A Novel Dedicated Route Protection Scheme for Survivability of Link Failure in Elastic Optical Networks

Sridhar Iyer and Shree Prakash Singh

***Abstract*—The spectrally efficient transportation of the high bit rate(s) data is achievable by the Elastic optical networks (EONs). However, in the EONs, owing to the failure occurrence even in an individual simple element, different service(s) maybe interrupted. Hence, it is imperative that the schemes for survivability be developed so that the issues due to the possible failure(s) can be overcome. In the current work, in view of survivability of the link failure(s) in the EONs, we propose the Spectrum Continuity and Contiguity Established DRP (SCC-E-DRP) algorithm which is a novel dedicated route protection (DRP) scheme that attempts to avoid the problem of trap topology during its exploration for a pair of link disjoint path. Further, to evaluate the link disjoint paths, we resort to the use of the SCC Established Shortest Route (SCC-E-SR) algorithm which is a modified Dijkstra's algorithm based scheme that selects the path(s) pair(s) based on the end-to-end SCC. We conduct extensive simulations considering realistic network topologies, and compare the performance of the SCC-E-DRP scheme with the existing techniques. The obtained results show that, compared to the existing schemes, the SCC-E-DRP scheme achieves better results in terms of blocking probability.**

***Keywords*—Elastic optical network, protection, survivability, blocking probability.**

I. INTRODUCTION

To satisfy demand(s) of the various heterogeneous services having different applications and bandwidth requirements, the optical transport network (OTN) architectures have evolved from the fixed-grid wavelength switched optical networks (WSONs) towards flexi-grid elastic optical networks (EONs) technology [1], [2]. In the WSONs, a particular transceiver type is assumed, and only a single demand serving method exists, which fixes, the bit-rate, the transmission reach (TR), and the spectrum utilization [3]. However, the WSONs are required to admit all channels within a fixed frequency grid which may not be adequate for high speed channels, and may also under-utilize the spectrum for low bit-rate requests. Hence, for future OTNs, it is essential to resort to the EON technology in which (i) on basis of requirement(s), wider channels are created by combining spectrum units (or frequency slots (FSs)), and (ii) use of multiple subcarrier(s) ensures that wavelength capacity can be zoned into finer granularities, hence provisioning increased flexibility in capacity allocation to heterogeneous demands. The other main features of EONs include the (i) use of different modulation formats (MFs) differing in both, the spectral-efficiency (SE) and the TR, (ii) signal regeneration execution ability with modulation conversion, and (iii) transmission of super-channel(s) (or multiple-carrier(s)) [4], [5].

In the planning of the EONs, the routing and spectrum allocation (RSA) problem, known to be *NP*-complete, is the simplest optimization problem [6]. The RSA must account for the (i) *Spectrum contiguity constraint*: a block of contiguous FSs to be assigned to a request as the spectrum, and (ii) *Spectrum continuity constraint*: sequential links over an end-to-end route of any demand to be allocated the same contiguous FSs. Further, if the MF(s) choice is also included then, the RSA transforms into the routing, MF and spectrum allocation (RMFSA) problem which, in addition to the *Spectrum contiguity constraint* and *Spectrum continuity constraint*, must also take into consideration the *MF decision*: necessitated bandwidth, and the limits on the TR govern the choice of the MF. The optimization approaches formulated in regard to the RSA problems can also be used to solve RMFSA problems; however, the procedure of optimization has high complexity owing to the additional optimization parameter in regard to choice of the MF [7]. The RSA and the RMFSA algorithms directly influence the FSs occupancy among network links and, hence, have a significant impact on network performance.

As in any communication network, an OTN's (WSONs or EONs) operation also occurs in an unpredictable environment and hence, there exists a high probability of device and media failure(s). As a result, it is impossible to predict, and also eliminate all the factors which affect the network connectivity. Therefore, network resilience is indispensable in regard to analysis and design of the OTNs since, the result(s) of network failure(s) can become critical.

In order to provision resilience in the OTNs, two key methods can be used see protection and restoration [8]. In the event of an occurrence of a failure(s), the restoration process can be used which aims at updating the rules for routing so that the required network connectivity can be restored. In comparison to protection, restoration is more cost-efficient since it does not require any advance reservation of redundant resources. However, the restoration approaches have a major disadvantage of requiring long recovery times and hence, the strategies and the algorithms in regard to restoration must take into consideration the crucial issue of processing time [9]. Among the many methods of restoration, the key methods are:

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(i) *path restoration*, in which a new lightpath is found between the source and the destination nodes, (ii) *sub-path restoration*, in which a new lightpath is found from the previous node to the failure until the destination node, also reusing an existing lightpath portion, and (iii) *link restoration*, in which a new lightpath is found from the adjacent nodes to the failure [10].

The methods of protection rely mainly on the actions which are undertaken during the network design phase and further, requisite the reservation of few redundant secondary (backup) resources. Thus, the use of protection methods increases the network's cost; however, such methods provision prompt recovery times. The protection schemes can be of route based (e.g. dedicated route protection (DRP), and shared backup route protection (SBRP)), or link based (e.g. *p*-cycle and co-operative fast protection (CFP)) types. The route based protection schemes (RBPSs) use lesser capacity compared to link based protection schemes (LBPSs) since, under LBPSs, the secondary paths turn out to be longer compared to those used in the RBPSs [11]. Also, the LBPSs are formulated for the networks with spectrum and/or wavelength conversion capability, and hence, these methods applicability is significantly limited for cases in which the spectrum and/or the wavelength continuity constraints are imposed. Further, the use of LBPSs leads to either (i) utilization of a less efficient MF over the secondary route, which results in an increase of the spectrum requirements, or (ii) the deployment of additional equipments (i.e., transponders or regenerators) to provision the lightpath with an efficient MF, which results in an increase of the network cost and power consumption [11]. Hence, in the current work, we focus only on the RBPSs.

In both types of RBPSs (i.e., DRP and SBRP), in addition to serving a primary lightpath for every demand, a secondary (or backup) lightpath is also pre-evaluated. The key difference between the two methods is that, in SBRP, sharing of the spectrum resources between the secondary lightpaths, which belong to different demands, is permitted, subjected to the fact that in a given failure case, these resources are used only by one request. However, in DRP, secondary lightpaths have their own dedicated spectrum resources, and hence, compared to the SBRP approach, the DRP method demonstrates lesser savings in spectrum and cost. However, in addition to its simpler implementation, the DRP method ensures fast and guaranteed traffic recovery from single failures even though it has been shown to present higher resource utilization ratio compared to both, the SBRP and the restoration methods [12], [13].

In the current work, we focus on the DRP methods application in the EONs. In regard to the aforementioned, we propose a novel algorithm to protect connections against an individual link failure, simultaneously considering the existence of physical layer impairments (PLIs). The proposed Spectrum Continuity and Contiguity Established Dedicated Route Protection (SCC-E-DRP) scheme finds a link-disjoint route pair based on the end-to-end spectrum continuity and contiguity (SCC).

The rest of the paper is organized as follows. Related studies in regard to our current work are presented in Section II. In Section III, we present details of the proposed SCC-E-DRP algorithm. Section IV presents the simulation setup, followed by the presentation and discussion of the obtained results. Finally, Section V concludes the study.

II. RELATED STUDIES

In this section, we review few existing studies that have presented solutions for solving the DRP problem in EONs. A simple method to solve the DRP problem in the WSONs is the use of the Dijkstra's or the Bellman-Fords algorithm in two steps [14] wherein, the first step comprises of evaluation of the working path in the network, followed by temporary removal of the working path's links from the network, and the second step which determines path to be used for protection. The aforementioned scheme is simple to implement; however, after the links, which are used in the working route, have been temporarily removed, there is a possibility of the network being broken into two disconnected components, which in turn makes it impossible to determine any secondary (backup) path. The aforementioned case(s) may also occur even when there is an existence of two link disjoint routes in network, and such network topology(s) are known as trap topologies (TrTs).

In view of the aforementioned, the author in [15] has proposed a scheme that solves the issue of evaluating link disjoint path pairs when the TrTs are considered. The proposed algorithm attempts to avoid the vital links in the TrT hence, permitting the determination of a link disjoint path pair, provided such a path pair exists.

In [16], the authors have proposed few algorithms in view of solving the RSA problem considering both, the DRP and the SBRP methods. The developed algorithms are formulated in the form of an integer linear programming (ILP) model which considers the constraint of distance adaptation. The simulations are performed with an aim to compare the proposed algorithms, considering the WSON case, and in regard to SE. The obtained results showed a 30 % minimization in the resources which are necessitated.

The authors in [17] have proposed scalable algorithms (heuristics) for the investigation of energy consumption, and cost model issues in both, WSONs and EONs. The authors have considered and evaluated both, the DRP and the SBRP methods, and results show possible improvements in energy-efficiency which is obtainable by the adoption of EONs.

In [18], the authors have formulated an ILP model in view of obtaining the solutions for the RSA with DRP. The ILP formulation uses a modified version of Tabu Search algorithm so as to provide almost optimal solutions.

The authors in [19] have developed the ILP models for minimizing the used link FSs amount, and the required spare capacity. Both, DRP and SBRP methods are considered, and analyzed under the cases of, with and without, tunable transponders. The developed models are compared considering three network topologies, and results show that the SBRP method requires lesser spare capacity in comparison to the DRP method.

In [20], the authors have proposed a heuristic algorithm for investigating congestion aware routing problem in non-linear EONs. The proposed algorithm uses a cost function based on congestion to evaluate network links, and after evaluation of link's cost, uses the Dijkstra algorithm to find the path so as to serve the demand. The results show that the proposed heuristics can be easily adapted to solve the DRP problem in the EONs.

The authors in [21] have investigated the gains which result from the utilization of EONs, and have also focused on the squeezed protection capability in the EONs. The authors have conducted simulations to compare the WSONs and the EONs, considering various protection schemes. The obtained results demonstrated that, for all the considered performance metrics, EONs significantly outperform the WSONs, and the squeezed protection approach allows for a significant minimization of resources; however, it only protects a fraction of the traffic.

III. THE SCC-E-DRP ALGORITHM

In this section, we present the details of the proposed SCC-E-DRP algorithm which is a novel DRP algorithm that (i) deals with the individual link failure in the EONs, and (ii) determines a link disjoint path pair in the network under the consideration of SCC. In Table I, we show the steps which are followed for the execution of the SCC-E-DRP algorithm.

The SCC-E-DRP algorithm begins by finding a path (R1) under the SCC constraints by resorting to the SCC Established Shortest Route (SCC-E-SR) algorithm, within the matrix corresponding to the network topology (Λ) . The SCC-E-SR algorithm (detailed later in this section and in Table II) has the responsibility of determining the lowest cost path(s) pair(s) based on the end-to-end SCC (see *Lines 2, 3, 7* and *9*). The SCC-E-DRP algorithm, in its next steps (see *line 5*), ensures the temporary removal of the R1 uplinks, or reversal of the R1 links from , and hence determines a new path (R2). Then, the algorithm utilizes few steps from the study in [15] (see *lines 5-9*) so as to determine a link disjoint path pair, and also to be able to tackle the issue of TrT. In the case when R2 is not determined, the demand is rejected by SCC-E-DRP algorithm (see *line 18*); else, for the links which are shared between R1 and R2, the algorithm compares these shared links, and then removes them. Further, as already stated before, these shared links must be avoided during calculation of both, the link-disjoint working and protection routes (*lines 79*), since use of these shared links may split the network into disconnected parts [15].

TABLE I
VARIOUS STEPS OF THE SCC-E-DRP ALGORITHM

```
Input  Demand for connection, matrix corresponding to the network
       topology ($\Lambda$), node which is the source, node which is the
       destination, and FSs amount needed by the demand ($w$);
1      Determine a path (R1) in ($\Lambda$) under the consideration of both,
       the spectrum continuity constraint and the spectrum contiguity
       constraint;
2      Ensure the temporary removal of R1 from $\Lambda$. Then, evaluate
       a new path (R2) resorting to the use of the SCC-E-SR algo-
       rithm under the consideration of both, the spectrum continuity
       constraint and the spectrum contiguity constraint;
3      if the paths R1 and R2 exist then
4        if R1 has a sharing link with R2 then
5          Ensure removal of the links which are shared by R1 and
           R2 from $\Lambda$;
6          Determine the working path under the spectrum continuity
           constraint by making use of the SCC-E-SR algorithm from
           $\Lambda$;
7          Ensure the removal of the working path links from $\Lambda$;
8          Evaluate the protection path under the spectrum continuity
           constraint by making use of the SCC-E-SR algorithm from
           $\Lambda$;
9          if working paths and protection paths exist then
10           return the working and the protection paths.
11         end if
12       else
13         R1 $\rightarrow$ working path; R2 $\rightarrow$ protection path;
14         return the working paths and the protection paths.
15       end if
16     else
17       Demand for connection is blocked.
18     end if
```

The SCC-E-SR scheme, which is a modified version of the Dijkstra's algorithm, considers the FSs SCC constraints in the process of routing. In specific, in the SCC-E-SR algorithm, the path's SCC information, which is determined starting from the source node till an intermediate node using the Dijkstra's process, is mixed with every link's available spectrum. However, in the aforementioned process, the node is neglected so as to formulate each of these link's cost. In Table II, we show the steps which are followed for the execution of the SCC-E-SR algorithm.

The initialization of the *continuous* vector, which is used for the storage of data corresponding to the availability of the FSs starting from the source node till the other nodes as per the

TABLE II
VARIOUS STEPS OF THE SCC-E-SR ALGORITHM

```
Input  network topology, node which is the source, node which is the
       destination, and FSs amount needed by the demand ($w$);
1      Initialization of the vector: cost, parent, continuous;
2      Initialization of the List $M \leftarrow empty$;
3      for all node $b$ from the network do
4        $cost[b] = \infty$; $parent[b] = -1$; $M \leftarrow b$;
5      end for
6      $cost$[source] = 0;
7      $continuous$[source] = 1, 1, 1,...1, 1, 1;
8      $a$ = source and source of $M$ is removed;
9      while $M$ is not empty do
10       for all adjacent node $b$ of $a$ do
11         if there exists a link between nodes $a$ and $b$ then
12           Define $N$ as the available FSs vector between nodes $a$
             and $b$;
13           Define the vector $B$;
14           Define $FS$ which corresponds to the FSs total number;
15           Define $d(a, b)$ corresponding to length of the physical
             link between nodes $a$ and $b$;
16           for every FS $s$ from $FS$ do
17             if $continuous[a][s] = 1$ & $N[s] = 1$ then $B[s] = 1$;
18               else $B[s] = 0$;
19             end if
20           end for
21           cost between the nodes = $F(d(a, b), B, w)$
22           minimum cost = $cost[a]$ + cost between the nodes;
23           if $cost[b] >$ minimum cost then
24             $cost[b]$ =minimum cost; $parent[b] = a$;
               $continuous[b] = B$;
25           end if
26         end if
27       end for
28       $b = M$'s element with lower cost, and remove $M$'s $b$;
29     end while
30     return the evaluated path as per the vector $parent$.
```

minimal cost path, occurs in *line 2*. Further, the initialization of the other vectors, *cost* and *parent*, and the list M, occurs between *lines 2-6*. Next, it is considered that, in the source node, all the FSs are available (i.e., a value of '1' is assigned). The vector *continuous* stores the aforementioned data (see *line 8*). The adjacent nodes of node a are explored, and a slot-by-slot comparison of the $continuous[a]$ vector, and N is conducted (see *lines 13-21*). Then, this comparison's resultant vector (B) is utilized for calculating the link's cost (see *line 22*).

Further, the cost function, denoted as $F(d(a,b),B,w)$, is evaluated by considering the following two variables. The first variable, denoted as $x_{a,b}$, accounts for the length of the physical link which is normalized:

$$x_{a,b} = \frac{d_{a,b}}{d_{max}}, \tag{1}$$

where $d_{a,b}$ denotes the length of the link between nodes a and b, and d_{max} represents the maximum length of the link in the network. In specific, $x_{a,b}$ has a contribution in minimization of the occurrences of the route demand blocking owing to the constraints imposed by the PLIs.

The second variable, denoted as $y_{B,w}$, accounts for the SCC information of the FSs, starting from the source node till the current node which is analyzed. Further, the aforementioned information is stored within the algorithm during the network link analysis. The variable $y_{B,w}$ shown in (2), contributes to minimization of the route demand blocking occurrences owing to the lack of resources.

$$y_{B,w} = \frac{1}{s_{B,w}+1}, \tag{2}$$

where $s_{B,w}$ considers the spectrum contiguity of the FSs. Further, $s_{B,w}$ is evaluated by considering all the number of ways of the assignment of the current w-slot demands within the vector B's available spectrum.

Hence, the total cost function (F) of the SCC-E-SR algorithm is given as follows:

$$F(x_{a,b}, y_{B,w}) = \frac{d_{a,b}}{d_{max}} + \frac{1}{s_{B,w}+1}. \tag{3}$$

IV. SIMULATION SETUP AND RESULTS

In this section, initially we detail the simulation setup and the parameters used in simulations, followed by a discussion of the obtained results.

A. Simulation setup and parameters

In order to evaluate the DRP algorithm, we use the blocking probability (BP) as the performance metric, which is defined as the ratio of blocked call demands numbers to the total call demands numbers. In order to evaluate BP of DRP algorithm for the cases of the survivable EONs, we use the model from our previous study [21]. For the simulation of every network, we generate a set of 200,000 calls whose pairs of source-destination are chosen by following a uniform distribution. The arrival of the call demand follows a Poisson process, and the duration of every lightpath which is established follows an Exponential distribution. In addition, every call demands the bit rate randomly by following a uniform distribution, and the bits rates which are permitted are 40/100/200/400 Gbps.

In the simulations, we use the algorithm (see Fig. 1 for the flow chart) in regard to the DRP, level of modulation, and assignment of spectrum. The algorithm works as follows:

i The DRP algorithm attempts to determine a link disjoint path pair for every call demand.
ii The demand is blocked if, no link disjoint pair exists for this call demand; else, beginning from the most efficient MF, algorithm attempts selection of appropriate MF for every path. It must be noted that, for every call demand, MF determines required contiguous FSs numbers.
iii In case when, for servicing a call demand, no continuous and contiguous FSs exist in either the working or the backup path, the call is blocked. However, when the free FSs are available, the quality of transmission (QoT) for the demand is calculated.
iv If the determined QoT for either the working or the backup paths is below the pre-defined threshold, then, the next (second) most efficient MF is tested. The aforementioned process continues till the most robust MF is found. It must also be noted that in all the conducted simulations, there may be an assignment of varied MFs for the working and the protection lightpaths.

Further, for the acceptance of any call demand, the DRP algorithm is requisited to determine a link disjoint paths pair with both, the available resources (i.e., FSs which are contiguous and continuous), and the appropriate QoT. In the current study, we consider the PLIs as detailed in [22], [23]. Further, we allow the following MFs in our simulations: QPSK, 8-QAM, 16-QAM, and 32-QAM [4], and the various other parameters used in the simulations are as in [4], [5], [21]-[23]. In Table III, we present the FSs numbers for every modulation level combination and the transmission bit rate, under the assumption of 320 numbers of FSs, and FSs of 12.5 GHz. The guard band assumed in all the simulations has a fixed value of 12.5 GHz.

In the simulations, following the studies in [4], [5], we use two realistic network topologies, the Telefónica (TID), and the GEANT as shown in Fig. 2, with their various dimensions values shown in Table IV. In the considered topologies, we assume that the links are bidirectional, i.e., the links are formed by an optical fibers pair, one for every direction. It is also assumed that both, the working and the backup lightpaths are bidirectional which implies that each lightpath is routed via the same links with fibers in the opposite directions. Also, the capability of conversion of the spectrum at the intermediate nodes is not considered.

It must also be noted that the topologies node degree and the links distribution majorly affect the DRP algorithms' performance since these characteristics impact the evaluation of paths pair with end-to-end FSs spectrum continuity. In addition, the available FSs amount and the MFs which are possible, also have a key role to play in the DRP algorithms' performance.

Further, it is known that the optical signal to noise ratio (OSNR) which is required for every MF is dependent on the

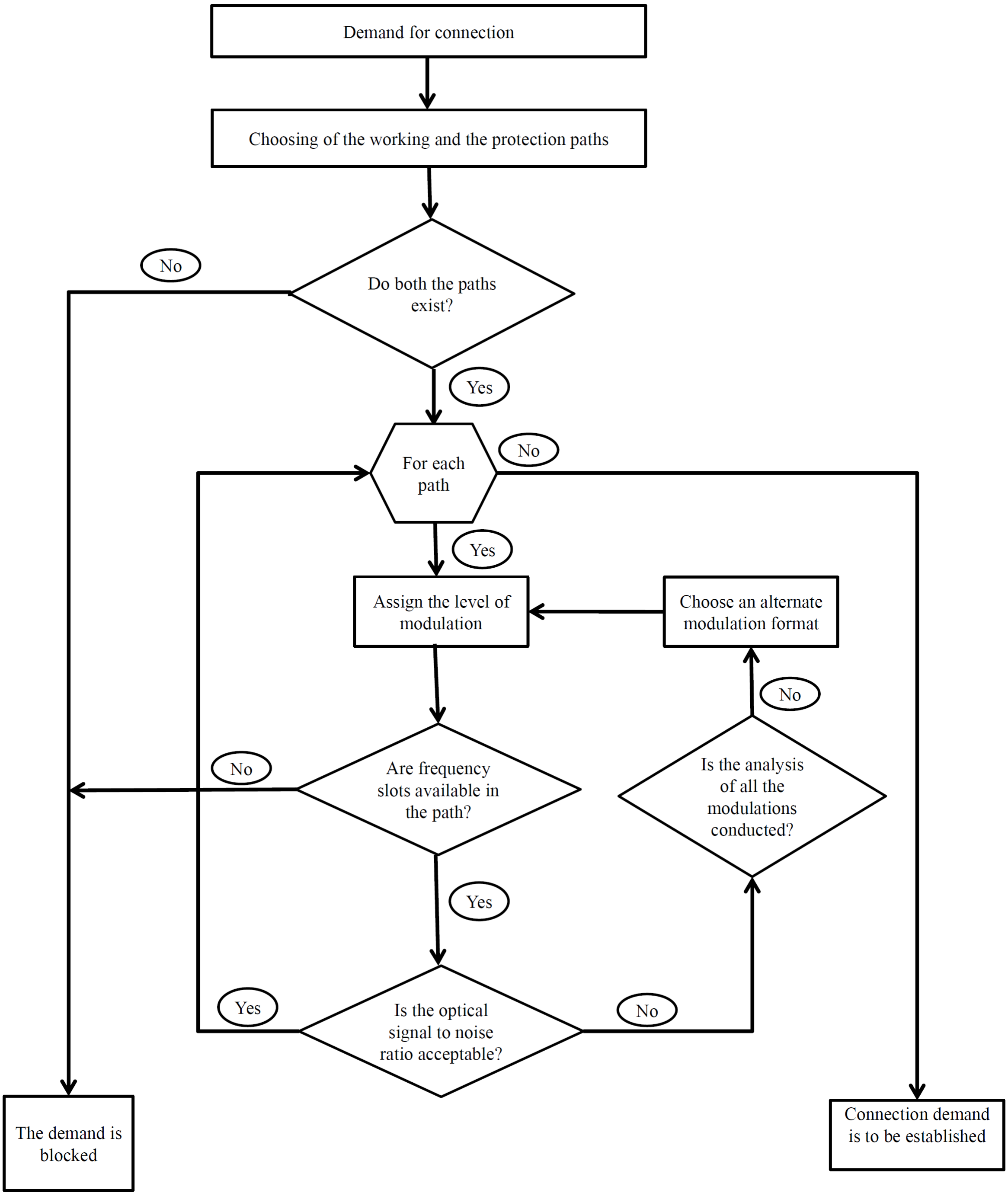


Fig. 1. Flowchart of the algorithm which is used in the simulations.

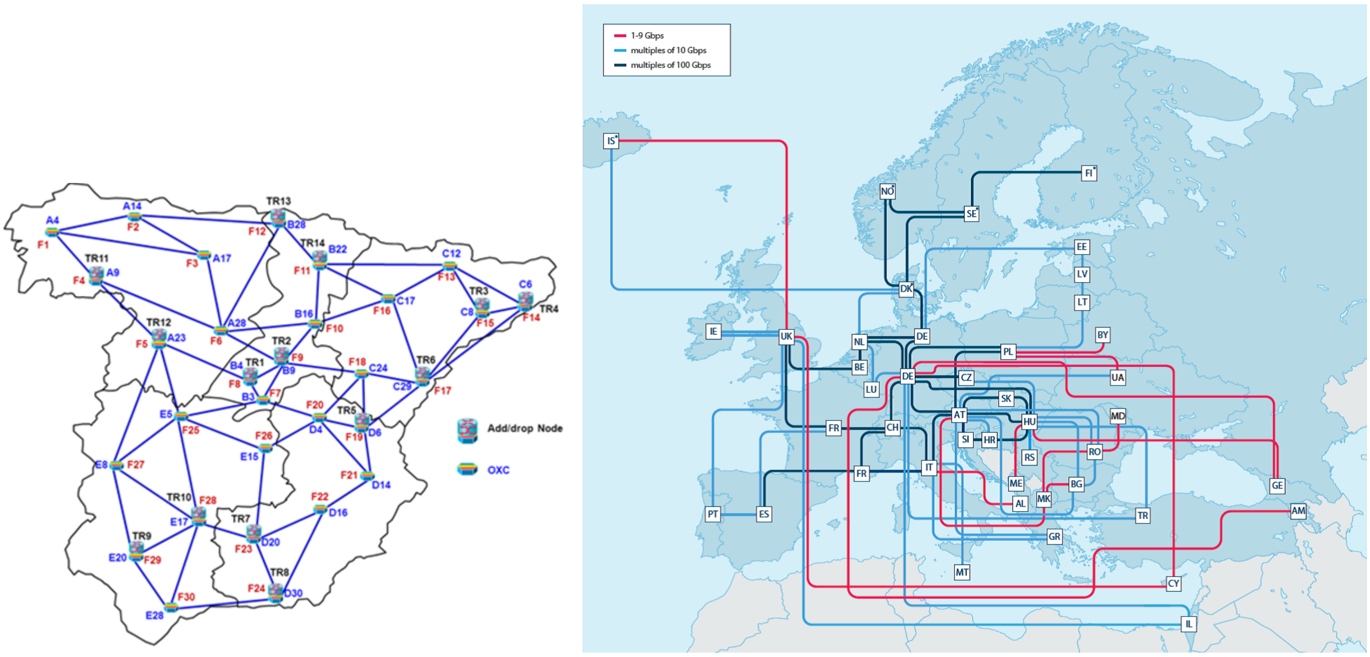
TABLE III
THE FREQUENCY SLOT NUMBERS FOR EVERY MODULATION LEVEL COMBINATION, AND THE TRANSMISSION BIT RATE

	Bit rate (Gbps)			
Modulation format	40	100	200	400
32-QAM	1	2	4	7
16-QAM	1	2	4	8
8-QAM	2	3	6	11
QAM	2	4	8	16

TABLE IV
VARIOUS NETWORK TOPOLOGY(S) CHARACTERISTICS USED IN THE SIMULATIONS

Network topology	Location	No. of nodes	No. of bidirectional links	Average length of link (km)	Maximum length of link (km)
TID	Spain	30	56	148	313
GEANT	Europe	34	54	752	2361

bit rate which is transmitted and the MFs SNR per bit [24]. In this study, the MFs SNR per bit and the OSNR are evaluated



(a) (b)

Fig. 2. Network topologies used in the simulations (a) TID, and (b) GEANT [4], [5].

TABLE V
OSNR FOR EVERY COMBINATION OF THE MODULATION LEVEL, AND THE TRANSMISSION BIT RATE

	Bit rate (Gbps)			
Modulation format	40	100	200	400
32-QAM	13.52	17.32	20.63	23.58
16-QAM	11.87	15.54	18.52	21.52
8-QAM	11.34	15.08	18.11	21.08
QAM	7.83	11.89	14.76	17.92

as detailed in [25]. In Table V, we show the OSNR (in dB) for every modulation level combination and the transmission bit rate.

During the simulation, initially it is assumed that the SCC-E-DRP algorithm accounts for the FSs amount which is used by QPSK (i.e., the most robust of the considered MFs), which however is the worst case scenario. Then, on completion of the routing process, for servicing the demand, the algorithm may resort to the use of another MF which is more efficient.

For comparative results, we use two versions of the SCC-E-DRP algorithm. The first version, denoted as SCC-E-DRP(y), uses the variable $x_{B,w}$, and hence searches for a pair of link disjoint path pair only based on the SCC information thus, neglecting the influence of the physical distance on the routing decision process. The second version, denoted as SCC-E-DRP(x,y), uses both the variables, $x_{a,b}$ and $y_{B,w}$, and hence during the search for a link disjoint path pair, uses information in regard to both, the link physical distance, and the SCC.

For comparison with our proposed algorithm's two versions, we use the following algorithms:

1) The algorithm proposed in [15], denoted as [15](x), which considers $x_{a,b}$ (i.e., the length of the link) as the link cost function.
2) The algorithm proposed in [15], denoted as [15](y), which accounts for $y_{B,w}$ for the network links' cost evaluation.
3) The routing algorithm proposed in [20], which is adapted to obtain solutions for the DRP problem, denoted as the congestion aware-DRP (CA-DRP). CA-DRP calculates network links based on (1), and then runs the Dijkstra's algorithm twice for determining the working, and the protection routes. Then, once the path pair(s) for the DRP process has(have) been determined, it resorts to the assignment of the spectrum by following the First-Fit (FF) algorithm [26].

B. *Simulation results*

In this sub-section, we present and discuss the results in terms of BP that were obtained when the proposed SCC-E-DRP(y) and SCC-E-DRP(x,y) algorithms were compared with the [15](x), [15](y), and CA-DRP algorithms. It must be noted that in all the aforementioned schemes, the FF method was used for the assignment of the spectrum.

Further, in order to obtain the results, on both considered network topologies, we run 50 different simulation processes for all the considered DRP schemes. We obtain the mean BP achievable by every algorithm considering a confidence interval of 98 %. In Fig. 3 and Fig. 4 we present the route demand BP comparison with a variation in the network load. In both the results, within both the graphs, the symbols denote the mean BP which is achieved by every algorithm, and the error bars represent the 98 % confidence interval. It can be observed that in few case(s), the error bars are much smaller than size of the symbols, and hence are not perceivable within the graphs.

From Fig.3 it can be observed that the SCC-E-DRP(y)

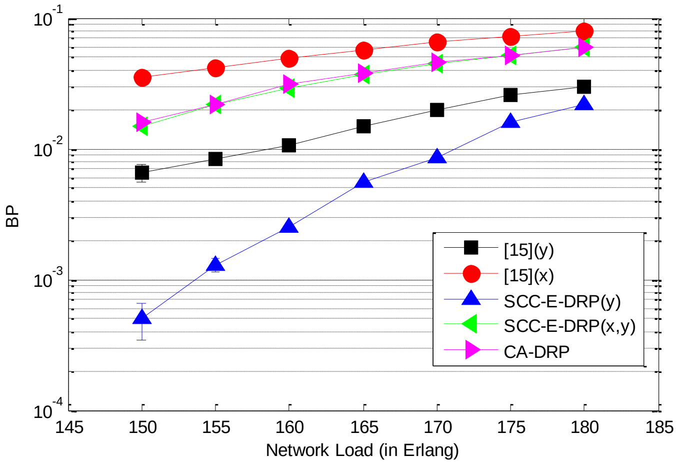


Fig. 3. In the TID topology, the BP comparison with a variation in the network load after 50 varied simulation runs, and its error margin set to 98 % confidence interval for all the considered DRP schemes.

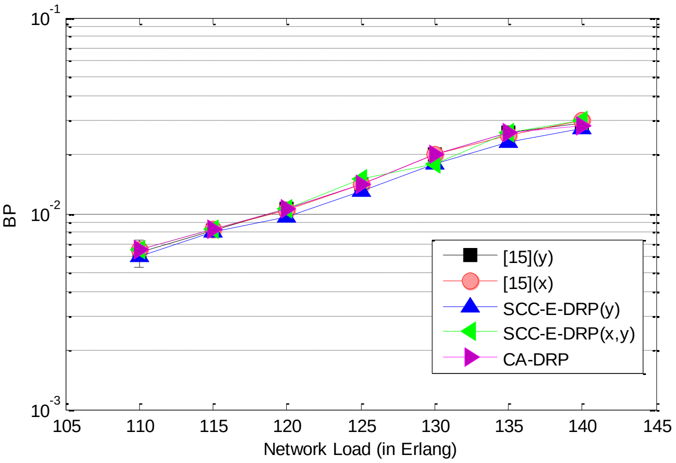


Fig. 4. In the GEANT topology, the BP comparison with a variation in the network load after 50 varied simulation runs, and its error margin set to 98 % confidence interval for all the considered DRP schemes.

scheme is able to outperform all the other considered schemes owing to the fact that it uses the FSs information on the SCC, and is hence able to choose the path pairs efficiently so as to service the network demands. It must be noted that although SCC-E-DRP(x, y) scheme accounts for spectrum continuity during the process of routing, owing to the presence of $x_{a,b}$, there occurs a frequent selection of shortest paths pair. This in turn minimizes the alternate paths with higher availability of the spectrum (which may provision more chance(s) of having an end-to-end free spectrum resource) being chosen by the algorithm.

From Fig. 3 it can also be observed that the [15](y) scheme presents the next best performance after the SCC-E-DRP(y) scheme since, it analyses and calculates the link(s) state in regard to the FSs spectrum contiguity. Hence, even though the SCC-E-DRP(y) scheme has no inference on the information in regard to the end-to-end FS spectrum continuity, it follows a routing process which is dynamic and adaptive. On the other hand, the CA-DRP scheme weighs the network links as a function of both, the physical length, and the available total spectrum proportion. However, it does no account for the information on the FSs SCC and hence, in certain cases in not able to select efficient paths with adequate spectrum resources so as to serve the demands.

From Fig. 4, it can be observed that similar results trends are obtained as in Fig. 3 i.e., with an increase in the network load, the BP also increases. It can also be observed from Fig. 4 that all the considered schemes obtain approximately similar BP performance since, in the GEANT topology there occurs a pre-dominant blocking owing to the lack of QoT. The reason for the aforementioned is that, in the GEANT topology, the links are of longer distances owing to which, in the absence of regeneration, the lightpaths suffer more degradation due to the impairments. It must also be noted that in this case, the SCC-E-DRP(y) scheme conducts the selection of paths as per the availability of FSs only, and hence, in few scenarios solution(s) which is(are) returned are unable to follow the required QoT. Another factor that contributes for the methods to obtain approximately similar performance is due to constraints in the GEANT topology i.e., the fact that majority of its nodes have connectivity equal to 2 which results in the methods finding just one pair of link-disjoint routes for most of source-destination nodes in the network.

From the above obtained results it can also be observed that we have aimed at achieving a BP of 1 % in view of dynamic network operation. For every demand, the DRP method is observed to requisite a dual lightpath assignment, and in regard to the topologies, few links are observed to result in the concentration of traffic and hence, there occurs a constriction during the process of lightpath assignment. Lastly, a demand is blocked when one of the two assigned lightpaths cannot be implemented owing to (i) resource(s) which are unavailable, or (ii) QoT being lesser than required value. The aforementioned is however a hard constraint and leads to the BP increase for even lower network loads.

V. CONCLUSION

In this work, considering the link(s) failure survivability in the EONs, we proposed a novel DRP algorithm (SCC-E-DRP) which attempts to avoid the trap topology issue when evaluating the link disjoint path pair. Also, the proposed algorithm accounts for the PLIs, and obtains every path such that the end-to-end spectrum continuity and spectrum contiguity is considered. Then, we conducted simulations considering realistic network topologies, and compared the performance of SCC-E-DRP with the existing techniques. The obtained results demonstrated that (i) compared to existing schemes, SCC-E-DRP achieves better results in terms of the blocking probability, and (ii) it is of importance to account for spectrum contiguity and spectrum continuity information within any DRP scheme since it majorly influences the algorithms performance.

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