Optical Fiber Technology 58 (2020) 102247

Contents lists available at ScienceDirect

Optical Fiber Technology

journal homepage: www.elsevier.com/locate/yofte

Performance of routing and spectrum allocation approaches for multicast traffic in elastic optical networks

Panchali Datta Choudhury[a,*], P.V. Rakesh Reddy[a], Bijoy Chand Chatterjee[b], Eiji Oki[c], Tanmay De[a]

[a] Department of Computer Science, National Institute of Technology Durgapur, India
[b] Department of Computer Science, South Asian University, New Delhi, India
[c] Graduate School of Informatics, Kyoto University, Kyoto, Japan

ARTICLE INFO

Keywords:
Elastic optical networks
Light-tree
Multicast
Routing
Spectrum allocation

ABSTRACT

In this paper, we investigate routing and spectrum allocation (RSA) approaches in elastic optical networks for multicast traffic demands. We consider that a light-tree is constructed for each multicast traffic demand and spectrum is allocated to this light-tree using the first-fit spectrum allocation policy. We present an approximation based Steiner tree approach for RSA (STA-RSA) and compare it with the shortest path tree based routing and spectrum allocation (SPT-RSA) to show the benefits of STA-RSA over SPT-RSA. The numerical results show that the presented approach outperforms the traditional approaches in terms of bandwidth blocking probability.

1. Introduction

Elastic optical networks (EONs) have been considered as a promising solution for high-speed networks that meet the exponential increase of Internet applications having high bandwidth requirement [1,2]. Routing and spectrum allocation (RSA) is defined as follows: given a network topology and a set of traffic demands, find a route for each traffic demand and allocate a number of required spectrum slots, so that spectrum utilization is enhanced [3].

Nowadays, a point-to-multipoint transmission is more popular because most Internet applications are multicast in nature having one source and multiple destinations. Some examples of popular multicast services are ultra-high-definition TV, video conferencing, scientific computing and data backup, etc. Multicast traffic is provisioned by utilizing a light-tree approach [4] for RSA instead of the light-path based approach [5], which is preferred for point-to-point services. Each multicast traffic follows two steps: (i) construction of a multicast tree and (ii) allocation of spectral resources to links of the tree. Typically, shortest path tree-based routing and spectrum allocation (SPT-RSA) approaches are considered for multicast tree construction [6,7].

The SPT-RSA approach is simple to implement but it has some drawbacks. It requires a higher number of hops to provision a traffic demand and it causes increased link cost. Since traffic demands traverse longer paths, this approach uses more spectrum resources.

To overcome the problem of the SPT-RSA approach, an approximation based Steiner tree approach for routing and spectrum allocation (STA-RSA) is presented, which is suitable for multicast traffic demands. A Steiner tree is constructed to route the multicast traffic, which is given as inputs in EONs. The Steiner tree problem is NP-complete [8], we use an approximation based approach to construct a Steiner tree. The first-fit spectral allocation policy [9] is adopted to allocate spectrum to the links of the constructed tree. We illustrate an example to show that the STA-RSA approach requires less link cost compared to the SPT-RSA based approach.

Simulation results on standard network topologies suggest that the STA-RSA approach requires less number of hops than the SPT-RSA approach, and hence it utilizes spectrum slots efficiently. The STA-RSA approach reduces the bandwidth blocking probability of multicast traffic demands compared to the SPT-RSA approach.

1.1. Related work

Multicast service provisioning and spectrum allocation in EONs have been studied by several researchers [10–16], which are discussed in the following.

In [10], the authors constructed a shortest path tree (SPT) by connecting every source–destination node pair with the shortest path. They use SPT as a routing technique to evaluate multicast traffic performance in EONs. The objective of using SPT is to minimize the delay between the source node and every destination node. The authors also use a minimum spanning tree based routing and spectrum allocation (MST-RSA) approach to find feasible routing paths for multicast traffic

* Corresponding author.

https://doi.org/10.1016/j.yofte.2020.102247
Received 28 November 2019; Received in revised form 5 March 2020; Accepted 14 April 2020

Table 1
Literature survey on different RSA approaches in EONs.

Reference	Summary
Wang et al. [10]	Two different service provisioning schemes for multicast traffic demands was presented and compared for fixed-grid optical networks and EONs.
Li et al. [11]	Software defined EONs was introduced for multicast service provisioning along with fragmentation aware schemes.
Fan et al. [12]	Sub-tree based routing, modulation and spectrum allocation in EONs.
Moharrami et al. [13]	Three different approaches for multicast traffic routing and spectrum allocation in EONs was presented.
Luo et al.[14]	A genetic algorithm based solution for routing, modulation level selection and spectrum allocation in EONs was presented.
Habibi et al. [15]	A MILP was formulated for solving impairment-aware routing, modulation level selection and spectrum assignment for manycast, multicast and unicast traffic in EONs.
Molnar et al. [16]	An ILP is presented to compute optimal multicast routes to support multicast data transmission.
Yao et al. [21]	A crosstalk-aware routing, spectrum, and core assignment approach was presented in SDM-EONs.
Yang et al. [22]	A dynamic resource assignment approach was introduced in SDM-EONs based on dynamic fuzzy clustering.
Yao et al. [23]	A transductive transfer learning based spectrum optimization was introduced for resource reservation in SDM-EONs.

demands. They simulate their provisioning approaches in EONs and fixed-grid optical networks. It is observed that the performance of these approaches in EONs is better compared to the fixed-grid optical networks.

Li et al. [11] investigated service provisioning for dynamic advance reservation multicast traffic demands in EONs and also studied fragmentation-aware schemes to handle two-dimensional fragmentation [17]. The results reveal that the introduced approach achieves a better performance in terms of blocking probability and average delay. In [12], the authors presented a sub-tree scheme for the routing, modulation, and spectrum allocation algorithm in EONs to improve spectrum utilization. According to the simulation results, the presented scheme achieves less blocking compared to the single-tree approach [18].

In [13], three variations of multicast routing and spectrum allocation approaches were introduced, which are (i) congestion based, (ii) distance adaptive based, and (iii) mixed that is a combination of previous two approaches. An integer linear programming (ILP) problem was formulated for static traffic, which provides an optimal solution but with significant computational complexity. The performance evaluation of the heuristic approaches suggests that the mixed approach reduces the blocking probability compared to the other two approaches.

The work in [14] presented a genetic algorithm-based solution for routing, modulation level and spectrum allocation in EONs for manycast traffic demands. For static network planning in EONs, an ILP model was presented to obtain an optimal solution while the heuristic solution is suited for large scale networks. The heuristic approach tries to jointly optimize the following: suitable modulation adaptation, spectrum allocation, light-tree construction, and destination nodes selection. In the dynamic scenario, the presented heuristic approach reduces the blocking probability to a significant extent compared to standard algorithms [19,20].

The authors in [15] presented a mixed-integer linear programming (MILP) formulation for an impairment-aware routing, modulation level and spectrum assignment scheme that could serve manycast, multicast, and unicast traffic and also presented heuristic approaches for solving the same for large-scale networks. The simulation results of the presented heuristic approach are comparable to the MILP solutions. The performance of the presented heuristic approach in terms of spectrum consumption is better compared to the modulation adaptive approach. In [16], the authors focus on the design of data-center based content distribution and consider heterogeneous EONs. A set of light-hierarchies is found, which constitute an optimal route. An ILP model is also presented in this paper to optimally find the set of light hierarchies initiated from different data-centers and that supports the delivery of multicast contents to end-users.

Recently, space-division multiplexing (SDM) technology has been incorporated with EONs to enhance the capacity, where inter-core crosstalk is one of the major limitations for quality of transmission. To overcome the inter-core crosstalk issue in space division multiplexing based elastic optical networks (SDM-EONs), the work in [21] presented a crosstalk-aware routing, spectrum, and core assignment approach to enhance spectrum utilization.

In [22], the authors introduced a dynamic resource assignment approach in SDM-EONs to enhance resource utilization. This approach is based on unsupervised fuzzy clustering algorithms and considers both crosstalk and physical layer impairments. This approach finds all available resource combinations meeting the service transmission requirements. Fuzzy C-means and direct clustering algorithms are executed depending on the available resources sample scale.

The work in [23] presented an approach for resource reservation based on transfer learning in SDM-EONs to enhance resource utilization. Two types of requests, which are IR: Immediate Reservation and AR: Advance Reservation (requests that are reserved in advance), were studied. The IR request that fails to reserve resources, occupies the resources of AR requests with the latest start-time. If AR requests fail to reserve resources, a transductive transfer learning based approach is used for spectrum optimization until the available resources are found for AR requests before their start-time.

A significant number of studies on different RSA approaches for EONs have been reported in the literature, which is summarised in Table 1. Although there have been many findings regarding the RSA problem in EONs, specific problems concerning light-tree based RSA are still under-explored; most of the existing RSA approaches are based on light-path based routing. Multicast applications are wide-spread and so we present suitable light-tree based approaches for RSA problems dedicated to multicast applications.

2. Steiner tree based approach for multicast routing and spectrum allocation

This section presents an approximation based Steiner tree for routing and spectrum allocation of multicast traffic demands.

2.1. Overview

The STA-RSA approach consists of two phases, which are (i) routing phase: a Steiner tree is constructed and (ii) spectrum allocation phase. The routing phase is intended to reduce the overall link cost and the number of hops during route discovery for multicast traffic demands.

In the routing phase, the STA-RSA approach constructs a Steiner tree for each multicast traffic demand. This approach considers the source node and destination nodes as the points to be included, and hence a routing tree is generated from the source node to the destination nodes by selecting the minimum cost path. Since the type of traffic input is multicast in nature, the presented approach adopts a light-tree concept [4].

The second phase of the STA-RSA approach uses the Steiner trees constructed in the first phase for spectrum allocation; first-fit spectrum allocation is used for light-tree establishment. The detail steps of the STA-RSA approach for each multicast traffic demand is given in Algorithm 1.

2.2. Network model and assumptions

We define the network topology as a graph $G(V, E)$, which comprises of a set of nodes, denoted by V, and a set of fiber links, denoted by E. The fiber links are assumed to be bidirectional, such that two unidirectional fibers operate in opposite directions. Each link has an ordered set of spectrum slots, denoted by F. We consider multicast traffic demands, each of which is represented by the following tuple: (s, D', h, b), where s is the source, D' is a set of destinations, h is the holding time, and b is the requested bandwidth. Let R be the transmission reach in km and LR be the bit-rate in Gbps. The transmission reach in the network is determined using Eq. (1) [24].

$$R = 5584.6 - 804.3\ln(\mathrm{LR}) \tag{1}$$

Let Ω be the number of required spectrum slots for each traffic demand, Y_{slot} be the granularity of spectrum slot, and N_G be the number of slots used for guard band. The relation between modulation format and number of slots needed depending upon transmission reach, is determined using Eq. (2) [25].

$$\Omega = \left\lceil \frac{LR}{Y_{\mathrm{slot}}.\ m} \right\rceil + N_G \tag{2}$$

LR denotes the bit-rate requirement of a light-tree. In our model, we consider binary phase-shift keying (BPSK), 4-quadrature amplitude modulation (QAM), 8-QAM, 16-QAM, 32-QAM, and 64-QAM according to the lightpath length, where different modulation formats are specified by level $m = 1, 2, 3, 4, 5, 6$, respectively. Y_{slot} is considered as 12.5 Gbps.

Note that a less robust modulation format, such as quadrature phase shift keying (QPSK), carries twice the number of bits per symbol than a more robust modulation format, such as binary phase shift keying (BPSK), which means that the baud rate for QPSK is the half of BPSK. Typically, a less robust modulation format is used for shorter distance and a more robust one is used for longer distance [26]. The following assumptions are considered in our model.

- All nodes in the network are equipped with multicast capabilities, but without spectrum converting capabilities.
- The number of spectrum slots provided by links is the same.

Algorithm 1: An approximation based Steiner tree approach for routing and spectrum allocation.

Input: A multicast traffic demand $\{s, D'\}$.
Output: Spectrum allocation of the multicast traffic demand.
Step 1: Multicast routing tree construction:
1(a): Select the source node as the root; initially, the multicast tree contains only the root node.
1(b): Select each node d_i from destination set D', sequentially, and estimate the shortest path of each d_i from every node of the tree.
1(c): Select the node $d_i \in D'$ having the minimum value of path length among all the shortest paths estimated in Step 1(b), and select the node x of the tree to which selected node d_i has the lowest shortest path.
1(d): Add a path between selected node $d_i \in D'$ and the node x of the tree.
1(e): Mark the node d_i in D'.
1(f): Repeat Step 1(b) to Step 1(e) until all nodes in D' are marked.
Step 2: Spectrum allocation:
2(a): If spectrum continuity and contiguity constraints are satisfied, go to Step 2(b), and otherwise go to Step 2(c).
2(b): Assign the required spectrum slots to all links of the tree using the first-fit policy.
2(c): Block the traffic demand.

2.3. Demonstration of Algorithm 1

We consider a network that consists of six nodes and eight bi-directional physical links, as shown in Fig. 1; each link has 13 slots. To demonstrate the steps of Algorithm 1, we consider a traffic demand $\{A, \{B, C\}\}$, where the source is node A and the destinations are nodes B and C; the number of required slots is three. According to step 1, source node A is selected as the root of multicast tree T (initially, T contains only node A, as shown in Fig. 2(a)). In step 1(b), the shortest path between destination node B and node A of T is determined. Next, the shortest path between destination node C and node A of T is determined. According to step 1 (c), the node in destination set and the node of T, which provides the lowest distance is selected. In this example, the destination node B and destination node C have the same shortest path from node A of T, so any one of them is randomly selected, here, B is selected. In general, the node in the destination set, which provides the lowest distance from tree T, is selected.

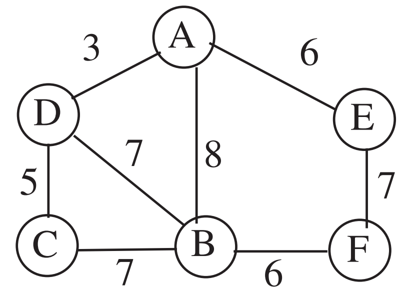


Fig. 1. Sample physical network with link cost.

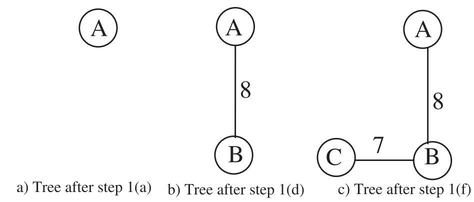


Fig. 2. Step-wise explanation of the tree construction phase of the STA-RSA approach.

In step 1 (d), the path between node B and node A is added to T as shown in Fig. 2b) and and node B is now marked in the destination set according to step 1 (e).

According to step 1 (f), steps 1 (b) to 1 (e) are repeated until all nodes in the destination set are marked. The shortest distance from node C to tree T is estimated. As the destination node C is closer to node B of T than node A of T, the shortest distance from node C to node B is added to T. Thus, node C is marked in the destination set. Tree construction stops when all nodes in the destination set are marked. The completed tree is shown in Fig. 2(c).

The spectrum allocation are described in step 2. In step 2 (a), the required spectrum slots are searched according to spectrum continuity and contiguity constraints. In our example, three adjacent spectrum slots are searched in link $A - B$ and link $B - C$ of the multicast tree constructed in step 1. If the required continuous and contiguous spectrum slots are available, the slots are allocated using the first-fit spectrum allocation policy, which is stated in step 2 (b). If the continuous and contiguous spectrum slots are not available, the traffic demand is blocked; this is stated in step 2 (c). The spectrum allocation for the traffic demand considered in this demonstration is shown by traffic demand 1 in Fig. 6.

2.4. Advantages of STA-RSA over SPT-RSA

We demonstrate the benefit of the presented STA-RSA approach with an example. For this purpose, we consider the same network, as shown in Fig. 1. The traffic demands used in this example are shown in Table 2; we consider four multicast traffic demands.

Fig. 3 shows the routes of the multicast traffic demands, which are obtained using the SPT-RSA approach [10]. The routes of the multicast traffic demands using the presented STA-RSA approach are shown in

Table 2
Sample input traffic demands.

Multicast traffic	Source	Destinations	Requested slots
1	A	B, C	3
2	A	B, F	4
3	D	E, F	2
4	F	A, D	4

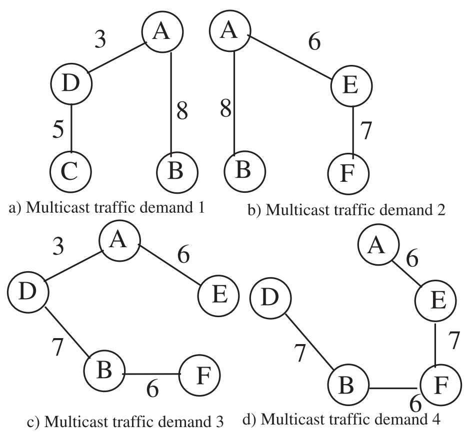


Fig. 3. Multicast tree for different traffic demands using SPT-RSA approach.

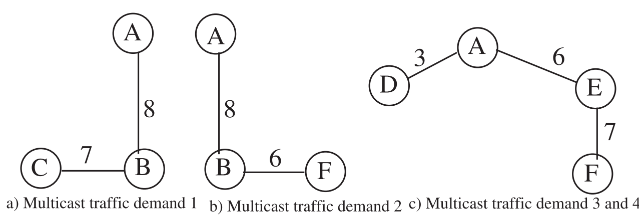


Fig. 4. Multicast tree for different traffic demands using STA-RSA approach.

Table 3
Routing path cost of multicast traffic demands.

Multicast traffic	SPT-RSA scheme	STA-RSA scheme
1	16	15
2	21	14
3	22	16
4	26	16

Fig. 4. The link cost of each traffic demand after routing using both schemes is shown in Table 3; the STA-RSA approach reduces link cost for each traffic demand compared to the SPT-RSA approach.

Figs. 5 and 6, respectively, demonstrate the spectrum allocation using the SPT-RSA approach and the STA-RSA approach. We notice that the STA-RSA approach requires a less number of spectrum slots compared to the SPT-RSA approach, and hence the spectrum utilization using the STA-RSA approach is improved compared to the SPT-RSA approach.

2.5. Time complexity

In the following, we analyze the computational time complexity of Algorithm 1. The time complexity in step 1(a) to select the source node as the root of the initially constructed tree is $O(1)$. Step 1(b) estimates the shortest path of each destination in the destination set from every node of the tree. The shortest path between two nodes is calculated using Dijkstra's algorithm [27], and hence the worst case time complexity of step 1(b) is $O(|D'||E|\log|V|)$. The worst case time complexity to select node d_i in D' and the node of the tree, which provides lowest distance among shortest paths using step 1(c) is $O(|V|)$. Steps 1(d) and 1(e) is performed in constant time. The overall worst case time complexity of step 1 is $O(|D'|^2|E|\log|V| + |D'||V|)$.

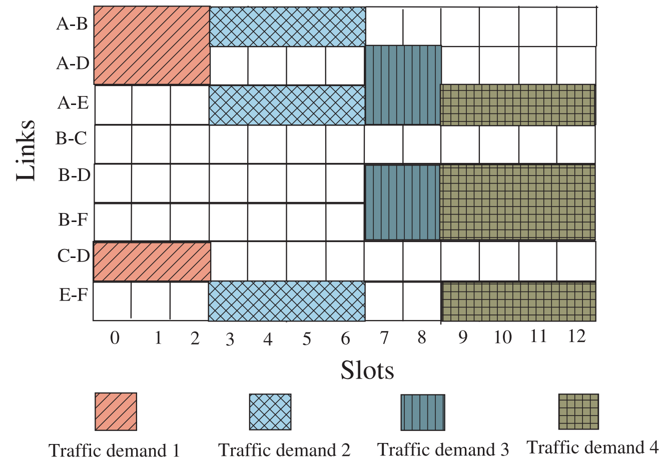


Fig. 5. Spectrum allocation of multicast traffic demands using SPT-RSA scheme.

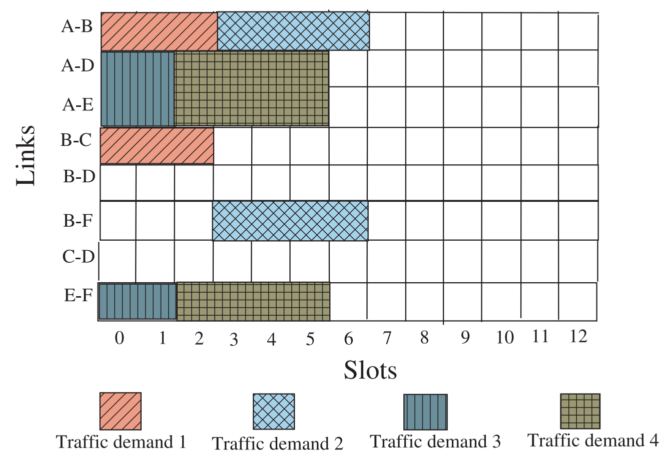


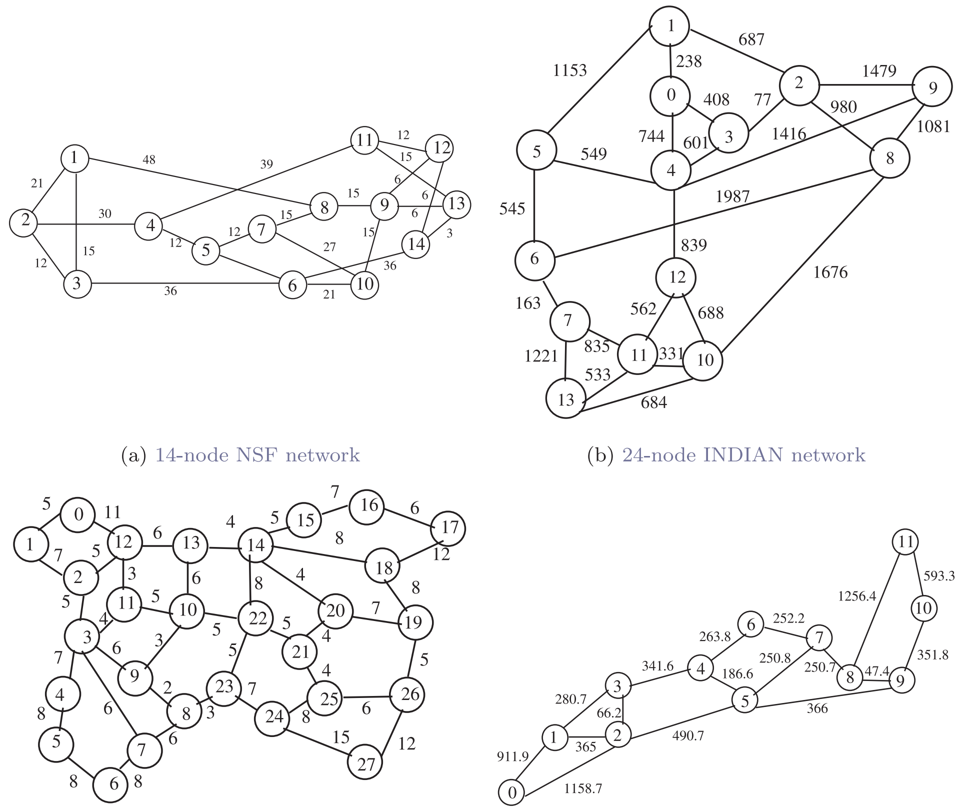
Fig. 6. Spectrum allocation of multicast traffic demands using STA-RSA scheme.

Let M represents the set of modulation techniques and the time complexity to estimate the number of required spectrum slots considering different modulation techniques for a traffic demand is $O(|M|)$. The worst case time complexity to perform spectrum allocation of a multicast traffic demand using step 2 is $O(|F||E||M|)$.

Therefore, the overall worst case time complexity of Algorithm 1 is $O(|D'|^2|E|\log|V| + |D'||V| + |F||E||M|)$.

3. Performance analysis

The presented approach is evaluated in this segment. The standard network topologies, namely the national science foundation (NSF) network with 14 nodes [28], INDIAN network with 14 nodes [29], EUROPEAN network with 28 nodes [28], and JAPANESE network with 12 nodes [30] are used for simulation. The average node degrees of NSF network, Indian network, European network, and Japanese network are 3.14, 3.357, 2.82, and 2.83, respectively. The network topologies along with distance among nodes are shown in Fig. 7. For Fig. 7(a) and (c), the number on each link of the networks corresponds to the distance between two nodes as a multiple of 100 km. For Fig. 7(b) and (d), the number on each link of the networks corresponds to the distance in km between two nodes. We consider each fiber has 320 spectrum slots. We



(a) 14-node NSF network (b) 24-node INDIAN network

(c) 28-node EUROPEAN network (d) 12-node JAPANESE network

Fig. 7. The physical network topologies.

consider both sub-wavelength and super-wavelength traffic demands. The bandwidth requirement for each traffic demand lies in set of {10, 40, 100, 400, 1000} Gbps.

The multicast traffic demands are generated randomly based on a Poisson distribution process with arrival rate λ and the holding time of traffic demands follows an exponential distribution ($H = 1/\mu$). The network load is a term used to measure the load in the network at a particular instance of time. If δ_t is the number of traffic demands per unit time and A_h is the average holding time, then the network load is defined as: $\text{Network load} = \delta_t \times A_h$. The simulation results computed are the average of 100 iterations. The algorithms compared here are SPT-RSA, MST-RSA, and STA-RSA. For the bandwidth blocking probability, simulation results are obtained with a 90% confidence interval that is within 2% of the reported average results for the STA-RSA approach, within 3% for the MST-RSA approach and within 4% for the SPT-RSA approach.

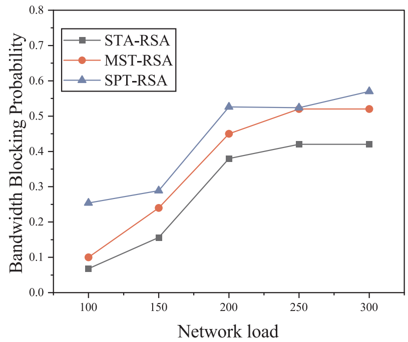
The bandwidth blocking probability is defined as the amount of bandwidth blocked over the amount of bandwidth offered in the network. The routing and spectrum allocation approaches are compared based on their bandwidth blocking probabilities. The relationship between bandwidth blocking probability and the network load is shown in Fig. 8(a)–(d) for NSF, INDIAN, EUROPEAN and JAPANESE networks respectively. We assume that the session size (number of destinations) is three. The results show that the STA-RSA approach has the least bandwidth blocking probability compared to SPT-RSA and MST-RSA approaches. In all the networks, the STA-RSA approach can reduce bandwidth blocking probability compared to MST-RSA and SPT-RSA based approaches.

The STA-RSA approach outperforms the other approaches because it utilizes an efficient routing strategy compared to SPT-RSA and MST-RSA approaches, and hence the possibility of getting available slots through the routing path is higher. As a result, the blocking of traffic demands become low.

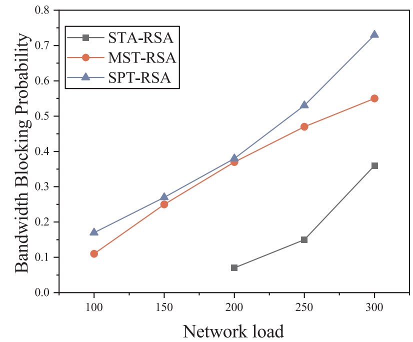
The relationship between the average hop count and network load is shown in Fig. 9(a)–(d), for NSF, INDIAN, EUROPEAN and JAPANESE networks respectively; the session size is considered three. The average hop count indicates the average number of hops (number of links per light-tree) traversed by a set of multicast traffic demands. In all the networks, the MST-RSA approach reduces the average hop count compared to the STA-RSA approach and the STA-RSA approach reduces the average hop count compared to the SPT-RSA approach. The performance evaluation of different routing approaches reveals that the MST-RSA approach has the lower number of average hop count, because constructing the MST-RSA approach is simpler compared to the STA-RSA approach, and the STA-RSA approach has slightly higher average hop count than that of the MST-RSA approach. The SPT-RSA has the highest average hop count because it traverses more hops compared to both MST-RSA and STA-RSA approaches.

It is observed that the MST-RSA approach has the lowest average hop count, while STA-RSA outperforms MST-RSA in terms of bandwidth blocking probability. This is because MST-RSA uses a fixed set of nodes in the routing tree of all traffic demands. For a particular traffic demand, the routing tree does not have much variations in the links; the same links are used frequently, which causes a load on a particular link to be high. After serving some traffic demands, there is a possibility that the required bandwidth of a new incoming traffic demand is unavailable in the higher load links of its routing tree, thus resulting in blocking of that traffic demand. On the other hand, in STA-RSA, the bandwidth blocking probability is lower than MST-RSA. This is because, in STA-RSA, a variety of nodes are used in the routing tree, and hence the alternate routes are used during multicast-tree construction, which enhances spectrum utilization.

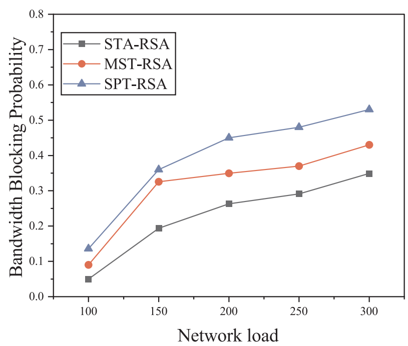
We investigate the average slot utilization, which is a function of network load, signifies how the slots are being utilized by the



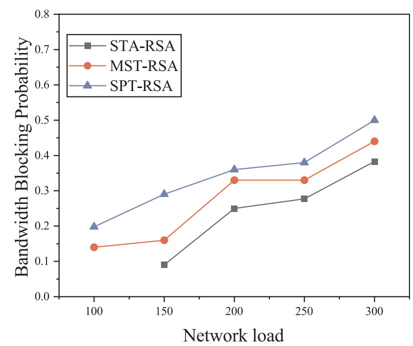
(a) NSF network.



(b) INDIAN network.

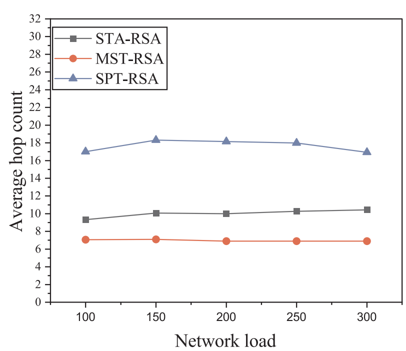


(c) EUROPEAN network.

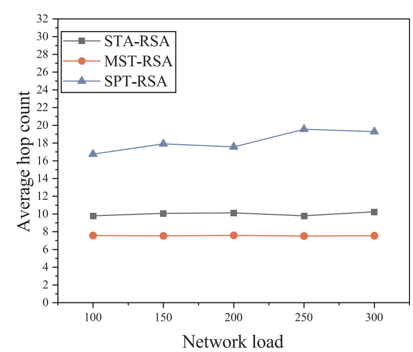


(d) JAPANESE network.

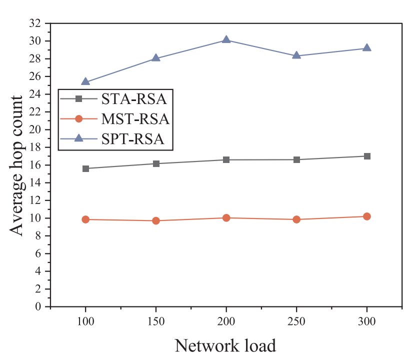
Fig. 8. Relationship between bandwidth blocking probability and network load.



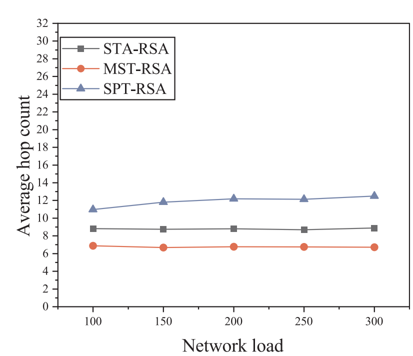
(a) NSF network.



(b) INDIAN network.

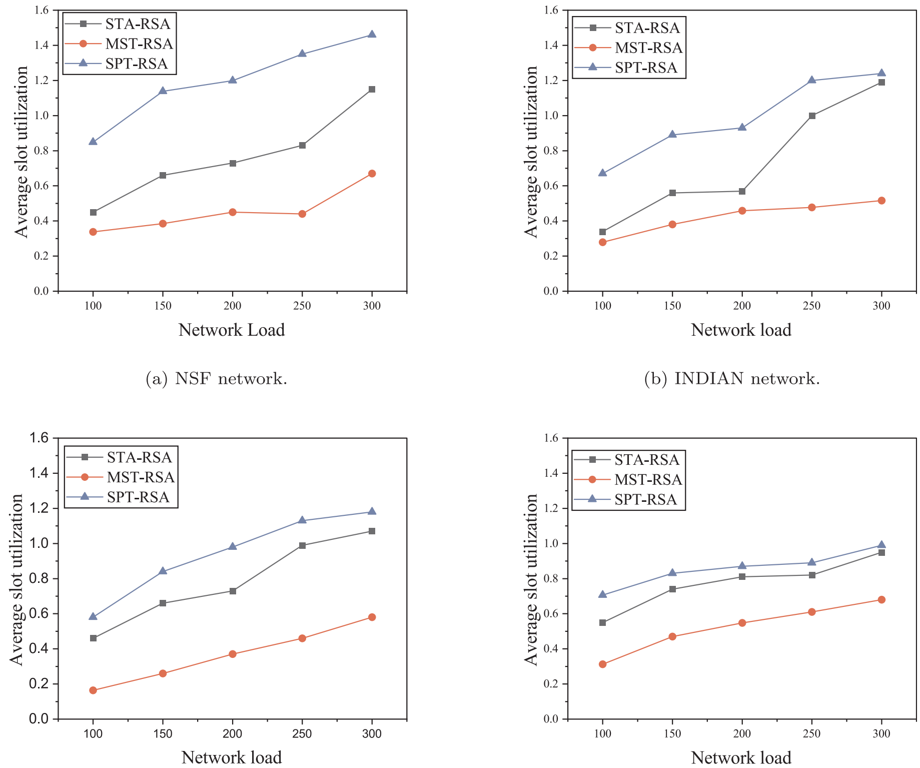


(c) EUROPEAN network.



(d) JAPANESE network.

Fig. 9. Relationship between average hop count and network load.



(a) NSF network. (b) INDIAN network.

(c) EUROPEAN network. (d) JAPANESE network.

Fig. 10. Relationship between average slot utilization and network load.

established traffic demands for a given network load. It is defined by the following formula [31]:

$$\text{Avg. slot utilization(network load)} = \frac{\text{Network load}\times\text{Avg. hop count}\times\text{Avg. slot count}}{|F| \times |E|},$$

where avg. slot count represents the average requested slots of the satisfied traffic demands. Fig. 10(a)–(d) illustrate the relationship between the average slot utilization and the network load in NSF, INDIAN, EUROPEAN and JAPANESE networks respectively. The average slot utilization is directly proportional to the average hop count, since the average hop count of the SPT-RSA approach is higher than those of the other two approaches, so the average slot utilization for SPT-RSA is higher than those of the STA-RSA and MST-RSA approaches for all the network topologies considered in our simulations.

We analyze the sensitivity of bandwidth blocking probability and average hop count used in the simulation process for STA-RSA, MST-RSA, and SPT-RSA approaches. The sensitivity analysis investigates how the changes in the output of a system is related to the changes in the input of that system. We use the sensitivity defined in [32], which is given by the ratio of changes in the output to changes in the input.

Table 4 show the sensitivity of bandwidth blocking probability with respect to network load for EUROPEAN, INDIAN and NSF networks. We observe that STA-RSA approach has least sensitivity value compared to MST-RSA and SPT-RSA concerning the bandwidth blocking probability parameter, which means for different input settings the simulation result (bandwidth blocking probability) for the STA-RSA do not vary abruptly compared to the other approaches. Generally, less sensitivity value implies that the presented approach is more robust.

Table 5 show the sensitivity of average hop count with respect to network load for EUROPEAN, INDIAN and NSF networks. We observe that the MST-RSA approach is the least sensitive concerning average hop count. The STA-RSA approach is moderately sensitive and SPT-RSA is the most sensitive among all approaches. It is inferred that, with changes in network load, the average hop count of the MST-RSA approach does not change abruptly. The STA-RSA approach gives moderate robustness and the STA-RSA approach is more robust than the SPT-RSA approach.

Table 5
Sensitivity of average hop count with respect to network load.

Scheme	Sensitivity		
	EURO	IND	NSF
STA-RSA	0.0341	0.0107	0.033
MST-RSA	0.0066	0.0011	0.004
SPT-RSA	0.1401	0.0624	0.044

Table 4
Sensitivity of bandwidth blocking probability with respect to network load.

Scheme	Sensitivity		
	EURO	IND	NSF
STA-RSA	0.0081	0.0035	0.0089
MST-RSA	0.0108	0.0100	0.0112
SPT-RSA	0.0118	0.0093	0.0069

Table 6
Sensitivity of average slot utilization with respect to network load.

Scheme	Sensitivity		
	EURO	IND	NSF
STA-RSA	0.01325	0.0154	0.0130
MST-RSA	0.00803	0.0063	0.0044
SPT-RSA	0.01586	0.0134	0.0208

Table 6 show the sensitivity of average slot utilization with respect to network load for EUROPEAN, INDIAN and NSF networks. We observe that the MST-RSA approach is the least sensitive concerning average slot utilization. The STA-RSA and SPT-RSA approaches are moderately sensitive. It is inferred that, with changes in network load, the average slot utilization of the MST-RSA approach does not change abruptly. The STA-RSA approach and SPT-RSA gives moderate robustness.

4. Conclusion

The elastic optical network paradigm has been explored by several researchers over the last few years, most of these research focused on minimizing spectrum utilization and reduced the bandwidth blocking probability of the traffic demands. Our work focused on solving the problem of traffic routing and spectrum allocation for multicast traffic demands. Three routing approaches were discussed, and their performances were analyzed concerning bandwidth blocking probability, average hop count and average slot utilization. It was observed the STA-RSA approach reduces bandwidth blocking probability compared to the SPT-RSA approach and the MST-RSA approach. Two more parameters: average hop count and average slot utilization, were also measured. The STA-RSA approach reduces average hop count and uses less spectrum slots as compared to the SPT-RSA approach.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work is supported in part by the Visvesvaraya PhD scheme, Sponsored by DeitY, MCIT, Govt. of India, Inspire Faculty Scheme, Department of Science and Technology, New Delhi, India, under Grant (DST/INSPIRE/04/2016/001316), and JSPS KAKENHI Grant No. 18H03230, Japan.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, athttps://doi.org/10.1016/j.yofte.2020.102247.

References

[1] M. Jinno, H. Takara, B. Kozicki, Y. Tsukishima, Y. Sone, S. Matsuoka, Spectrum-efficient and scalable elastic optical path network: architecture, benefits, and enabling technologies, IEEE Commun. Mag. 47 (11) (2009) 66–73.

[2] B.C. Chatterjee, E. Oki, Elastic Optical Networking Technologies: Fundamentals, Design, Control, and Management, CRC Press, 2020 (in press).

[3] S. Shirazipourazad, C. Zhou, Z. Derakhshandeh, A. Sen, On routing and spectrum allocation in spectrum-sliced optical networks, in: 2013 Proceedings IEEE INFOCOM, IEEE, 2013, pp. 385–389.

[4] L.H. Sahasrabuddhe, B. Mukherjee, Light trees: optical multicasting for improved performance in wavelength routed networks, IEEE Commun. Mag. 37 (2) (1999) 67–73.

[5] I. Chlamtac, A. Ganz, G. Karmi, Lightpath communications: an approach to high bandwidth optical wan's, IEEE Trans. Commun. 40 (7) (1992) 1171–1182.

[6] Z. Zhu, X. Liu, Y. Wang, W. Lu, L. Gong, S. Yu, N. Ansari, Impairment-and splitting-aware cloud-ready multicast provisioning in elastic optical networks, IEEE/ACM Trans. Netw. 25 (2) (2016) 1220–1234.

[7] C. Al Hasrouty, M.L. Lamali, V. Autefage, C. Olariu, D. Magoni, J. Murphy, Adaptive multicast streaming for video conferences on software-defined networks, Comput. Commun. 132 (2018) 42–55.

[8] R. M. Karp, Reducibility among combinatorial problems, in: Complexity of Computer Computations, Springer, 1972, pp. 85–103.

[9] A. Rosa, C. Cavdar, S. Carvalho, J. Costa, L. Wosinska, Spectrum allocation policy modeling for elastic optical networks, in: High Capacity Optical Networks and Emerging/Enabling Technologies, IEEE, 2012, pp. 242–246.

[10] Q. Wang, L. K. Chen, Performance analysis of multicast traffic over spectrum elastic optical networks, in: Optical Fiber Communication Conference, Optical Society of America, 2012, pp. OTh3B–7.

[11] S. Li, W. Lu, X. Liu, Z. Zhu, Fragmentation-aware service provisioning for advance reservation multicast in sd-eons, Opt. Express 23 (20) (2015) 25804–25813.

[12] Z. Fan, Y. Li, G. Shen, C. C.-K. Chan, Dynamic resource allocation for all-optical multicast based on sub-tree scheme in elastic optical networks, in: Optical Fiber Communication Conference, Optical Society of America, 2016, pp. W2A–50.

[13] M. Moharrami, A. Fallahpour, H. Beyranvand, J.A. Salehi, Resource allocation and multicast routing in elastic optical networks, IEEE Trans. Commun. 65 (5) (2017) 2101–2113.

[14] X. Luo, Y. Zhao, X. Chen, L. Wang, M. Zhang, J. Zhang, Y. Ji, H. Wang, T. Wang, Manycast routing, modulation level and spectrum assignment over elastic optical networks, Opt. Fiber Technol. 36 (2017) 317–326.

[15] M. Habibi, H. Beyranvand, Impairment-aware manycast routing, modulation level, and spectrum assignment in elastic optical networks, J. Opt. Commun. Netw. 11 (5) (2019) 179–189.

[16] M. Molnár, D.D. Le, J. Perelló, J. Solé-Pareta, C. McArdle, Multicast routing from a set of data centers in elastic optical networks, Opt. Switching Netw. 34 (2019) 35–46.

[17] B.C. Chatterjee, S. Ba, E. Oki, Fragmentation problems and management approaches in elastic optical networks: a survey, IEEE Commun. Surveys Tutor. 20 (1) (2017) 183–210.

[18] M. Ruiz, L. Velasco, Performance evaluation of light-tree schemes in flexgrid optical networks, IEEE Commun. Lett. 18 (10) (2014) 1731–1734.

[19] W. Run-Liu, Y. Yun-Hui, Research on shortest path tree algorithm for multicast routing, 2013 International Conference on Computational and Information Sciences, IEEE, 2013, pp. 1445–1448.

[20] M. R. S. Aghaei, Z. A. Zukarnain, A. Mamat, H. Zainuddin, A quantum algorithm for minimal spanning tree, in: 2008 International Symposium on Information Technology, vol. 3, IEEE, 2008, pp. 1–6.

[21] Q. Yao, H. Yang, Y. Zhao, R. Zhu, J. Zhang, J. Wu, Crosstalk-aware routing, spectrum, and core assignment in elastic optical networks with multi-core fibers, in: Asia Communications and Photonics Conference, Optical Society of America, 2016, pp. ATh2C–1.

[22] H. Yang, Q. Yao, A. Yu, Y. Lee, J. Zhang, Resource assignment based on dynamic fuzzy clustering in elastic optical networks with multi-core fibers, IEEE Trans. Commun. 67 (5) (2019) 3457–3469.

[23] Q. Yao, H. Yang, A. Yu, J. Zhang, Transductive transfer learning-based spectrum optimization for resource reservation in seven-core elastic optical networks, J. Lightwave Technol.

[24] A. Klekamp, U. Gebhard, F. Ilchmann, Energy and cost efficiency of adaptive and mixed-line-rate ip over dwdm networks, J. Lightwave Technol. 2 (30) (2012) 215–221.

[25] J. Zhao, B. Bao, B.C. Chatterjee, E. Oki, J. Hu, D. Ren, Dispersion based highest-modulation-first last-fit spectrum allocation scheme for elastic optical networks, IEEE Access 6 (2018) 59907–59916.

[26] B.C. Chatterjee, E. Oki, Dispersion-adaptive first–last fit spectrum allocation scheme for elastic optical networks, IEEE Commun. Lett. 20 (4) (2016) 696–699.

[27] T.H. Cormen, Introduction to algorithms, third ed., MIT Press, 2009.

[28] P.D. Choudhury, S. Bhadra, T. De, A brief review of protection based routing and spectrum assignment in elastic optical networks and a novel p-cycle based protection approach for multicast traffic demands, Opt. Switching Netw. 32 (2019) 67–79.

[29] B.C. Chatterjee, N. Sarma, P.P. Sahu, Priority based routing and wavelength assignment with traffic grooming for optical networks, IEEE/OSA J. Opt. Commun. Netw. 4 (6) (2012) 480–489.

[30] C. Lee, X. Cao, N. Yoshikane, T. Tsuritani, J.-K.K. Rhee, Scalable software-defined optical networking with high-performance routing and wavelength assignment algorithms, Opt. Express 23 (21) (2015) 27354–27360.

[31] S. Ba, B.C. Chatterjee, E. Oki, Defragmentation scheme based on exchanging primary and backup paths in 1 + 1 path protected elastic optical networks, IEEE/ACM Trans. Netw. 25 (3) (2017) 1717–1731.

[32] EduPristine: Sensitivity analysis: meaning, uses, methods of measurement,https://www.edupristine.com/blog/all-about-sensitivity-analysis/, accessed: 2019-06-24.