before the disruption it could cause a loss of money either for the bank in case the customer withdrew money and the update was interrupted or for the customer who managed to deposit money in the case.

In this work, we have focused on a static and deterministic reconfiguration context where established connections must simply be reconfigured in case of disturbance phenomena that trigger the process.

In the following, we can extend it to a dynamic framework in which we reconfigure ourselves to establish new connection requests. In this case, other performance metrics such as fragmentation rate, blocking probability will be evaluated in addition to the performance metrics studied in this work.

References

[1] M. Yaghubi-Namaad, A. G. Rahbar, and B. Alizadeh, 'Adaptive Modulation and Flexible Resource Allocation in Space-Division-Multiplexed Elastic Optical Networks', *J. Opt. Commun. Netw*, vol. 10, nº 3, March 2018, pp. 240.

[2] M. Jinno, 'Roles and Benefits of Elastic Optical Networks in Beyond 100-Gb/s Era', in *ECOC 2016; 42nd European Conference*

on Optical Communication, Sept. 2016, pp. 1-3.

[3] Y. Tan, R. Gu, and Y. Ji, ‘Energy-efficient Routing, Modulation and Spectrum Allocation in Elastic Optical Networks’, *Opt. Fiber Technol.*, vol. 36, Jul. 2017, pp. 297-305.

[4] M. Aibin, J. Gotengco, J. Tran, J. Soukchamroeun, C. Vinchoff, and N. Chung, ‘Energy Consumption Reduction of the Survivable Spectrally-Spatially Flexible Optical Networks’, in *2020 22nd International Conference on Transparent Optical Networks (ICTON)*, Jul 2020, pp. 1-4.

[5] J. López, Y. Ye, V. López, F. Jiménez, R. Duque, and P. M. Krummrich, ‘On the Energy Efficiency of Survivable Optical Transport Networks with Flexible-grid’, in *European Conference and Exhibition on Optical Communication,* Amsterdam, 2012, pp. P5.05.

[6] K. K. Munasinghe, M. N. Dharmaweera, U. L. Wijewardhana, C. De Alwis, and R. Parthiban, ‘Joint Minimization of Spectrum and Power in Impairment-Aware Elastic Optical Networks’, IEEE Access, vol. 9, 2021, pp. 43349-43363.

[7] A. Kadohata, A. Hiro, F. Inuzuka, A. Watanabe, and O. Ishida, ‘Wavelength Path Reconfiguration Design in Transparent Optical WDM Networks’, Journal of Optical Communications and Networking, VOL.5 Issue.7 2013, pp. 751-761.

[8] Y. Xin, M. Shayman, R. J. La, and S. I. Marcus, ‘Reconfiguration of Survivable IP over WDM Networks’, *Opt. Switch. Netw.* Opt. 21, Jul. 2016, pp. 93-100.

[9] K.-C. Lee and V. O. K. Li, ‘A Wavelength Rerouting Algorithm in Wide-area all-Optical Networks’, *J. Light. Technol.*, vol. 14, nº 6, June 1996, pp. 1218-1229.

[10] X. Chu, T. Bu, and X.-Y. Li, ‘A Study of Lightpath Rerouting Schemes in Wavelength-routed WDM Networks’, in *2007 IEEE International Conference on Communications*, 2007, pp. 2400-2405.

[11] A. de Sousa, P. Monteiro, and C. B. Lopes, ‘Lightpath Admission Control and Rerouting in Dynamic Flex-grid Optical Transport Networks’, *Networks*, vol. 69, nº 1, Jan 2017, pp. 151-163.

[12] S. Zhang, Z. Xu, S. Du, and J. Wu, ‘Routing and Spectrum Assignment Algorithm with Traffic Prediction and Periodic Rerouting in Elastic Optical Networks’, in *2019 IEEE 11th International Conference on Communication Software and Networks (ICCSN),* Chongqing, China, June 2019, pp. 17-21.

[13] P. Biswas, S. Kr. Dey, and A. Adhya, ‘Auxiliary Graph-based Energy-Efficient Dynamic Connection Grooming for Elastic Optical Networks’, in *2016 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS),* Bangalore, Nov. 2016, pp. 1-3.

[14] M. Hadi and M. R. Pakravan, ‘Energy-Efficient Fast Configuration of Flexible Transponders and Grooming Switches in OFDM-Based Elastic Optical Networks’, *J. Opt. Commun. Netw.* J. Opt. 10, nº 2, Feb. 2018, pp. 90.

[15] F. Shirin Abkenar and A. G. Rahbar, ‘The Energy Minimization Algorithm for Elastic Optical Networks’, *Photonic Netw. Commun.*, vol. 42, nº 1, Aug. 2021, pp. 15-26.

[16] N. G. Anoh, J. C. Adépo, M. Babri, and B. Aka, ‘Hybrid Protection Scheme for Elastic Optical Networks with Regenerator and Efficient Energy Consideration’, International Journal of Computer Science and Telecommunications, vol. 6, nº 10, Nov 2015, p. 1-7.

[17] Y. Tan, R. Gu, and Y. Ji, ‘Energy-efficient Routing, Modulation and Spectrum Allocation in Elastic Optical Networks’, *Opt. Fiber Technol*, vol. 36, Jul. 2017, pp. 297-305.

[18] P. Biswas and A. Adhya, ‘Energy-Efficient Network Planning and Traffic Provisioning in IP-Over-Elastic Optical Networks’, *Optik*, vol. 185, May 2019, pp. 1115-1133.

[19] T. Kudo, T. Kimura, Y. Fukuchi, and K. Hirata, ‘Static Routing and Spectrum Allocation Method for Design of Low-Power Elastic Optical Networks with Multifiber Environments’, *Opt. Switch. Netw.* Opt. 40, May 2021, p. 100604.

[20] K. K. Munasinghe, M. N. Dharmaweera, U. L. Wijewardhana, C. De Alwis, and R. Parthiban, ‘Joint Minimization of Spectrum and Power in Impairment-Aware Elastic Optical Networks’, IEEE *Access*, vol. 9, 2021, pp. 43349-43363.

[21] G. Beletsioti, Stathis Mavridopoulos, Georgios A. Tziroglou, Constantine A. Kyriakopoulos, Georgios I. Papadimitriou and Emmanouel Varvarigos, ‘Power-Aware Algorithms for Energy-Efficient Elastic Optical Backbone and Metro Networks’, 2019, pp. 63-70.

[22] S. Y. M. Bandiri, T. C. Pimenta, F. R. Durand, and D. H. Spadoti, ‘Adaptive Modulation Allocation Algorithm in Elastic Optical Networks’, *Int. J. Commun. Syst*, August 2020, pp. 4581.

[23] B. Patel, H. Ji, S. Nayak, T. Ding, Y. Pan, and M. Aibin, ‘On Efficient Candidate Path Selection for Dynamic Routing in Elastic Optical Networks’, in *2020 11th* IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference *(UEMCON),* New York, NY, USA, Oct. 2020, pp. 0889-0894.

[24] S. Zhao, S. Shah, K. Patel, N. Patel, V. Shetty, and M. Aibin, ‘Adaptive Modulation Regenerator and Distance Aware Algorithm for Dynamic Routing in Elastic Optical Networks’, in *2020 11th* IEEE Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), New York, NY, USA, Oct. 2020, pp. 0875-0880.

[25] J. Gotengco, J. Tran, J. Soukchamroeun, D. F. de Almeida, and M. Aibin, ‘Energy Consumption Reduction of the Spectrally-Spatially Flexible Optical Networks Based on the Energy Savings Algorithm’, in 2020 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE), London, ON, Canada, August 2020, pp. 1-5.

[26] J. Halder, T. Acharya, M. Chatterjee, and U. Bhattacharya, ‘On Spectrum and Energy Efficient Survivable Multipath Routing in Off-line Elastic Optical Network’, Comput. Commun, vol. 160, Jul. 2020, pp. 375-387.

[27] Jiawei Zhang Yongli Zhao, Xiaosong Yu, Jie Zhang, Mei Song, Yuefeng Ji, and Biswanath Mukherjee, ‘Energy-Efficient Traffic Grooming in Sliceable-Transponder-Equipped IP-Over-Elastic Optical Networks [Invited]’, J. Opt. Commun. Netw, vol. 7, nº 1, Jan. 2015, p. A142-A152.

[28] M. Ju, F. Zhou, S. Xiao, and Z. Zhu, ‘Energy-efficient protection with directed p-Cycles for asymmetric traffic in Elastic Optical Networks’, 21st European Conference on Networks and Optical Communications. 2016, pp. 1-6.

[29] Z. Zhang and A. Acampora, ‘A heuristic Wavelength Assignment Algorithm for Multihop WDM Networks with Wavelength Routing and Wavelength Reuse’, in *Proceedings of INFOCOM '94 Conference on Computer Communications*, vol.2, June 1994, pp. 534-543.

[30] H. Zang, J. P. Julet and B. Mukberjeet Mukberjeet, ‘A Review of Routing and Wavelength Assignment Approaches for Wavelength-Routed Optical WDM Networks’, optical networks magazine, 2000.

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