Efficient Energy Routing with connections Rerouting in Elastic Optical Networks under static connections

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Abstract

The development of Internet traffic in recent years led telecommunication operators to increase networks bandwidth and motivate evolution of traditional WDM network towards SLICE networks (*Spectrum-sLICed Elastic optical path network*). The SLICE networks such as all-optical network inherit the problems of power consumption. Therefore, we present, in this paper, an efficient energy routing algorithm and spectrum allocation with connections rerouting under spectrum contiguity and spectrum continuity constraints. When a connection request must be established and there are no adequate and continuous spectrum resources between a source and a destination node, rerouting technique is used to move some existing connections to free resources. To meet such a connection request, and for power consumption management of a service requested, our proposition takes into account the path length, the number of links on optical paths and appropriate modulation format. Analysis of the results of our algorithm to the existing routing algorithm RMLSA in the literature shows that our approach has better performance in terms of the connections established in the network.

Keywords*: Efficient energy, routing algorithm, connection rerouting, elastic optical network, spectrum contiguity, spectrum continuity***.**

1. Introduction

Transport networks are faced with the development of very different services, massively deployed and requiring relatively large network resources. A terminals extension supporting these types of services to the household and the requirements of current users are a major challenge for these transport networks. Wavelength multiplexing Technology (WDM: *Wavelength Division Multiplexing*) used in these networks can share the wide spectrum available in order to meet several requests for connections with interesting rates.

Several studies have been conducted in order to improve optical spectrum management on the problem of routing and wavelength assignment [1-3], rerouting / optical reconfiguration problem [4-7] and problem of traffic grooming in such networks. However, fixed grid frequency at optical WDM networks generally lead to resources waste due to large sub-bands allocated to less demanding bandwidth applications. For better management of bandwidth offered by WDM networks, new studies have led to implementation of elastic optical networks called SLICE networks (*Spectrum-sLICed Elastic optical path*) [8-12]. SLICE networks are also faced with problem of routing, resources allocation and connections rerouting.

The mechanism of routing and spectrum allocation consists in determining in the first instance a physical path between a source and a destination node. Thereafter, to this path, some number of frequency slots are allocated taking into account the length of the physical path, to rate desired for the connection and modulation format. This causes some heterogeneity of the frequency grids in the SLICE network unlike WDM networks where the grids are fixed [13-15]. When the optical routing fails due to lack of resources available to satisfy a connection request, in the literature the technique of connection rerouting is applied. This technique consists to modify the optical path of a connection. It therefore allows moving an existing connection in the network from an initial path to another final path that has free and sufficient resources to release resources for one connection that may be blocked. Rerouting problem has been extensively studied in WDM networks. The rerouting applying in SLICE networks in the interesting subject in this paper.

As all-optical network, the elastic optical networks consist also to active components that have an impact on the overall energy consumption of the network. For example, for each service requested, an optical path between a source s and a destination d with a large number of nodes and with a long distance will consume more energy compared to another path from the same source and same destination however with fewer nodes and a shorter length. When there is no sufficient resource to establish a new connection request, connection rerouting technique is used to increase the number of connections established in the network. Our rerouting technique allows improving network performance by increasing the blocking probability of network. We consider static connections requests with the goal of finding efficient energy paths and low blocking probability to meet future demands.

Section 2 presents the SLICE networks architecture. In section 3, we present works existing on routing in elastic optical networks. Section 4 presents the motivation of the problem addressed. In Section 5, the analytical model of SLICE networks is presented. Section 6 presents our routing with rerouting technique proposed. Sections 7 and 8 present the analysis of the numerical results and conclusion respectively.

2. SLICE networks architecture

SLICE networks are networks in which the frequency grids are flexible from a connection request to another contrary to fixed frequencies grids of current optical networks. Fig.1 below shows (at the top), fixed frequency grids representation of 50 GHz ITU (International Telecommunication Union) compared to flexible frequency grids adopted by elastic optical networks (at the bottom). The above representation shows that the fixed frequency grid does not take into account the bit rates of 400 Gb / s and 1Tb / s because of frequency grid limit to 50 GHz. Whereas, with the representation at the bottom, frequency grids are proportional to the flow of data and can support any bit rate from 10 Gb / s to 1 Tb / s.

This new optical network is based on the optical OFDM (Orthogonal Frequency Division Multiplexing) modulation [16]. OFDM technology in the optical domain provides a great flexibility for SLICE networks to support applications for heterogeneous traffic and high spectral capacity. This flexibility is achieved through to new elements that make up architecture of these networks such as the bandwidth variable transponder (BV_T) and bandwidth variable Optical-Cross-connect (BV_OXC) which is show in fig. 2. In the basic operation of SLICE networks, the transponder BV_T adjusts a number of slots and the associated modulation type based on a request. Then each node in the path with bandwidth variable Optical-Cross-connect between source and destination nodes defines appropriate spectrum of connection to establish end-to-end optical path.

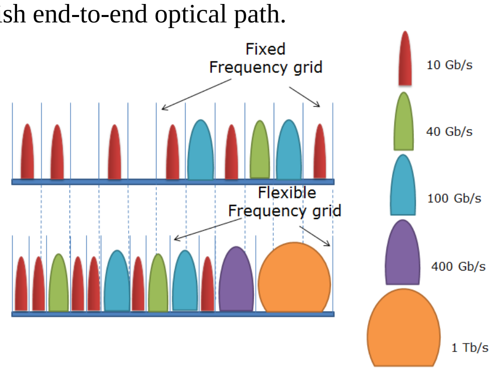

Fig. 1 fixed frequency grid/flexible frequency grid

It is possible at that moment to allocate necessary spectrum required for an optical path for making better use of spectrum resources.

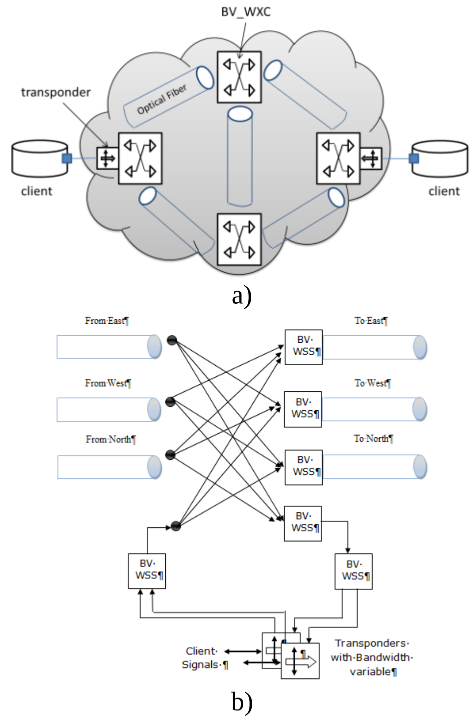

Fig. 2 SLICE networks Architecture a) SLICE network Model, b) SLICE node Model (BV_OXC)

3. Related work in optical routing in SLICE networks

It is obvious that SLICE network optimizes the frequency spectrum use and that emergence of this network is presented as a promising solution for the effective management of the optical spectrum. However, it inherits optimization problems such as optical routing and connections rerouting. OFDM technology also introduces new challenges in the design and such networks control. These challenges require new spectrum management techniques effectively and efficiently responding to questions related to:

- Spectrum continuity which consists in allocating the same spectrum resources on each link along an optical path.
- Spectrum contiguity which consists in allocating a spectrum blocks in which frequency slots are consecutive.

Fig. 3 below, shows the spectrum continuity and contiguity / consecutive through two connections C1 and C2. Connection C1 (A, D, 2) which has source node A and destination node D, uses two frequency slots on the path A-B-D. On the link A-B, connection C1 uses the contiguous slots 1 to 2 (slots from 1 to 2 are consecutive) and as on the link B-D, slots from 1 to 2 are not available then the same connection used slots 3 to 4 therefore. Thereby, connection C1 has not respected the spectrum continuity since it does not use the same frequency slots along the optical path. On the other hand, connection C2 (A, D, 3) uses about the same number of contiguous frequency slots 1 to 3 (the slots 1 to 3 are consecutive) on links A-C and C-D which represents the optical path A-C-D of connection C2. Here, spectrum continuity and spectrum contiguity / consecutive have observed.

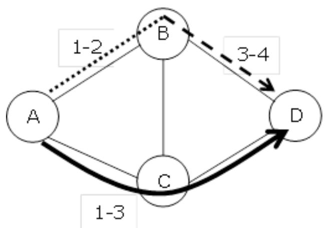

Fig. 3 Illustration of spectrum continuity / contiguity

In recent years, studies have focused on the problem of routing and spectrum assignment (RSA)[17-24]. There are two types of routing based on connection requests: static and dynamic routing. This issue remains a very active area of research in the center of many optimization problems in the SLICE networks.
One of the main challenges in the elastic optical network is to determine necessary spectral resources to a connection and allocate them to an optical path with the smallest guard band between the optical channels. In this direction, Xin Wan et al 2011 [20], propose different optical routing algorithms. However, this study doesn't take into account some important features of SLICE networks such as modulation format and guard band between the optical channels.
Ori Gerstel et al 2012 have integrated modulation format in their studies [21]. They solve the problem in two steps: In the first step, from a physical topology of the network, their algorithm determines a list of paths between source node and destination node by associating in each path, the appropriate modulation format. The second step consists in assigning a set of free contiguous frequency slots to the path chosen taking into account the rate and modulation format.
Yin Wang et al 2012 [22] propose three routing and spectrum allocation algorithms by considering spectrum consecutiveness constraint. All the free frequency slots on the given path is grouped into different blocks based on slots occupied. The goal is to allocate the slots so that the blocking probability in the network is minimized by avoiding the maximum dispersed slots.
Therefore, for each path p , it determines the set of spectrum blocks containing consecutive slots and the block which has the largest value of c_p is selected from the following expression:

$$c_p = \frac{\sum_{i=1}^{F-1} u_i^p . u_{i+1}^p}{B_p} \times \frac{\sum_{i=1}^{F} u_i^p}{F}$$

- With F the number of available slots on link,
- B_p the number of slot blocks on path p ,
- $\sum_{i=1}^{F} u_i^p / F$ represents the percentage of available frequency slot along the path p
- and $\sum_{i=1}^{F-1} u_i^p . u_{i+1}^p$ is the total number of free consecutive slots along the path p among all the slots of the path.

These algorithms [22] don't take into account the modulation format in resources spectrum allocation. This may not optimize the spectrum resources use. Indeed, modulation formats are dependent upon optical path lengths for an effective spectrum management [10, 21].
Cristina Rottondi et al 2013 [23] propose new methods based on linear integer programming and heuristics for solving the problem of routing and spectrum allocation by considering the modulation formats. The objective is to minimize the use of spectrum.
Although routing algorithms discussed above optimize optical spectrum management, it becomes necessary to consider the energy consumed by the elements of network during optical routing face with increase of Internet traffic. Indeed, the global consumption of video traffic on the internet according to [24], will be 69% of the general public Internet traffic in 2017, up 57% from 2012.

Another approach to improve the routing has been proposed by J. Lopez Vizcaino et al 2012 [25]. These authors present a comparative study of elastic optical networks and WDM in terms of energy consumption through the optical routing problem. Therefore, they propose heuristic algorithms to solve the problem of resource allocation statically and dynamically integrating the energy consumed by a connection of an optical path as metric. This metric is defined from network elements such as the transponder, the optical-cross-connect and amplifier. The basic idea of these algorithms is to establish a connection with the candidate path which has the lowest energy consumption among all the candidate paths of connection. A number of mathematical magnitudes have defined for this purpose:

- The power consumption by a transponder is a function of the transmission rate of the connection to be set : $PC_{OFDM}(w) = 1.25 \times Tr(Gb/s) + 31.5$
- The power consumption by an optical-cross-connect depends on the number N of fibers linking a node to its neighbors: $PC_{OXC}(\mathrm{w}) = N \times 85 + 150$
- The average power consumption by an amplifier is estimated at 60 W. However, an additional cost of 140 W is added by amplifier.

Thus, the energy consumed by a connection of an optical path is defined by the following expression:

$$MetricPC = NoDataSubc \times PC_{SUBC} + \frac{NoSubc}{TotalNoSubc}(PC_{EDFAs} + PC_{OXCs})$$

with

- $NoDataSubc$, the number of data sub-channel,
- PC_{SUBC} the power consumption of a sub channel,
- $NoSubc$ the number of sub channels in the optical path with two (2) slots for guard band,
- $TotalNoSubc$ the total number of sub-channels per fiber,
- PC_{EDFAs} the power consumption of EDFA amplifiers on the optical path
- PC_{OXCs} the power consumption of optical cross connect on the optical path.

This approach optimizes optical routing by integrating energy consumption of a service network in the selection of the optical paths in addition to optimizing optical spectrum management.

The majority of existing works on optical routing does not address the issue of rerouting connection. Now, rerouting prominently in optimization of resources management in optical networks and improving network performance. Therefore, consider rerouting connections in the implementation of existing routing algorithms would be beneficial for users and for network operators. Rerouting usually occurs during a maintenance action on a link in the network; address the problem of congestion at a node or adding a new connection in the network. The problem of re-routing has been extensively studied in the literature in WDM networks and it stay research topic to explore in the elastic optical networks.

4. Motivation of problem

Solution motivated by traditional WDM networks weakness has been the emergence of elastic optical networks called SLICE networks (spectrum-SLIced Elastic optical path network). So SLICE network inherits thus known problems in optical networks notably satisfaction of a new connection request in a network where connections are already established issues. Indeed, the main idea of SLICE networks is to allocate necessary spectrum resources based on bit rate of customers, modulation formats and the length of optical paths. The evolution of traffic in Internet consists generally to insert new connections in network. In some network configurations, it is impossible to satisfy a new connection request with the routing. This happens when the connection must share one or more links that to not have adequate and continuous spectral resources with other existing connections. To meet such connection request, it is often necessary to move existing connections one after the other in order to free up resources. Therefore, we must develop strategies that improve rerouting network performance. Rerouting must first reduce the blocking probability of connection requests. On the other hand, SLICE networks such as all-optical network inherit problems of power consumption. However, rerouting must minimize power consumption of the network. So to solve this problem, we propose an efficient energy routing algorithm with rerouting connection to reduce blocking probability of connection request (increase the number of connections established in the network). The objective of such strategies is to improve the network performance.

5. Analytical model of elastic optical network

A SLICE network (Spectrum-Sliced Elastic optical network) is modeled by a graph $G = (N, L, fs, C)$ with

- N, the set of network nodes, each equipped with switches to variable bandwidth.
- $L = \{(i, j), i \neq j \in N\}$, the set of network links (optical fiber).
- $fs^{li} = \{fs_1, fs_2, ..., fs_m\}$, the set of frequency slots on link li.
- $C = \{c_1, c_2, ..., c_n\}$ is all connections in network.

Each connection is associated with a bit rate w_i, $1 \leq i \leq n$ which corresponds to a specific number of frequency slots. A connection c_i between source s_i and destination d_i is characterized by $c_i(s_i, d_i, w_i)$.

Further characterization of connection c_i means replacing the bite rate w_i by the number of frequency slots, $Nfs(c_i)$ for connection c_i along path ch [26], with

$$Nfs(c_i) = \left\lceil \frac{w_i}{M_i \times w_{slot}} \right\rceil + Ngb \quad (1)$$

where w_{slot} is the capacity of frequency slot, M_i is modulation format associated with the connection c_i and Ngb is guard-band. Therefore, a connection c_i is characterized by $C_i(s_i, d_i, Nfs(c_i))$. Modulation format M_i depends on the length l of path on which connection is established. It can be defined as follows : $M_i = h(l)$ where *h(.)* returns the appropriate value of M_i that transmission reach can support.

Costs about energy consumed by an optical path:

When transmission reach l of the path in which connection i will be established is known, the power consumed by the channel obtained from the $Nfs(c_i)$ necessary slots for transmission is obtained by the following expression: $PC_{SUBC} = f(l)$ where *f(.)* returns the power consumed by the transmission channel. Power consumption by one optical cross-connect OXC is represented as follow: $PC_{OXC} = g(NoFib) + 150$ where $NoFib$ represents the average number of fiber linking a node to its neighbors. The power consumed by EDFA amplifier is constant. Metric in [25] is modified to give the cost of the power consumed by a connection c_i in network on optical path as following:

$$CoutPC = (Nfs - Ngb) \times \phi \times PC_{SUBC} + \frac{Nfs}{TotalNoSF}(\alpha PC_{EDFA} + \beta PC_{OXC}) \quad (2)$$

With $\alpha = C_{Amp} \times \frac{l}{d_{Amp}}$ dependent upon amplification cost, amplification distance and length of optical path; $\beta = h \times C_{Fib} \times NoFib$ depend on h, number of nodes on path, fiber cost and average number of fiber linking a node to its neighbors (average degree of nodes in the network) and $\phi = C_{Fib} \times \frac{1}{TotalNoSF}$ frequency slot cost per fiber. $TotalNoSF$ is total number of frequency slots per fiber.

Value of α depends essentially on path length since C_{Amp} and d_{Amp} are constants values. Therefore, when path length l is very large, α is too very big, in other words α increases with path length. Also, the path length l is used to determine modulation format and necessary number of slots for the connection establishment with equation (1). In fact, for each modulation format, an integer value is associated, from one to six [26] representing M_i in (1). However, when the optical path length is high, the number of slots increases according to bit rate because modulation format takes a small value. From these facts, the number of amplifier required to path length is high if the length is greater and lesser if path length is less. So a path that has a large number of amplifiers or big length supposes that a connection which is established on this path will consume enough energy compared to another set on a path of shortest distance. In addition to path length which is a factor which has an impact on power consumption, the number of node *h* on a path is another factor. Indeed, when the number of nodes on a path is high, the power consumed by this path is important. From these facts, the length and number of nodes of a path are the two essential elements to power consumption; that is why we use them in the choice of paths on which connections will be established through the expression of path cost in terms of power consumption (2).

Costs about available resources on optical path:

When the path on which connection is established is known, the following expression is used to estimate the capacity of the path to accept connections.

$$CoutRssCh = \frac{\eta}{NoSFLC} \quad avec \;\; NoSFLC \neq 0 \quad (3)$$

where $NoSFLC$ is number of free contiguous frequency slots on path and η is number of free frequency blocks slots of the path.

Equation (3) measures ability of path to accommodate future connections. Indeed, if η the number of frequency blocks slots of path is high, $NoSFLC$ the number of free contiguous frequency slots is less, cost about to available resources (3) is high. Yet, if the number of frequency blocks slots is small and the number of available slots is high, the path capacity to accommodate future connections is important. Therefore, this equation (3) will be used in our algorithm to choose paths that have more resources to establish our connections.

Cost about optical path is formulated as follows:

$$Co\hat{u}tCh = CoutPC \times CoutRssCh \quad (4)$$

Our objective is that connections are established on the paths which minimizes power consumption and has the lowest blocking probability. This leads us to define an equation of cost about path (4) from equations (2) and (3) for this purpose. To achieve our objective, expression (4) will allow us to choose the optimal paths when establishing our connections.

From all that precede, we propose an efficient energy routing algorithm with connections rerouting to establish optical connections between source s and destination d using the shortest distance physical paths. Thus, paths that use less power will be used thanks to equation (2). As for equation (3), it can use paths which have enough resources available. Equation (2) and (3) allow us to use the paths that require less power and have sufficient spectrum resources for connections establishment with our algorithm. This corresponds to our goal of establishing connections on efficient energy paths and low blocking probability with equation (4).

6. Routing and connection rerouting

We assume in our routing and rerouting algorithm that establishment of new connection in the network or moving an existing connection to a different path, is subject to compliance with the constraints:

- Spectrum contiguity: if an application requires t units of spectrum, then t contiguous carriers should be allocated.
- Spectrum continuity: the same t contiguous carriers should be allocated on each link of the path from source node to destination ode.

We assume that our connections requests are static and permanent connections in the network. Our routing and rerouting scheme has two phases (see Fig. 4 below): a routing phase and connection rerouting phase.

- The routing phase is to determine for each connection request, the path to lower blocking probability of future connections and efficient energy.
- The rerouting Phase occurs when the routing phase fails (that is to say, a connection may be blocked). Connections to reroute and theirs new paths are determined in this phase. Paths that reduce blocking probability of future connections with less power consumption are used.

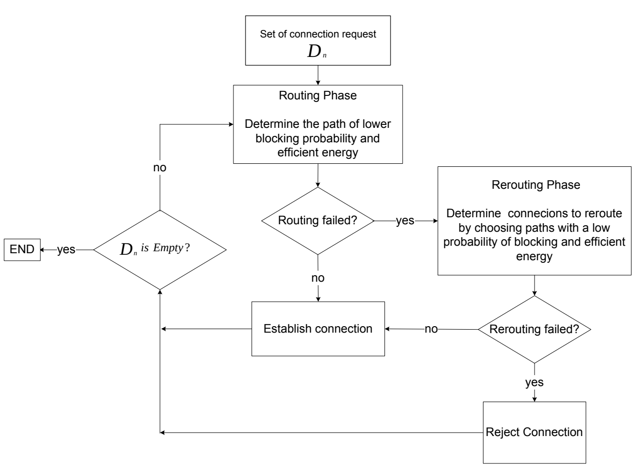

Fig. 4 routing technique with rerouting

6.1 Routing algorithm *RecEn*

From a set of static connection to establish, connections are established one by one. For a connection request, our algorithm determines the k shortest length paths of this connection and for each path, it determines the free frequency blocks slots available, the appropriate modulation format and the number of slots required for connection establishment Then, the smallest block size that satisfies the connection establishment called candidate block is determined. All paths that have spectrum resources are saved in the data structure ROUTE to adding the new connection with the cost and blocking probability of each path. At the end, the path of least cost and low blocking probability is chosen.

Routing algorithm *RecEn*

Input : TailleBlockCandidat = | fs^{li} |, distance matrix of network, set of connections
Output: path Ch_i for connection C_i

BEGIN
FOR each connection request C_i *DO*
  FIND ListeChemin (C_i), the k-shortest paths for C_i
  FIND number of slot $Nfs(C_i)$ for connection C_i
  FOR each path Ch_i from C_i *DO*
    FIND appropriate modulation format
    FIND the blocks of free frequency slots
    FOR each Block slots B of path Ch_i *DO*
      IF size of Block B $\geq$ $Nfs(c_i)$ and TailleBlockCandidat $\geq$ size of Block B *THEN*
        BlockCandidat = Block B
        TailleBlockCandidat = size of Block B
      ENDIF
    ENDFOR
    IF BlockCandidat is not empty *THEN*
      EXTRACT the Nfs first contiguous slot of BlockCandidat
      CALCULATE path cost and blocking probability
      RECORD in ROUTE (C_i) path, modulation format, path cost and Nfs
  ENDIF
ENDFOR
IF ROUTE (C_i) is not empty *THEN*
  CHOICE path with minimum cost and low blocking probability
  ESTABLISH connection C_i
ELSE

EXECUTE Procedure *RerCon* (ListeChemin (C_i),, C_i)

ENDIF
ENDFOR
END

For a given connection, when there is no path which has available resources, RerCon procedure is executed to determine connections to be rerouted to establish connection C_i.

6.2 Connections rerouting procedure, *RerCon*

For each route likely to accept connection blocked after routing phase, our rerouting procedure determines the number of slots blocks on initial path and size of the candidate block. Then all critical connections of the path are determined. An existing connection on a path is critical when its moving minimizes the number of path blocks slots and maximizes the size of path candidate block. All frequency blocks slots of a path *ch* are defined as follows:

$$bfs(ch)=\left\{\{bfs^{(i)}\};i\in \mathrm{N},\textit{the number of ch blocks}\right\} \quad (5)$$

where $\{bfs^{(i)}\}$ represent the set of frequency slots of block *i*.
Candidate block of *ch* for connection C_{id} is determined by following equation:

$$bfs_C(ch,C_{id})=\left\{bfs^{(i)}\right\};\forall i\in \mathrm{N},\left|bfs^{(i)}\right|\geq Nfs(C_{id})\vee \left(\left|bfs^{(i)}\right|\geq Nfs(c_{id})\wedge \exists j\in \mathrm{N};\left|bfs^{(i)}\right|\leq\left|bfs^{(j)}\right|\right) \quad (6)$$

A set of critical connections *ConCr* of path *ch* for connection C_{id} is determined by following equation:

$$ConCr(ch,c_{id})=\left\{C_j;\left|bfs_C(ch,c_{id})\right|+Nfs(c_j)\geq Nfs(c_{id})\wedge\left|bfs_C(ch)^{init}\right|\leq\left|bfs_C(ch)^{fin}\right|\right\} \quad (7)$$

where $bfs_C(ch)^{init}$ and $bfs_C(ch)^{fin}$ represent respectively candidate block of path *ch* before and after the moving of connection C_j.

Rerouting procedure *RerCon* (ListeChemin (C_i), C_i)

Input : connection C_i and et set of k-shortest path of C_i

Output : path Ch_i for connection C_i

SAVE source node and destination node of C_i and CREATE virtual links of network

FOR each path Ch_i of ListeChemin (C_i) *DO*

DETERMINE the number of slot blocks of initial (tailleblockinit) path Ch_i

DETERMINE the size of candidate block (tailleblockcandinit) of path Ch_i

DETERMINE the set of critical connections *ConCr* using path Ch_i

FOR each critical connections C_j of path Ch_i *DO*

SAVE connection C_j

RELEASE virtual slots of connection
DETERMINE the number of virtual blocks slot (tailleblockfin) of path Ch_i

DETERMINE the size of candidate block (tailleblockcandfin) path Ch_i

IF ((tailleblockinit >= tailleblockfin) &&
(tailleblockcandinit < tailleblockcandfin)) *THEN*
IF ((tailleblockcandfin >= nfse) && (succes = = 0)) *THEN*

DETERMINE new path for C_j

IF path for connection C_j is found *THEN*

DETERMINE candidate slots block of path found
IF candidate block has sufficient resources *THEN*
UPDATE path and slots of connection C_j

ETABLISH connection C_j on new path found

RELEASE first resources of connection C_j

ETABLISH connection C_i *on path* Ch_i

Succes = 1
ENDIF
ENDIF
ENDIF
ENDIF
RESTORE virtual resources of connection C_j

ENDFOR
ENDFOR
IF (succes $\neq$ 1) *THEN*
Reject connection
ENDIF

7. Analysis of numerical results

This section describes the evaluation of our routing algorithm with connection rerouting in terms of blocking probability compared with RMLSA algorithm in [25]. The algorithm is evaluated and tested on a PC Intel Core (TM) i3 CPU, 2.6 GHz and 4 GB of RAM. The algorithm is implemented in Java under Eclipse, under Windows 8.1 system.
The topology of the network used for the simulation and the analysis is shown in Figure 5 below. It has 14 nodes and 22 links and each link has a specific length. For each optical link, we assumed the availability of 30 frequency slots.

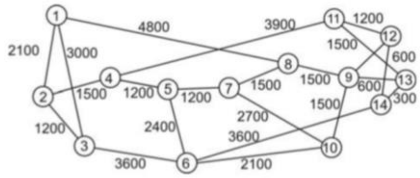

Fig. 5 NSF network topology

We assume for example to establish twenty (20) connections in the network (with bit rate of 80Gb / s). Our routing algorithm provides the data in table 1 below.

Table 1: Overview of connection requests after routing

id	*S*	*D*	*Path Selected*	*Slots used*	*Length of path*
0	1	3	1-3-6	1, 2, 3, 4, 5, 6, 7, 8	6600
1	3	5	3-2-4-5	1, 2, 3	3900
2	2	6	2-4-5-6	4, 5, 6, 7, 8, 9, 10, 11	5100
3	5	8	5-7-8	1, 2, 3	2700
4	9	1	9-8-1	1, 2, 3, 4, 5, 6, 7, 8	6300
5	12	7	12-9-8-7	9, 10, 11	3600
6	8	11	8-9-12-11	12, 13, 14	3300
7	4	3	4-2-3	12, 13, 14	2700
8	6	12	6-14-12	1, 2, 3, 4, 5, 6, 7, 8	4200
9	13	4	13-11-4	1, 2, 3, 4, 5, 6, 7, 8	5400
10	7	2	7-5-4-2	15, 16, 17	3900
11	10	9	10-9	1, 2	1500
12	11	10	11-13-9-10	9, 10, 11	3600
13	14	13	14-13	1, 2	300
14	13	1	13-9-8-1	15, 16, 17, 18, 19, 20, 21, 22	6900
15	10	3	10-6-3	9, 10, 11, 12, 13, 14, 15, 16	5700
16	9	2	9-12-11-4-2	18, 19, 20, 21, 22, 23, 24, 25	7200
17	2	5	2-4-5	26, 27, 28	2700
18	**4**	**9**	**-**	**-**	**-**
19	3	1	3-1-8	23, 24, 25, 26, 27, 28, 29, 30	7800

To establish connection 18 with a bit rate of 80Gb / s, the number of frequency slots required is 8 slots obtained from the expression (1).

Our algorithm has selected for connection 18 with source node 4 to destination 9, the following two shortest paths: 4-5-7-8-9 and 4-11-12-9 using the topology below above.

After execution of routing phase, for the path 4-5-7-8-9, slots available on each link giving by algorithm is:

Slots of link 4-5: [[12, 13, 14], [18, 19, 20, 21, 22, 23, 24, 25], [29, 30]]

Slots of link 5-7: [[4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14], [18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]]

Slots of link 7-8: [[4, 5, 6, 7, 8], [12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]]

Slots of link 8-9: [[23, 24, 25, 26, 27, 28, 29, 30]]

From links slots of path 4-5-7-8-9, the algorithm identifies contiguous and continuous blocks slots (slots available and common to all links) of the path are: [[23, 24, 25], [29, 30]].

After execution of routing phase, for the path 4-11-12-9, slots available on each link giving by algorithm is:

Slots of link 4-11: [[9, 10, 11, 12, 13, 14, 15, 16, 17], [26, 27, 28, 29, 30]]

Slots of link 11-12: [[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11], [15, 16, 17], [26, 27, 28, 29, 30]]

Slots of link 12-9: [[1, 2, 3, 4, 5, 6, 7, 8], [15, 16, 17], [26, 27, 28, 29, 30]]

From links slots of path 4-11-12-9, the algorithm identifies contiguous and continuous blocks slots (slots available and common to all links) of the path are: [[26, 27, 28, 29, 30]].

Available slots and common to all links of path 4-5-7-8-9 and 4-11-12-9 are not sufficient to establish the connection 18. Thus, the connection is 18 blocked.

In this case, our routing algorithm calls for connections rerouting procedure. After execution of rerouting procedure, the algorithm provides some data in table 2:

Table 2: Overview of connection requests after rerouting

id	*S*	*D*	*Path Selected*	*Slots used*	*Length of path*
0	1	3	1-3-6	1, 2, 3, 4, 5, 6, 7, 8	6600
1	3	5	3-2-4-5	1, 2, 3	3900
2	2	6	2-4-5-6	4, 5, 6, 7, 8, 9, 10, 11	5100
3	5	8	5-7-8	1, 2, 3	2700
4	9	1	9-8-1	1, 2, 3, 4, 5, 6, 7, 8	6300
5	12	7	12-9-8-7	9, 10, 11	3600
6	8	11	8-9-12-11	12, 13, 14	3300
7	4	3	4-2-3	12, 13, 14	2700
8	6	12	6-14-12	1, 2, 3, 4, 5, 6, 7, 8	4200
9	13	4	13-11-4	1, 2, 3, 4, 5, 6, 7, 8	5400
10	7	2	7-5-4-2	15, 16, 17	3900
11	10	9	10-9	1, 2	1500
12	11	10	11-13-9-10	9, 10, 11	3600
13	14	13	14-13	1, 2	300
14	13	1	13-9-8-1	15, 16, 17, 18, 19, 20, 21, 22	6900
15	10	3	10-6-3	9, 10, 11, 12, 13, 14, 15, 16	5700
16	9	2	9-12-11-4-2	18, 19, 20, 21, 22, 23, 24, 25	7200
17	**2**	**5**	**2-3-6-5**	**17, 18, 19, 20, 21, 22, 23**	**7200**

18	**4**	**9**	**4-5-7-8-9**	**23, 24, 25, 26, 27, 28, 29, 30**	**5400**
19	3	1	3-1-8	23, 24, 25, 26, 27, 28, 29, 30	7800

From the data in table, the connection 17 initially established in the optical path 2-4-5 using spectral resources {26, 27, 28} has been rerouted in the optical path 2-3-6-5 after rerouting procedure using spectral resources {17, 18, 19, 20, 21, 22, 23}. And the connection 18 initially blocked, has been successfully established on the optical path 4-5-7-8-9 using spectral resources {23, 24, 25, 26, 27, 28, 29, 30}.
Therefore, we conclude that compared to RMLSA routing algorithms, our routing algorithm with rerouting connections improves the number of established connections in the network as shown in Figure 6 below.

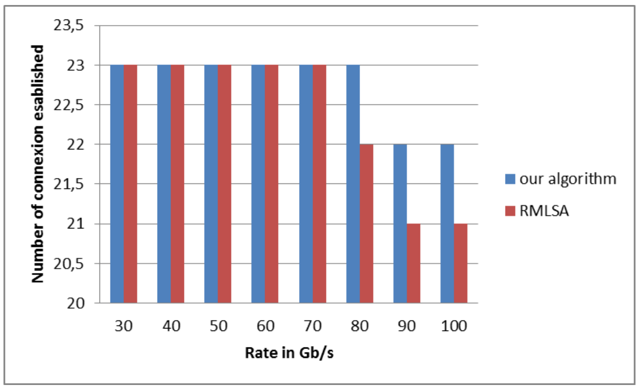

Fig. 6 Comparison Chart

8. Conclusion

In this paper, the problem of routing and connection rerouting is addressed in elastic optical networks. We have proposed a routing algorithm and allocation of spectrum which takes into account connections rerouting. To select a path for the establishment of a connection request, the paths that consume less energy and have more spectrum resources are selected by our algorithm. The analysis of our numerical results shows that the number of connections established in the network increases with our approach and therefore has a better performance compared to the existing RMLSA routing algorithm.

References

[1] Kouji Hirata Dewiani, “Dynamic Routing and Wavelength Assignment in Multifiber WDM Networks with Wavelength Conversion Capability”, Network and Communication Technologies; Vol. 1, No. 2; 2012

[2] JianhuaShenet Xi Cheng, “An Improved Ant Colony Based Algorithm for Dynamic Routing and Wavelength Assignment Scheme in Optical Networks”, The 2nd International Conference on Computer Application and System Modeling (2012)

[3] Joan Triay and Cristina Cervello´-Pastor, “An Ant-Based Algorithm for Distributed Routing and Wavelength Assignment in Dynamic Optical Networks”, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 28, NO. 4, MAY 2010

[4] Amit Wason and R.S. Kaler, “Rerouting Technique with Dynamic Traffic in WDM Optical Networks”, *Optical FiberTechnology 16 (2010) 50-54*

[5] AmitWason and R.S. Kaler, “Lightpath Rerouting Algorithm to enhance blocking performance in all-optical WDM network without wavelength conversion”, *Optical FiberTechnology 16 (2010) 146-150*

[6] Mohamed Koubaa and Maurice Gagnaire, “Lightpath Rerouting Strategies in WDM All-Optical Networks Under Scheduled and Random Traffic”, VOL. 2, NO.10/OCTOBER 2010/J. OPT. COMMUN. NETW

[7] Chong yang Xie, Hamed Alazemi, Nasir Ghani, “Rerouting in Advance reservation networks”, Computer Communications 35 (2012) 1411-1421

[8] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, T. Yoshimatsu, T. Kobayashi, Y. Miyamoto, K. Yonenaga, A. Takada, O. Ishida, and S. Matsuoka, “Demonstration of Novel Spectrum-Efficient Elastic Optical Path Network with Per-Channel Variable Capacity of 40 Gb/s to Over 400 Gb/s”, Vol. 7 – 49, ECOC 2008, 21-25 September 2008, Brussels, Belgium.

[9] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, Y. Sone, and S. Matsuoka, “Spectrum-efficient and scalable elastic optical path network: architecture, benefits, and enabling technologies,” *IEEE Commun. Mag.*, vol. 47, no. 11, pp. 66 –73, november 2009.

[10] M. Jinno& al, Distance –Adaptative Spectrum Ressource Allocation in Spectrum-Sliced Elastic Optical Path Network, IEEE Communications Magazine, August 2010.

[11] M. Jinno, T. Ohara, Y. Sone, A. Hirano, O. Ishida, and M. Tomizawa, “INTRODUCING ELASTICITY AND ADAPTATION INTO THE OPTICAL DOMAIN TOWARD MORE EFFICIENT AND SCALABLE OPTICAL TRANSPORT NETWORKS”, 2010 ITU-T Kaleidoscope Academic Conference.

[12] Ke Wen, XinranCai, Yawei Yin, David J. Geisler, Roberto Proietti, , Ryan P. Scott, , Nicolas K. Fontaine, , and S. J. B. Yoo, “Adaptive Spectrum Control and Management in Elastic Optical Networks”.IEEE JOURNAL ON SELECTED

AREAS IN COMMUNICATIONS, VOL. 31, NO. 1, JANUARY 2013.

[13] Kouji Hirata &Dewiani,"Dynamic Routing and Wavelength Assignment in Multifiber WDM Networks with Wavelength Conversion Capability", Network and Communication Technologies; Vol. 1, No. 2; 2012

[14] JianhuaShenet Xi Cheng, "An Improved Ant Colony Based Algorithm for Dynamic Routing and Wavelength Assignment Scheme in Optical Networks", The 2nd International Conference on Computer Application and System Modeling (2012)

[15] Joan Triay, and Cristina Cervello´-Pastor, "An Ant-Based Algorithm for Distributed Routing and Wavelength Assignment in Dynamic Optical Networks", IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 28, NO. 4, MAY 2010

[16] G. Zhang, M. De Leenheer, A. Morea, B. Mukherjee, "A survey on OFDM-based elastic core optical networking", IEEE Commun. Surv. Tutor. 15 (First Quarter (1)) (2013) 65–87

[17] M. Klinkowski, K. Walkowiak, Routing and spectrum assignment in spectrum sliced elastic optical path network, IEEE Commun. Lett. 15 (8) (2011) 884–886.

[18] Y. Wang, X. Cao, Y. Pan, A study of the routing and spectrum allocation in spectrum-sliced elastic optical path networks, in: Proceedings of IEEE INFOCOM, 2011, pp. 1503–1511

[19] T. Takagi1 et al, "Dynamic Routing and Frequency Slot Assignment for Elastic Optical Path Networks that Adopt Distance Adaptive Modulation", OSA/OFC/NFOEC 2011

[20] Xin Wan et al,"Dynamic Routing and Spectrum Assignment in Flexible Optical Path Networks", OSA/OFC/NFOEC 2011

[21] OriGerstel, Masahiko Jinno, Andrew Lord, S. J. Ben Yoo, "Elastic Optical Networking: A New Dawn for the Optical Layer?",IEEE Communications Magazine • February 2012

[22] Ying Wang et al, "Spectrum consecutiveness based routing and spectrum allocation in flexible bandwidth networks", CHINESE OPTICS LETTERS June 30, 2012

[23] Cristina Rottondi, Massimo Tornatore, AchillePattavina, and Giancarlo Gavioli, "Routing, Modulation Level, and Spectrum Assignment in Optical Metro Ring Networks Using Elastic Transceivers", Journal of Optical Communications and Networking, Vol. 5, Issue 4, pp. 305-315 (2013)

[24] Cisco white paper, Cisco Visual Networking Index, Mai 2013

[25] J. Lopez Vizcaino et al, "Energy efficiency analysis for flexible-grid OFDM-based optical networks", Computers Networks 56 (2012) 2400-2419

[26] Zuqing Zhu et al, "Dynamic Service Provisionning in Elastic Optical Networks With Hybrid Single-Mulipath Routing", JOURNAL OF LIGTWAVE TECHNOLOGY, VOL. 31, NO.1, JANUARY, 2013

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