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Hybrid Protection Scheme for Elastic Optical Networks with Regenerator and Efficient Energy Consideration

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***Abstract*– The evolution of communication technology promotes the growth of Internet traffic with different QoS requirements in optical transport networks. With this evolution, several challenges must be taken up namely the need to increase network capacity, minimize energy consumption and that of ensuring the resilience of the network face increasing traffic connectivity failure. To take up these challenges, we proposed a hybrid protection approach based adaptive routing introducing the regenerator activation while considering energy consumption. In our study, we considered two types of connections (critical and non-critical). Critical connections require dedicated end-to-end protection unlike non-critical applications whose backup resources are shared between them. The simulation results show that activation of the regenerators has a significant impact on energy consumption of the network. However, it significantly reduces the blocking probability in the network.**

***Index Terms*– Hybrid Protection, Shared, Dedicated, Critical Connection, Non-Critical, Power Consumption and Regenerator**

I. Introduction

THE development of high bit rate communication technologies arouse the real-time services development such as video-conferencing, online gaming and telemedicine which are very demanding in QoS (Quality of Service). To support the bandwidth demands, elastic optical networks which based on optical orthogonal division multiplexing frequency technology (OOFDM) has been proposed [1] - [4]. This technology which adopted in elastic optical (*Spectrum-sLICed Elastic optical path network*) has been considered as a promising solution for optimizing the optical spectrum management. With this optical OFDM technology, the spectrum is divided into many frequency slots and several contiguous and consecutive slots can be used as a single optical channel for the data transmission. The SLICE networks are known for their flexibility which permit to provide an optical connectivity to a wide variety bandwidth requests from gigabit to terabit per second. This heterogeneity in the resources allocation is possible thinks to the key elements of SLICE networks architecture including: bandwidth variable transponder, bandwidth variable optical cross-connect and flexible frequency grids. However, these elements have an impact on the overall power consumption of the network. But global power consumption of video traffics in internet according to [5], will be 69% of internet traffic in 2017, up 57% compared to 2012. And the number of IP devices connected to internet networks will be almost three times higher than the world population in 2017. Therefore, take into account the power consumption in optical routing becomes a necessity as network resilience problem. Sure enough, when the number of devices connected to increases, the problem of connectivity failure is taken into account.

II. Related Work

Several studies in protection of connection area were conducted in the field of elastic optical networks. In [6], the authors have proposed heuristic algorithm for protection schemes in different networks technologies (WDM and SLICE) and compared them in terms of energy efficiency and cost under dedicated (1+1 or 1:1) and shared protection (SP). The power consumption of optical cross-connect (OXC) is defined from each node degree and add/drop degree. Each candidate path metric based on the end-to-end lightpath power consumption is calculated as in [7], considering the power consumption of transponder, and approximate consumption from the EDFA amplifiers and optical cross-connects (OXC) along the path. For established connection, total power consumption metric is calculated with the contribution of working and backup paths power metric. The working-backup path combination which has the most efficient energy is chosen for transmission and protection.

The candidate pair of working-backup paths for each connection was computed using k-shortest paths algorithm. The variety of services and applications in networks involves different survival needs. It is in this perspective that the authors have proposed in [8] three different types of connections based on the bandwidth squeezed restoration approach. The first category represents connection request, whose restoration bandwidth is identical to its initial bandwidth when connectivity failure occurs. With the second category, the restoration bandwidth is inferior to the initial bandwidth and so forth for all the connections of this category, the third category of traffic concerns the best-effort connections. For backup resources, best effort connections resources depend on available resources in the network as opposed to the first two connection categories where the backup bandwidths are fixed and guaranteed. In [9], the authors have proposed two algorithms to solve RSA (Routing and Spectrum Allocation) protection problems.

In this study shared backup resources and adaptable transponders are adopted. Transponder's adaptability permits to use different frequency slots on the main and backup paths as well in the network. The concept of frequency slots windows has been adopted. It consists to reproduce several copies of the network topology. The links of each copy use a part of the principal frequency slots of these optical links, slots are contiguous, consecutive and the same on all links corresponding to a required connection request bandwidth. To address a connection request, the eligible main and backup paths are determined. The first algorithm of this study determines the best eligible main path and its resources according to the selected modulation format. The main path is one of the shortest path in hops whose length is smaller than the transparent reach, corresponding to the modulation format determined among all the shortest paths of network copy. When the main path is found, the second algorithm is used to determine the disjoint backup path and its resources. The backup path determined is similar to that of its main path. However, the cost of each link is calculated for each copy of topology. The backup path with the minimum cost among all backup paths of network copies is selected. The connection request is blocked when a pair of main and backup path is not found. In [10], the authors have proposed a routing and spectrum assignment algorithm with power consumption model based on key elements of an elastic optical network architecture.

This model takes into account the modulation impact on the power consumption of each component. The proposed algorithm uses this model to get most energy efficient optical path among the possible candidate paths. The author in [11], developed an integer linear programming model considering shared backup path protection in comparison with dedicated (1+1) path protection for elastic optical networks. In this protection technique, two transponder models have been considered: i) full tunable transponder and ii) non-tunable transponder. With the non-tunable transponder, the same set of contiguous frequency slots is required to be used for both working and backup paths. In this case, if the primary path uses slots 5, 6 and 7, its backup path also uses slots 5, 6 and 7. Now with the full tunable transponder, working and backup paths can use different set of contiguous frequency slots. For example, if the primary path uses slots 5, 6 and 7, its backup path can use slots 1, 2, 3 and 4. When failures occur in networks, Bandwidth squeezing restoration scheme is applied to obtain maximum restoration levels for the connections affected.

In most of these study, when a connection request is to be established and that among a lot of modulation formats, if there is a modulation format whose its transmission reach is greater than the optical path length, this connection request is accepted. Otherwise, the request is blocked [6], [7]. The authors of [10] introduce regenerator placement in order to determine the impact of modulation format of the power consumption. However, this action may have an impact on network power consumption. In an environment where coexist different types of connections with different QoS requirements, what is the best way to ensure the protection of connection requests in SLICE networks with regenerators placement, by taking into account the requests QoS requirements, minimizing power consumption and ensure an acceptable quality of service ?

The rest of this paper is organized as follow. Section III describe Mathematical model. Section IV power consumption model. The section V presents the different algorithms for paths determination presents. Simulation and results analysis are presented in section VI. The paper is concluded in Section VII.

III. Mathematical Model

The network topology is defined as undirected graph $G=\left(N,L,FR,CR\right)$, where

- N is the set of variable bandwidth nodes;
- $L=\left\{(i,j);i,j\in\mathbb{N}\ \ and\ \ i\neq j\right\}$ is the set of network fiber links;
- $FR=\left\{fs_1, fs_2,..., fs_m : m\in\mathbb{N}\right\}$ is the set of frequency slots of each fiber link;
- $CR=\left\{cr_1, cr_2,..., cr_n : n\in\mathbb{N}\right\}$ is the set of connection requests in the network.

$|N|,|L|,|FR|\ and\ |CR|$ represent respectively the number of nodes, links, frequency slots of each fiber link and connection request in the network.

A connection cr_{id} between source node s_{id} and destination d_{id} is represented by $cr_{id}(s_{id},d_{id},w_{id},\varepsilon_{id})$ where ε_{id} represents the type of connection request.

The number of frequency slots of a connection request cr_{id} on path P, $Nfs\left(P\left(cr_{id}\right)\right)$ can be calculated as follows:

$$Nfs\left(P\left(cr_{id}\right)\right)=\left\lceil \frac{\mu\times w_{id}}{M\left(P\left(cr_{id}\right)\right)\times w_{slot}}\right\rceil+Ngb \qquad (1)$$

where

- w_{slot} is an optical signal speed for one frequency slot;
- $M\left(P\left(cr_{id}\right)\right)$ corresponding to a modulation format;
- μ is a constant value $\left(\frac{1}{2}\leq\mu\leq 1\right)$ which permit to define maximum and minimum bandwidth for each connection request;

- Ngb is the number of frequency slots used as guard band;
- $\lceil . \rceil$ returns higher integer part.

In the fact, a connection request cr_{id} is represented by $cr_{id}\left(s_{id}, d_{id}, Nfs\left(P\left(cr_{id}\right)\right), \varepsilon_{id}\right)$. The type of each connection request is defined by:

$$\varepsilon_{id} = \begin{cases} 1 \ \text{if} \ \ critical \ \ connection \\ 0 \ \text{if} \ \ non-critical \ \ connection \end{cases}$$

Assume that $l_{(i,j)}$ is the link (i, j) length on the path. The modulation format can be defined as follows:

$$M\left(ch\left(cr_{id}\right)\right) = Modform\left(\sum_{(i,j) \in ch} l_{(i,j)}\right)$$

where $Modform(.)$ returns the appropriate value of modulation between 1 to 6 as defined in [12] that the transmission distance can support. For BPSK QPSK, 8QAM, 16QAM, 32QAM and 64QAM modulation formats, the corresponding number returned by $Modform(.)$ are 1, 2, 3, 4, 5 and 6 bits/s/Hz, respectively.

IV. Power Consumption Model of Network

A) Bandwidth variable transponder

The transponder is an important component in elastic optical networks. It contains optical OFDM transmitter and receiver. The transmitter consists of Digital Signal Processor and Digital Analog Convertor modules. However, this type of transponder increase considerably networks power consumption. The power consumption of transponder is given by [7]:

$$PC_{TRANS} = \left(Nfs - Ngb\right) \times PC_{fm} \qquad (2)$$

where PC_{fm} is power consumption of one sub-channel for corresponding modulation format (fm).

B) Bandwidth variable cross-connect (BV_OXC)

The Bandwidth variable cross-connect (*BV_OXC*) is an essential component in elastic optical network. The energy consumption of BV_OXC is not dependent from modulation level and traffic volume. It is because OXC is a switching device forwarding the signals from input ports toward output ports. However, the energy consumption of BV_OXC depends on the node adjacent links (dg) and add/drop degrees (ad), and its defines as follow [6], [13]:

$$PC_{OXC} = N_{OXC} \times \left(85 \times dg + 50 \times ad + 150\right) \qquad (3)$$

where N_{OXC} is the number of active OXC on a path.

C) Optical Amplifier (OA)

We consider that the line amplifiers are used every 100 km $\left(d_{Amp}\right)$ on optical link along the path. The energy of amplifiers contribute to network power consumption and it defines as:

$$PC_{OA} = \sum_{(i,j)} \rho(i, j) \times PC_{Amp} \qquad (4)$$

with $\rho(i,j) = \begin{cases} 0 & si \ \frac{l_{(i,j)}}{d_{Amp}} \leq 1 \\ \left\lfloor \frac{l_{(i,j)}}{d_{Amp}} \right\rfloor & sinon \end{cases}$ and $\lfloor . \rfloor$ represent lower integer part.

D) Regenerator (Reg)

On optical path, the regenerator compensate for the distortion imposed by signal transmission. Its activation on path depends of corresponding modulation format transmission reach. Energy consumption by regenerators of optical path is define as [12] follows:

$$PC_{reg} = \left\lfloor \frac{\ell}{d_{reg}^{fm}} \right\rfloor \times 2 \times PC_{fm} \qquad (5)$$

where d_{reg}^{fm} represent the modulation format transmission reach and ℓ is the path length.

E) Power consumption of path

The power consumption of lightpath P is defined by using equation (1), (2), (3), (4) and (5) as follows:

$$PC\left(ch\left(cr_{id}\right)\right) = PC_{TRANS}\left(ch\left(cr_{id}\right)\right) + PC_{OA}\left(ch\left(cr_{id}\right)\right) + PC_{OXC}\left(ch\left(cr_{id}\right)\right) + \tau \times PC_{reg}\left(ch\left(cr_{id}\right)\right) \qquad (6)$$

where $\tau = \begin{cases} 1 \ if \ \ regenerator \ \ placement \\ 0 \ else \end{cases}$

V. Algorithms For Paths Determination

A) Primary paths algorithm

Algorithm 1 below identifies the primary paths of each connection request according to the connection type (critical or non-critical). In the fact, it calculates the k-shortest paths and their corresponding modulation formats. After primary paths are calculated, Algorithm 2 is used to select the paths with minimal power consumption with their appropriate modulation formats. When a path has no modulation format, if the request is critical, an appropriate modulation format is assigned else the request is blocked.

To satisfy a set of connection requests, our hybrid protection algorithm, class connection requests in descending order (higher demand first) and applications are processed one by one.

ALGORITHM 1 : Primary paths determination

Input : network topology, connection requests

Output : primary path

WAIT the set of connection requests
IF connection request arrived **THEN**
DETERMINE the k-shortest paths for the request
ENDIF
IF the paths are found **THEN**
FOR each path $P_p\left(1\le p\le K\right)$ found **DO**
DETERMINE the possible modulation formats
IF connection is critical **THEN**
type_connection = *crirtical*
ELSE type_connection = *non-critical*
ENDIF
ALGORTHM 2 : Selection of the paths and resources
ENDFOR
ENDIF

ALGORITHM 2 : Selection of the paths and resources

Input : *type_connect*, *type_path*, modulation format, *PCmin* = 0

Output : Path, resources, energy consumption of path

IF modulation formats are found **THEN**
FOR each modulation format (*f_mod*) **DO**
IF type_path == primary THEN
$\mu = 1$
DETERMINE the dedicated resources (1)
ELSE IF *type_connect* == critical **THEN**
$\mu = 0.75$
DETERMINE the dedicated resources with (1)
ELSE
$\mu = 0.5$
DETERMINE the shared resources
ENDIF
ENDIF
IF there are available resources **THEN**
CALCULATE the energy PC of request
IF PC < PCmin || PCmin == 0 **THEN**
PCmin = PC
Mod = *f_mod*
ENDIF
ENDIF
ENDFOR
ELSE
IF *type_connect* == critical **THEN**
DETERMINE the appropriate modulation format
DETERMINE the necessary resources for request with (1)
DETERMINE the number of regenerator
CALCULATE an energy PC of request with (6)
ELSE the request is blocked
ENDIF
ENDIF
IF PCmin !=0 THEN
SAVE (Resources, PCmin, Path) of the request
ENDIF

B) Backup paths algorithm

The algorithm 3 permit to determine the backup path when a primary path with available resources was found by algorithm 1.

ALGORITHM 3 : Backup paths determination

Input : Primary paths with available resources

Output : Backup paths

IF Primary paths are found **THEN**
FOR each primary path **DO**
DETERMINE the k-shortest backup paths for the request $\neq$ Primary path
IF backup paths are found **THEN**
FOR each backup path **DO**
DETERMINE the possible modulation formats
ALGORTHM 2 : Selection of the paths and resources
IF Backup paths with available resources are found **THEN**
DETERMINE backup path which minimize resources utilization
SAVE The primary path and her backup paths with their resources
ENDIF
ENDFOR
ENDIF
ENDFOR
ENDIF

C) Primary and Backup paths selection algorithm

The resources used by both primary and backup paths is the sum of resources used by the primary path and those used by the backup path. Assume that, for a request cr_{id}, $P\left(cr_{id}\right)$ is the primary path and $S\left(cr_{id}\right)$ is the backup path. The resources used by the pair of paths can be defined as follows:

$$Rss\left(P,S\right)=\begin{cases} H_c\left(P\left(cr_{id}\right)\right)\times Nfs\left(P\left(cr_{id}\right)\right)+ \\ \qquad H_c\left(S\left(cr_{id}\right)\right)\times Nfs\left(S\left(cr_{id}\right)\right) \end{cases} \tag{7}$$

$$Rss(P,S)=\begin{cases} H_c\left(P\left(cr_{id}\right)\right)\times Nfs\left(P\left(cr_{id}\right)\right)+ \\ \sum_{(i,j)\in S(cr_{id})}\eta_{(i,j)}\times\left(Nfs\left(S\left(cr_{id}\right)\right)-\delta_{(i,j)}\right)\end{cases} \quad (8)$$

If connection request is critical, (7) is used to calculate resources used by both paths, else (8) is used.

$$\eta_{(i,j)}=\begin{cases}0\ if\ \ link\ (i,j)\ resources\ are\ shared \\ 1\ else\end{cases}$$

$$\theta_{(i,j)}=\begin{cases}0\ if\ backup\ resources\ are\ dedicated\ on\ link\ (i, \\ c\ if\ resources\ are\ shared\ on\ link\ (i,j)\left(c\le Nfs\right)\end{cases}$$

In this work, two types of connections are assumed (critical and non-critical connection request). For a connection request, if there are several pairs of paths with available resources, both primary and backup paths with minimal power consumption is selected for critical connections. For non-critical connection requests, the pairs of path with the minimum resources used is selected.

ALGORITHM 4 : Determination of primary and backup paths

Input : Primary and Backup paths

Output.: primary path and their backup path

IF primary and backup paths are found **THEN**
  FOR each pair of primary and backup path **DO**
    IF type_connect == critical **THEN**
      SELECT the pair of path which minimize network energy consumption
    ELSE
      SELECT the pair of path which minimize network resources utilization
    ENDIF
  ENDFOR
ENDIF
IF the pair of path is found **THEN**
  UPDATE the performance indicators
  ELSE connection request is blocked
ENDIF

VI. Simulation Results And Analysis

We have used the NSFNET topology (14-nodes, 22-links) and US Backbone topology (24-nodes, 43-links), as shown in Fig. 1 and Fig. 2, to evaluate the performance of the network through the protection algorithm proposed for elastic optical networks. We assume that each link is bidirectional. The bandwidth required for each connection request is function of the modulation format which is proportional at transmission path length and the signal propagation speed on a unit of bandwidth and connection speeds. For each link capacity, firstly, there are 80 frequency slots. Guard band is fixed to 1. Both primary and backup paths are determined by a K shortest paths algorithm with K = 2.

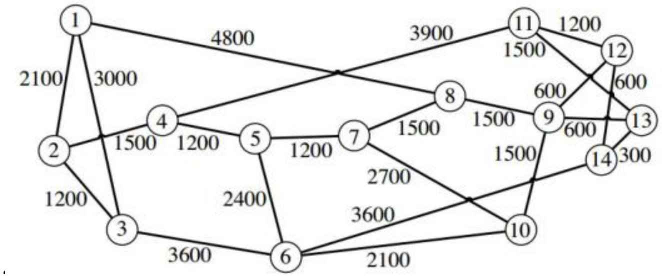

Fig. 1. NSFNET topology

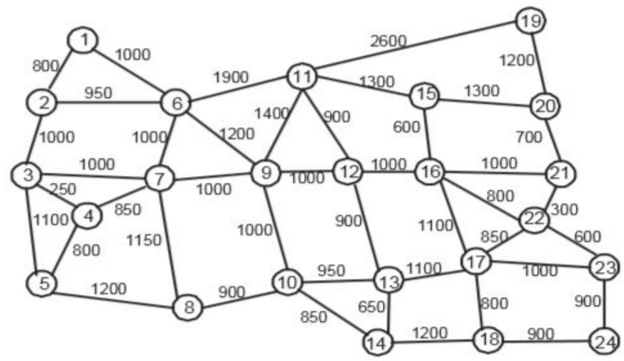

Fig. 2. US BACKBONE topology

The performance of the proposed algorithm is evaluated considering two different techniques and comparing their performance in terms of blocking probability and network power consumption.

1) Hybrid protection approach with regenerator activation (With-Reg): All the connection requests require regenerators activation when they do not have corresponding modulation formats.

2) Hybrid protection approach without regenerator placement (Without-Reg): All the connection requests do not require regenerator placement when they do not have corresponding modulation formats.

In fact, each modulation format has a transmission reach in which the signal can be transmitted without being regenerated. This assumes that the signal is good. When the path length is higher than the transmission reach of different modulation formats, we say that this path does not have appropriate modulation format. And thus, to transmit a signal on path without appropriate modulation format requires that the signal is regenerated by the regenerator in order to obtain a good quality of signal.

Firstly, we consider that all requests require regenerator placement when appropriate modulation format is not found (With-Reg), only critical requests can require regenerator activation (With-Reg-Critical) and finally no request require regenerator placement (Without-Reg). The results of Fig. 3 and Fig. 4 show that regenerator activation reduces considerably the blocking probability compared to case when requests not require regenerator placement.

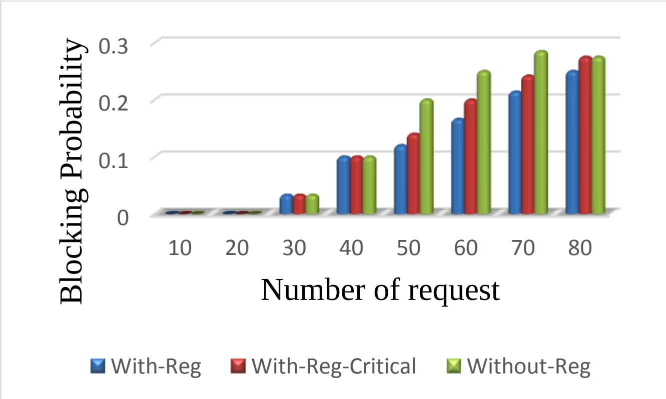

Fig. 3. Blocking probability/Number of requests – NSFnet

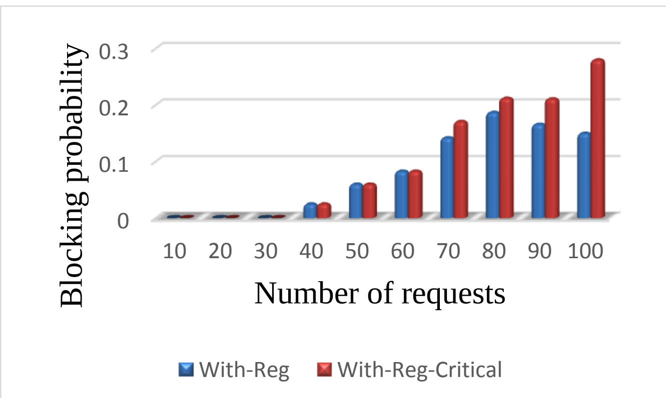

Fig. 4. Blocking probability/Number of requests - US

Although regenerator placement reduce the blocking probability, it has an impact of network power consumption as shows Fig.5. When the connection requests which require regenerator placement are numerous, network power consumption is high contrary to the case where the number of requests which require is smaller.

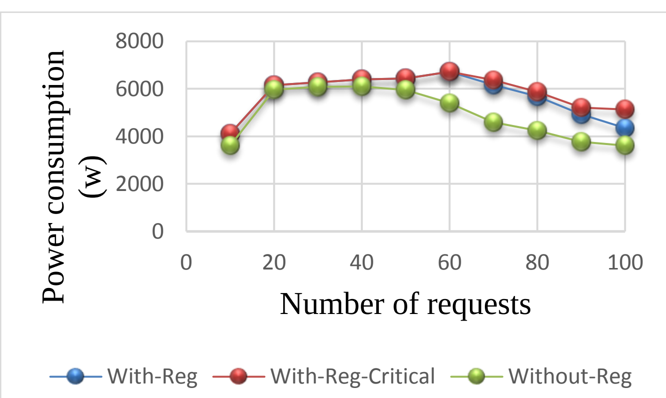

Fig. 5. Power consumption/Number of requests - US

VII. Conclusion

In this paper, we have focused on the protection problem in elastic optical networks with the objectives of minimizing the network power consumption with a low blocking probability.

In our proposition, two types of traffic are considered: the critical traffics and non-critical traffics. The critical traffic requests are identified by the connection requests that require immediate restoration when a connectivity failure occurs. In these requests, the associated protection type is the dedicated protection contrary to non-critical traffic requests where the backup resources are shared. During the paths resources determination, the modulation formats that minimize resources utilization are selected. When a connection request has no appropriate modulation format, regenerator placement is used to permit connection establishment with a good quality of signal. All this has helped to provide better performance in terms of blocking probability.

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