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CLEAR: A Non-Linear Impairment-Aware Resource Allocation Algorithm for MultiBand Elastic Optical Networks

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***Abstract*—Optical networks, characterized by high speed, substantial capacity, and dependable communication, constitute the foundation of 6G Internet of Things (IoT) networks. 6G IoT devices and next-generation applications are expected to generate vast amounts of data that require substantial processing capacity as well as data transport resources, which optical networks are uniquely able to satisfy. However, the existing fiber infrastructure may be unable to accommodate the future bandwidth demands due to 6G networks. MultiBand Elastic Optical Networks (MB-EONs) are one of the possible solutions to solve the capacity crunch problem due to the intensive increase in Internet traffic demand. MB-EONs utilize the unused spectrum of the already deployed optical fiber by extending the bands used from conventional C-band to other optical bands such as L band. However, the increase in capacity comes at the cost of degradation of the quality of transmission of the signal due to the Inter-band Stimulated Raman Scattering effect. In this paper, we propose Comprehensive Link Evaluation and Allocation for Routing (CLEAR), a Routing, Modulation, Band, and Spectrum allocation algorithm that considers different types of weights of links, i.e., capacity, length, ratio of capacity to length, weighted sum of the normalized link length and capacity, and different fragmentation metrics to find the route that has the most availability of resources among different paths. The results show that reduced blocking performance is observed along with better computational speed when we use the average scoring mechanism and capacity as link weight.**

***Index Terms*—6G Internet of Things (IoT) networks, Elastic Optical Network (EON), Multi-Band Elastic Optical Network (MB-EON), Inter-channel Stimulated Raman Scattering (ISRS), Physical Layer Impairments (PLIs), NLI Aware Routing, C + L band.**

I. Introduction

In the coming decade, 6G promises extensive connectivity and exceptional data speeds of up to several Gbps per device. As the amount of generated data proliferates, vast data centers are needed to process the data. As a result, the backbone network's capacity is expected to be in the range of tens to hundreds of Tbps per link. Achieving and sustaining such high capacities requires multiple technical breakthroughs. Optical fiber, with its inherently high capacity and reliability, is the obvious physical medium of choice for backbone networks, but the capacity of the conventional C band of fibers is expected to be exhausted in the near future. Research has been going on to make use of other spectrum bands in the already deployed single core fiber. This type of optical network that exploits the extended optical spectrum is known as Multi-Band Elastic Optical Network (MB-EON).

The extension of bands increases the capacity but at the expense of degradation of the Quality of transmission (QoT) of the signal due to the interference between the neighboring bands. The physical layer impairments need to be considered in the routing and spectrum allocation problem to ensure the Generalized Signal to Noise (GSNR) of the request remains above a threshold value. To efficiently manage the additional resources there needs to be an appropriate routing, modulation, band and spectrum allocation (RMBSA) algorithm [1]–[3] that judiciously allocates spectrum resources along with the consideration of impairments to the incoming connection requests.

In the literature, several works [4]–[6] have been reported on impairment-aware provisioning techniques in MB-EONs. Shen *et al.* [4] have introduced an SRS impact-reduced RMBSA algorithm for C + L EONs. Their proposed algorithm uses a path that has shortest transmission distance and has less occupied resources in the C-band to reduce SRS. Modifications in the routing and spectrum allocation phase considerably reduce the blocking probability and increase the resource usage of the spectrum as compared to the First Fit (FF) and First-Last Fit (FLF) RMBSA algorithms. Yao *et al.* [5] have presented a novel RMBSA technique that mitigates the influence of SRS for a network topology that includes only C-band enabled and both C + L-band enabled fibers. For a path including both C and C+ L -band enabled fibers, C band is used for resource assignment while for a path containing only C + L band fibers, L band is used for resource assignment to reduce traffic

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congestion. Simulation findings demonstrated substantial decrease in blocking and improvement in SNR tolerance of already established requests. Zhang *et al.* [6] have proposed a dynamic resource allocation algorithm that lowers the NLI effect by selecting a primary band in periodic manner among C, L, and S bands. Different spectrum allocation strategies are utilized to allocate resources for different bands. Simulation experiments demonstrate a 25 percent reduction in blocking probability and increase in GSNR of the bands as compared to the conventional first-fit RMBSA algorithm.

In this paper, we propose a nonlinear impairement-aware resource allocation algorithm for MB-EONs called Comprehensive Link Evaluation and Allocation for Routing (CLEAR), which uses capacity as link weight and average function as the scoring mechanism to select the best route. It ranks the paths between each source and destination based on the scoring criterion. Instead of following the conventional strategy to find a static route, CLEAR finds the most appropriate route considering the availability of resources in the links of a path. It gives least priority to those paths that contain a bottleneck link, i.e., a link with least resources. Simulation results indicate that we can achieve better performance by using only one path per connection request with the help of CLEAR compared to as high as three paths per connection request when other routing approaches are used.

The rest of the paper is organized as follows. Section II presents our proposed work and explains the various link weight calculations and scoring criteria used to select the route. Section III describes the proposed CLEAR algorithm along with its pseudocode. Section IV presents the results of our simulation experiments. Finally, Section V concludes the work.

II. Proposed Work

The existing research [7] in the literature focuses on the typical K-shortest path routing approach to find the route between a source and destination based on path length, i.e., the link weight is the length of the link. While link/path length does play a significant role in path selection, existing approaches tend to ignore other important parameters such as capacity and the fragmentation of bandwidth resources. Our proposed routing algorithms take into account eight distinct link weights: capacity, length, capacity-to-length ratio, weighted sum of the normalized link length and normalized capacity, and four different fragmentation metrics, i.e., external fragmentation, Shannon entropy, access blocking probability, and root sum square [8], [9]. The equations (1) are utilized for calculating the weights of links. In order to rank the paths between a source and a destination, we use four distinct scoring criteria: average, minimum, maximum, and sum. Instead of following the conventional method of finding a route, we intend to identify the most suitable route by taking into account the availability of resources in the links of a path. In our proposed method, we assign the lowest priority to paths that have a bottleneck link, i.e., a link with the lowest amount of resources.

$$L_w = \begin{cases} \frac{C}{C_{max}}, \\ \left(1 - \frac{L_l}{L_{max}}\right), \\ \left(\frac{C}{L_l}\right), \\ \alpha\left(1 - \frac{L_l}{L_{max}}\right) + (1-\alpha)\left(\frac{C}{C_{max}}\right), \\ \frac{M_{contg}}{C_{max}}, \\ \sum_{i=1}^{|A_{slots}|} \frac{A_{slots}(i)}{C_{max}} \log\left(\frac{C_{max}}{A_{slots}(i)}\right), \\ \frac{\sum_{i=1}^{|A_{slots}|}\sum_{i=1}^{|G_i|}\lfloor A_{slots}(i)/G_i \rfloor}{\sum_{i=1}^{|G_i|}\lfloor C_{max}/G_i \rfloor}, \\ \frac{\sqrt{\sum_{i=1}^{|A_{slots}|}(A_{slots}(i))^2}}{\sum_{i=1}^{|A_{slots}|} A_{slots}(i)}, \end{cases} \tag{1}$$

where L_w, C, C_{max}, L_l, L_{max}, L_{min}, M_{contg}, A_{slots} are the link weights, available capacity of a link, the maximum capacity (total number of slots in each link), the length of links in kms, the maximum length, the minimum length of link among all the links in the considered network topology, the maximum number of contiguous slots in a link, and the number of available slots per block in a link. Here $G_i = \{3, 6, 9\}$ is the set of available superchannel granularities including guardbands.

The various link weights and the scoring criteria used to select the most appropriate path among multiple paths are listed below:

1) **Weight**
   - Capacity (W_C)
   - Ratio of Capacity by Length ($W_{\frac{C}{L}}$)
   - Weighted sum of Capacity and Length ($W_{\alpha LC}$)
   - Length (W_L)
   - External Fragmentation (W_{EF})
   - Shannon Entropy (W_{SE})
   - Access Blocking Probability (W_{ABP})
   - Root sum Square (W_{RSS})
2) **Scoring criteria for a path with weight w_i in i^{th} link among L links in the path**
   - Average ($S_a = \frac{1}{L}\sum_{i=0}^{L} w_i$)
   - Minimum ($S_m = \min\{w_i | \forall i = 0, 1, \ldots, L\}$)
   - Maximum ($S_M = \max\{w_i | \forall i = 0, 1, \ldots, L\}$)
   - Sum ($S_s = \sum_{i=0}^{L} w_i$)

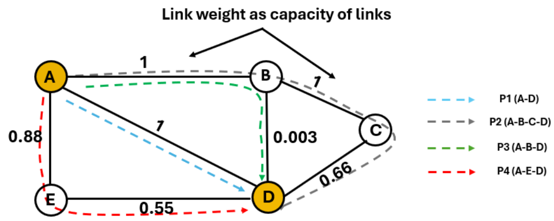


Figure 1: Optical network topology with capacity as link weight.

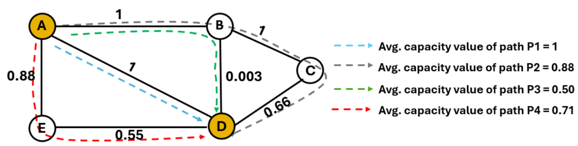


Figure 2: Illustration of paths with average capacity values in the optical network topology.

The notation S_a^C signifies the average scoring criterion when capacity is used as link weight and $S_m^{\frac{C}{L}}$ signifies the minimum scoring criterion when ratio of capacity to length is used as link weight. The scoring criterion when capacity is used as link weight is explained in detail with the help of network topology as shown in Fig. 1. If a connection request (CR) arrives at A for the destination node D, then all the possible paths between A and D are $A-D$, $A-B-D$, $A-B-C-D$, and $A-E-D$. If the available capacity in path A-D is 900 (maximum capacity assumed in this case), path A-B-D consisting of link AB and BD are 900 and 3, path A-B-C-D consisting of link AB, BC, and CD are 900, 900, and 600, and path A-E-D consisting of link AE and ED are 800 and 500 respectively. If the link weight is assumed to be capacity then the individual weights of links are calculated as $\frac{900}{900} = 1$ for path A-D, $\frac{900}{900} = 1$ and $\frac{3}{900} = 0.003$ for link AB and BD, $\frac{900}{900} = 1$, $\frac{900}{900}$ =1 and $\frac{600}{900} = 0.66$ for link AB, BC and CD in path A-B-D, $\frac{800}{900} = 0.88$ and $\frac{500}{900} = 0.55$ for link AE, ED in path A-E-D.

- **Weight Mechanism used is Capacity**

Table I: Path selection according to Average Scoring Criterion.

Paths (P)	Available Capacity (C_i)	Average Capacity (S_a^C)	Preference Order
A-D	1	1	I
A-B-C-D	1, 1, 0.66	0.88	II
A-B-D	1, 0.003	0.5015	IV
A-E-D	0.88, 0.55	0.715	III

1) **Average Scoring Criterion**: In the average scoring criterion, the score of paths between source A and destination D is calculated by taking the mean of the capacity of individual links in a path as shown in Fig. 2.

$$S_a^C = \left(\frac{T_c}{N_l}\right) \tag{2}$$

where S_a^C, T_c, and N_l are the score when the link weight is C and the scoring criteria used is average, the total available capacity in all the links of the path, and the total number of links in the path. For example, the average capacity (S_a^C) for the path A-B-C-D is calculated as $\frac{1+1+0.66}{3} = 0.88$. From Table I, the sorted paths that will be used for searching of resources are A-D, A-B-C-D, and A-E-D respectively.

2) **Minimum Scoring Criterion**: In the minimum scoring criterion, the minimum value of capacity among all the links in a path is found and is used as a criterion to arrange the possible paths in decreasing order of capacity. Paths that have a lower capacity score will be given the lowest preference in sorting. For example the minimum capacity for the path A-B-C-D, S_m^C is found as min(1,1,0.66) = 0.66. From Table II, the sorted paths that will be used for searching for resources are A-D, A-B-C-D, and A-E-D.

Table II: Path selection according to Minimum Scoring Criterion.

Paths (P)	Available Capacity (C_i)	Minimum Capacity (S_m^C)	Preference Order
A-D	1	1	I
A-B-C-D	1, 1,0.66	0.66	II
A-B-D	1, 0.003	0.003	IV
A-E-D	0.88, 0.55	0.55	III

III. CLEAR: Non-linear Impairment-aware Resource Allocation Algorithm for MB-EONs

The CLEAR algorithm (psuedocode shown in Algorithm 1) calculates possible paths from the source to destination whenever a connection request $C_r(s, d, bw_r, t_a, t_h)$ arrives at s for d with a bandwidth requirement of bw_r with t_a and t_h as its arrival and holding time respectively. The next step involves the calculation of the weight of each link on the possible paths based on distinct weight mechanisms.

The computed routes are thereafter arranged in a decreasing order value according to the selected scoring criteria, namely average, minimum, maximum, and sum. The three best routes (K=3) are then used to search for resources. The resource checking will start from the

Table III: Parameters used for GSNR calculation. [11]

Parameters	Values
P	-3dBm (C Band)
P	-1.5dBm (L Band)
f_{end}	196.04 (THz)
$f_{start} - C$	191.08 (THz)
$f_{start} - L$	184.62 (THz)
Δ	12.5 (GHz)
$Total - FS$	916
n_{sp}	1.5
h	6.626 $\times$ 10^{-34} (J.s)
α	0.046 $\times$ 10^{-3} (Neper/m)
L_s	80 (Km)
β_2	-21.6 $\times$ 10^{-15} (ps^2)/Km)
β_3	0.144 $\times$ 10^{-15} (ps^3/Km)
γ	1.21 $\times$ 10^{-3} (1/W.m)
C_r	0.028 $\times$ 10^{-3} (1/W.Km.THz)

path (k=1) with the highest modulation format $m = 5$ (i.e., the highest threshold value of GSNR) in order to maintain the QoT of the signal. Here, GSNR is signal-to-noise ratio of the connection request and is calculated using (3):

$$GSNR^r = \frac{P}{P^r_{ASE} + P^r_{NLI}}, \tag{3}$$

where P, P^r_{ASE} and P^r_{NLI} are the launch power, Amplified Spontaneous Emission noise (ASE), and Non-linear interference (NLI) noise power of request r, respectively.

The total ASE and NLI noise power of each request is computed using (4) and (5) [10]:

$$P^r_{ASE} = \sum_{l \in p^r} \sum_{s=1}^{N_l} 2 n_{sp} h f_r B_r (e^{\alpha L^l_s} - 1). \tag{4}$$

Here p^r, N_l, n_{sp}, h, f_r, B_r, α, L^l_s are the selected route for request r, total number of spans in link l, spontaneous emission factor, Planck's constant, center frequency of request r, bandwidth of request r, fiber attenuation coefficient and length of s^{th} span in link l.

$$P^r_{NLI} = \sum_{l \in p^r} P^{r,l}_{SCI} + P^{r,l}_{XCI}. \tag{5}$$

Here, SCI and XCI are the self-channel and the cross-channel interference of request r in the link l of the selected path and they are computed using (6) and (7). The parameters used for GSNR calculation are listed in Table III and the GSNR threshold values for each modulation format are listed in Table IV.

The required number of spectrum slots is calculated using (8).

$$SS_r(m,k) = \left\lceil \frac{bw_r}{12.5 \times 3 \times \eta_k} \right\rceil \times 3. \tag{8}$$

Table IV: GSNR thresholds for different modulation formats. [12]

Modulation level	Modulation Format	GSNR Threshold (dB)
1	BPSK	12 dB
2	QPSK	16 dB
3	8-QAM	18.6 dB
4	16-QAM	21.6 dB
5	32-QAM	24.6 dB

Algorithm 1 CLEAR: NLI-aware Resource Allocation Algorithm for MB-EONs

Input: Network Topology $G(N, L)$, Connection request $C_r(s, d, bw_r, t_a, t_h)$

Output: Established connection request

1: Connection request arrives $C_r(s, d, bw_r, t_a, t_h)$
2: Compute all possible paths between s and d
3: Update the weight of links L_w of all possible paths using the selected weight mechanism S_i
4: Compute the score of all possible paths according to selected scoring criteria
5: Sort the paths in decreasing value of the calculated score
6: Find three best paths among all possible paths
7: **for** each path k = 1, 2, 3 **do**
8:     **for** each modulation format m = 5, 4, 3, 2, 1 **do**
9:         **if** resources available and satisfy the constraints **then**
10:             Calculate GSNR for selected m
11:             **if** GSNR of current request and existing connections are satisfied **then**
12:                 Assign the spectrum and establish connection
13:             **else**
14:                 Decrease the value of modulation format m
15:             **end if**
16:         **end if**
17:     **end for**
18:     Continue the steps 8-14 for next best path
19:     **if** resources checked in all the paths **then**
20:         Connection Blocked
21:     **else**
22:         **continue**
23:     **end if**
24: **end for**

where η_k is the spectral efficiency. We employ the first-fit spectrum allocation policy in our study, which searches for resources from the first-index spectrum slot. The C_r will occupy the spectrum if the resources available in the path satisfy the spectrum continuity, con-

$$P_{SCI}^{r,l} = N_l \frac{8}{81}\frac{\gamma^2 P^3}{\Pi\alpha^2}\frac{1}{\phi_d B_r^2}\left[\frac{(2\alpha - D^l P C_r f_r)^2-\alpha^2}{\alpha}\text{asinh}\left(\frac{3\Pi}{2\alpha}\phi_r B_r^2\right) + \frac{4\alpha^2-(2\alpha-D^l P C_r f_r)^2}{2\alpha}\text{asinh}\left(\frac{3\Pi}{4\alpha}\phi_r B_r^2\right)\right] \tag{6}$$

$$P_{XCI}^{r,l} = N_l \frac{16}{81}\frac{\gamma^2 P^3}{\Pi^2\alpha^2}\sum_{r'}\frac{1}{\phi_{r,r'} B_{r'}}\left[\frac{(2\alpha - D^l P C_r f_{r'})^2-\alpha^2}{\alpha}\text{atan}\left(\frac{2\Pi^2}{\alpha}\phi_{r,r'} B_r\right) + \frac{4\alpha^2-(2\alpha-D^l P C_r f_{r'})^2}{2\alpha}\text{atan}\left(\frac{\Pi^2}{\alpha}\phi_{r,r'} B_r\right)\right] \tag{7}$$

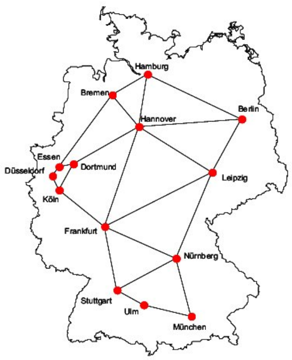


Figure 3: DT-12 Network.

tiguity, and GSNR threshold constraints. If the resources are available and the GSNR requirement is not met, then the resources will be checked for the next lower modulation format $m = 4$.

Resources will be checked in the first path for all the modulation format values until they satisfy the GSNR constraints. If resources are unavailable or if the GSNR requirements are not met then the resources will be searched in the next best path (k=2) . In case none of the three best paths satisfies the constraints pertaining to resource availability, spectrum continuity and contiguity, and GSNR threshold value, then the C_r will be blocked.

IV. Network Model and Simulation Results

We evaluate the performance of CLEAR on the DT-12 network topology consisting of 14 nodes and 23 bi-directional links shown in Fig. 3 [13]. The considered links use conventional single core fiber with each link comprising 916 spectrum slots (320 for C and 596 for L band).

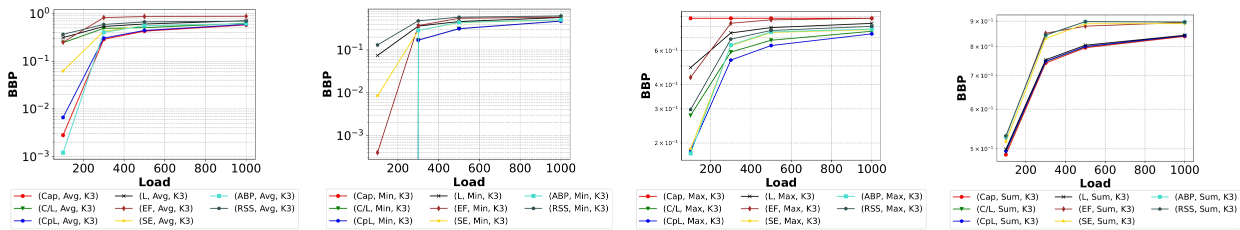
Each spectrum slot has a slot width of 12.5 GHz. The arrival process of 100Gb/s requests is Poisson distributed and the holding time follows exponential distribution with requests evenly distributed over all the nodes of the topology. The traffic load is expressed as $\frac{\lambda}{\mu}$, where λ and $\frac{1}{\mu}$, denote the average arrival rate and average holding time respectively. In our work, five modulation formats—BPSK, QPSK, 8-QAM, 16-QAM, and 32-QAM—are taken into consideration. The simulations are performed for 75k connection requests over 5 iterations with four load values. Results were observed once the system reached a steady state, defined as six times the average holding time after the experiment began. Bandwidth Blocking Probability (BBP), defined as the ratio of bandwidth of blocked requests to total bandwidth of arrived requests, is used as the performance metric.

Fig. 4a - Fig. 4d shows the variation in blocking performance for different schemes when $K = 3$. In Fig. 4a - Fig. 4d, we observe the blocking performance for each scoring criteria with all the considered link weights. In addition, we get the best algorithm in Fig.4a - Fig. 4d and plot the same variant with $K = 1$.

We finally combined all the better performing algorithms in each case and compared them together to see the difference in performance. We also compared the performance of traditional K-shortest path algorithm when $K = 1$ (KSP, K1) and when $K = 3$ (KSP, K3). The comparison of BBP for all these cases is shown in Fig. 5. We observe that we can achieve better performance with K=1 when we select average scoring mechanism with capacity as a weight. This shows that we can lower down the computational complexity in resource selection leading to low latency and still achieve better performance.

V. Conclusion

Optical networks play a crucial role in transporting large volume of information produced by 6G IoT devices and for efficiently managing the spectrum resources. MB-EONs have been studied in recent years to address the capacity scarcity issue due to large amount of traffic, and it is essential to account for impairments in the RMBSA problem for managing the spectrum resources efficiently. Consequently, CLEAR, an NLI- aware RMBSA algorithm utilizing several types of link weights and scoring mechanisms, has been proposed. The simulation performed considers two types of routes available for resource checking, first three best paths ($K = 3$) and the first best path ($K = 1$) for all the link weights and scoring techniques. In this work we have found that we can achieve better



(a) scoring mechanism: avg (b) scoring mechanism: min (c) scoring mechanism: max (d) scoring mechanism: sum

Figure 4: Variation of BBP versus load for different scoring mechanisms.

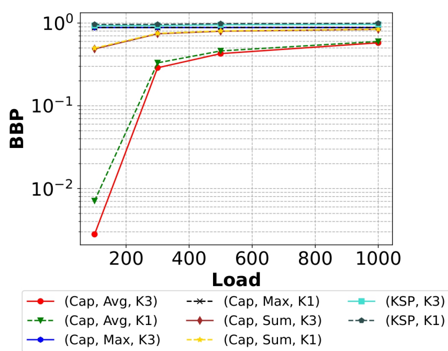


Figure 5: Variation of BBP with respect to load values for different link weights and scoring mechanism for K = 3 paths and K = 1 paths.

performance with only one path per connection request when capacity is used as a weight as compared to three paths per connection request when we use length as a weight. This is due to the effect of weight on the overall performance of the network. When we select capacity as weight, we tend to choose paths that offer better resources each time. However, weights such as length do not deliver such information to make informed decisions. Our proposed method, with capacity as the weight, outperforms all other variations and exhibits lower blocking as compared to traditional benchmark techniques.

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References

[1] N. Sambo, A. Ferrari, A. Napoli, N. Costa, J. Pedro, B. Sommerkorn-Krombholz, P. Castoldi, and V. Curri, "Provisioning in multi-band optical networks," *Journal of Lightwave Technology*, vol. 38, no. 9, pp. 2598–2605, 2020.

[2] R. K. Jana, B. C. Chatterjee, A. P. Singh, A. Srivastava, B. Mukherjee, A. Lord, and A. Mitra, "Quality-aware resource provisioning for multiband elastic optical networks: a deep-learning-assisted approach," *Journal of Optical Communications and Networking*, vol. 14, no. 11, pp. 882–893, 2022.

[3] F. Calderón, A. Lozada, P. Morales, D. Bórquez-Paredes, N. Jara, R. Olivares, G. Saavedra, A. Beghelli, and A. Leiva, "Heuristic approaches for dynamic provisioning in multi-band elastic optical networks," *IEEE Communications Letters*, vol. 26, no. 2, pp. 379–383, 2021.

[4] L. Shen, N. Feng, Y. Liu, D. Yan, J. Lv, J. Hu, D. Ren, and J. Zhao, "Isrs impact-reduced routing, modulation, band, and spectrum allocation algorithm in c+ l-bands elastic optical networks," *Optical Fiber Technology*, vol. 82, p. 103640, 2024.

[5] Q. Yao, H. Yang, B. Bao, J. Zhang, H. Wang, D. Ge, S. Liu, D. Wang, Y. Li, D. Zhang, *et al.*, "Snr re-verification-based routing, band, modulation, and spectrum assignment in hybrid c-c+ l optical networks," *Journal of Lightwave Technology*, vol. 40, no. 11, pp. 3456–3469, 2022.

[6] W. Zhang, S. Yin, L. Liu, Y. Chai, and S. Huang, "Dynamic resource allocation algorithm based on periodic alternation of bands in c+ l+ s-bands eons," in *2022 Asia Communications and Photonics Conference (ACP)*, pp. 1215–1218, IEEE, 2022.

[7] V. Lohani, A. Sharma, Y. N. Singh, K. Akansha, B. S. Heera, and P. Athe, "Optical networks," 2024.

[8] P. Lechowicz, M. Tornatore, A. Włodarczyk, and K. Walkowiak, "Fragmentation metrics and fragmentation-aware algorithm for spectrally/spatially flexible optical networks," *Journal of Optical Communications and Networking*, vol. 12, no. 5, pp. 133–145, 2020.

[9] P. Lechowicz, M. Tornatore, A. Włodarczyk, K. Walkowiak, *et al.*, "Fragmentation-aware algorithm with bordering superchannels in spectrally/spatially-flexible optical networks," *Journal of Optical Communications and Networking*, vol. 12, pp. 133–145, 2020.

[10] M. Mehrabi, H. Beyranvand, and M. J. Emadi, "Multi-band elastic optical networks: inter-channel stimulated raman scattering-aware routing, modulation level and spectrum assignment," *Journal of Lightwave Technology*, vol. 39, no. 11, pp. 3360–3370, 2021.

[11] S. Petale, S.-C. Lin, M. Matsuura, H. Hasegawa, and S. Subramaniam, "Prodigy: A progressive upgrade approach for elastic optical networks," in *GLOBECOM 2023-2023 IEEE Global Communications Conference*, pp. 2129–2134, IEEE, 2023.

[12] A. Kumari, S. Petale, V. Lohani, S. Subramaniam, S. K. Bose, and Y. N. Singh, "Rmbsa algorithm using link removal strategy in multi-band elastic optical network," in *2023 IEEE International Conference on Advanced Networks and Telecommunications Systems (ANTS)*, pp. 1–6, 2023.

[13] S. Petale, J. Zhao, and S. Subramaniam, "TRA: an efficient dynamic resource assignment algorithm for MCF-based SS-FONs," *Journal of Optical Communications and Networking*, vol. 14, no. 7, pp. 511–523, 2022.