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RESEARCH ARTICLE

Multipath routing using genetic algorithm in elastic optical network

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Abstract Elastic optical networks (EON) are recognized as a promising approach to handle the increasing demands of Internet traffic in future optical networks, as they enable the efficient provisioning of connections with varying bandwidth requirements. EON's flexibility and efficiency are enhanced by aspects such as routing, modulation, and spectrum allocation. In this paper, routing and adaptive modulation are taken into account where a strategy for combining multipath routing with distance adaptive modulation format in EON based on a meta-heuristic approach called the Genetic algorithm (GA) has been proposed. Moreover, the proposed scheme enhances the EON flexibility while considerably reducing blocking probability. Further, to compare the effectiveness of multipath routing with GA and single-path routing with respect to blocking probability, two networks, NSFNET and DT14, are used in the simulation. The suggested approach outperforms other algorithms when used with distance adaptive modulation, providing the most optimal performance. This enables the system to perform better, enabling adaptability and flexibility while reducing the blocking probability.

Keywords Elastic optical network · Distance adaptive-modulation · Genetic algorithm · Multipath routing

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Introduction

As the Internet demand is exponentially growing with the advent of 5G services, there is a requirement of highly efficient and cost-effective solution of optical network that can provide good service provisioning. Elastic optical network (EON) is an advanced optical networking technology that offers significant scalability and versatility in providing spectrum as well as data rates to meet various traffic types [1, 2]. EON is based on three important techniques, i.e., routing, modulation and spectrum allocation [3, 4]. Some other key issues of EON are based on the amount of client traffic, bandwidth needed to meet demands, length of optical links which imply bandwidth adaptation, bit rate adaptation, and distance adaptation, respectively.

Routing and modulation format allocation is one of the important research problem in EON. Routing is the technique of determining the best and shortest path from source to destination in a network using an appropriate algorithm. Single path routing and multi-path routing approaches are two categories of routing. Single path routing, often known as unicast routing, is a network routing strategy that determines the optimal path for data to reach their destination. In single path routing, data is forwarded from the source to the destination along a single determined path. Path selection in single path routing is often based on a routing protocol or algorithm that takes into account numerous parameters such as network topology, link costs, and traffic conditions. The goal is to discover the shortest path with the least amount of latency, congestion, and other performance metrics. Single-path routing is appropriate for several scenarios where a direct path from the source to the destination is sought. However, it may not be useful in circumstances requiring fault tolerance, load balancing, or traffic engineering. In such instances, additional routing approaches such as multi-path

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routing or traffic engineering algorithms can be used. Multipath routing methods enable the source node to select the optimal path from among several options. The approach of multipath routing minimizes the amount of route searching activities provided there is a pool of routes available. In the event of a route failure, the alternate routes can be used to reduce the end-to-end latency [5]. The concurrent multipath transfer is an effective routing approach inspired by technological improvements in portable devices and wireless systems. This routing algorithm can be used to deliver high-quality mobile videos via a variety of access mediums [6]. In a dynamic environment, multipath routing algorithms can more flexibly utilize spectrum resources than single-path routing algorithms by partitioning a traffic request into multiple smaller size sub-connections and independently transmitting them through various optical channels [7]. Since EON includes multi-format transceivers, hence it is essential to incorporate modulation format adaptability. The choice of a modulation format assists in identifying the best modulation scheme with the highest spectral efficiency that can be used on a route with acceptable transmission quality. Inter-symbol interference (ISI), channel-noise, attenuation, and other factors all have an impact on modulation format performance, restricting the optical distance of the transmitted signal. Additionally, shorter routes could employ higher-order modulation techniques whereas larger connections can use lower-order modulation techniques.

The development and activation of light-paths on demand, on the other hand, is the next stage in the advancement of EONs, which is referred to as the dynamic scenario. Formulas for mathematics are impractical for dynamic EONs due to the requirement of large computing time. As a result, while dealing with dynamic routing, modulation and spectrum allocation (RMSA) difficulties, it is better to investigate approaches based on meta-heuristics algorithms. Genetic Algorithm (GA) is a meta-heuristic algorithm that simulates natural evolution in the actual world. [8]. It is a part of a larger class of evolutionary algorithms that create solutions to optimization issues. Since GA has minimal operational costs and is simple to set up and parallelize, it is utilized to tackle various optimization problems [9]. GA employs a population of solutions rather than a single solution, which significantly improves the algorithm's robustness. The assurance of genetic algorithms as an advanced optimization tool has recently generated much interest. In this research, innovative multipath routing algorithms with distance-adaptive modulation format technique using genetic algorithm in dynamic traffic circumstances has been investigated.

The major contribution of this research are given below:

1. Innovative multipath routing algorithms with distance-adaptive modulation format technique using genetic algorithm in dynamic traffic circumstances has been investigated.
2. The selection method used in GA is elitism, which is better as compared to other selection methods and considered to improve the efficiency of GA.
3. It is demonstrated that employing Genetic algorithm (GA) to combine multipath routing with distance-adaptive modulation format allocation can significantly reduce blocking probability and accommodate more connection requests with less computational cost.

Multipath routing with distance adaptive modulation in EON can be regarded as the genetic process in which the optimal path are searched, that can be realized by the process of selection, crossover and mutation. Multipath routing improves throughput and makes better use of network resources. In this process, first of all, multiple paths are computed and the best route is selected using GA and then the best modulation format is assigned to that route. Moreover, in this investigation, GA is applied, which is a computational technique used to identify effective solutions to issues. The basic approach of GA in networking [10] has been outlined below:

- Create the population, which is a collection of individual routes.
- The fitness function for each path is then calculated, and the best routes based on the fitness function are chosen to construct a new route, i.e., crossover operations are used to build new routes by rearranging the genetic information of the parents of the selected routes (children).
- The GA is terminated once a route with the optimal fitness value is found.

Figure 1 depicts a flowchart of the proposed algorithm.

The rest of the paper is organized in the following manner. After "Introduction" section, related work has been discussed in "Related work" section. "Numerical simulation" section focuses on the simulation and the parameters used in the simulation. In "Results" section, the results have been discussed and finally concluding remarks have been made in "Conclusion" section.

Related work

EON research focuses on developing routing and spectrum assignment algorithms that may optimally use existing spectrum resources, accommodate different traffic demands, and facilitate dynamic provisioning and reconfiguration of optical connections. Several researchers have addressed the RMSA problem from different perspectives. The authors of [11] have explored routing and spectrum allocation (RSA)

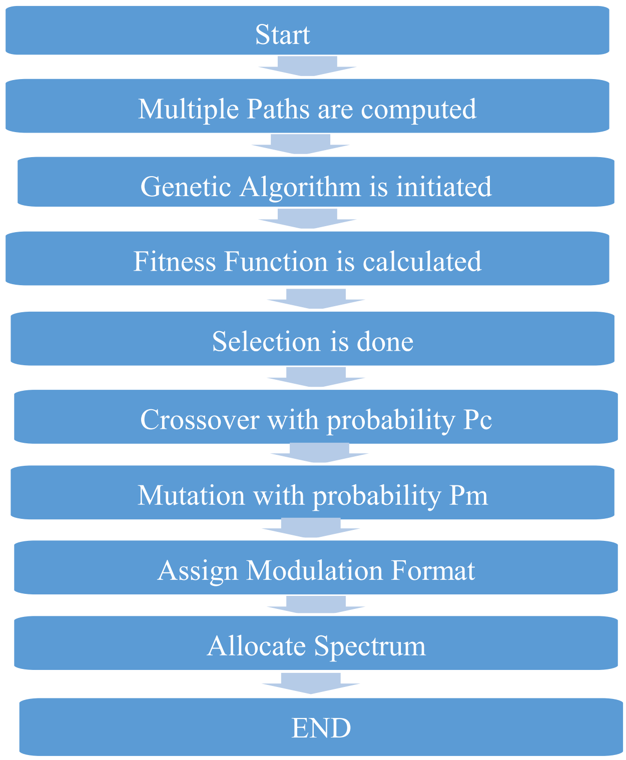

Fig. 1 Flowchart of genetic algorithm

problem along with certain operational and technological issues in EONs. According to [7], multipath routing with traffic grooming can use spectrum resources more flexibly in dynamic scenarios than single-path routing algorithms because it divides a traffic demand into several small-size sub-connections and sends them individually via several optical channels. Another investigation has presented adaptive online joint RSA based on sequential search and adaptive routing. In order to reduce connection request bandwidth requirements, the authors adopted adaptive modulation, load balancing, and multipath routing (MR) as effective defragmentation techniques [12, 13]. Without providing any design and tuning information, a Tabu search technique was employed in [14] for the RSA optimization with an objective function related to spectrum use. Another study presents an RSA heuristic strategy for limiting the maximum load and balancing traffic load on the network while minimizing the number of hops in the existing light-path [15]. Authors presented fragmentation aware multipath routing algorithm to reduce blocking probability and improve bandwidth utilization in EON [16]. Dual path allocation algorithm which is a form of multipath algorithm is used to reduce bandwidth blocking probability and path protection as well [17]. In another research, Brute Force algorithm is used to analyze routing and spectrum assignment to investigate all routing tables and to find best route in EON [18]. The authors of [19] implemented methods for dynamic routing and spectrum (re) allocation, wherein allotted light-path requests are redistributed to make way for additional light-path demands. For flexgrid all-optical core switches enabling multi-hop transparent paths in data centre networks, a hybrid routing approach with adaptive spectrum assignment is recommended. By reducing the maximum index of the assigned subcarriers, Gong et al.'s evolutionary method [20] was proposed for solving the joint RMSA problem. Alyatama [21] presented an RSA method that examines all potential paths between the source and destination nodes and computes the relative cost of carrying the requested traffic along the path, which is determined as the difference in revenue lost whether or not a connection is allowed. Ahmed et al. [22] has proposed RMSA method, which computes the k-shortest routes and chooses the one with the maximum spectral efficiency and uses the least amount of bandwidth to serve the requested traffic for coexisting fixed and flexi-grid optical networks. In another research [23], for both static and dynamic operation settings, an integer linear programming (ILP) algorithm has been devised to address routing, spectrum and modulation level assignment, and scheduling challenges. Furthermore, a variety of heuristic algorithms are proposed to reduce the complexity of the ILP algorithms and enhance the flexibility in large-scale networks, which consider two and three techniques for path selection and resource allocation, respectively [24–26]. However, there is no such research related to multipath routing using GA in EON. NSFNET (National Science Foundation Network) and DT-14 (Deutsche Telekom) networks have been considered for the simulation to evaluate the performance of multi-path routing using GA in EON.

Numerical simulation

Here, DT14, a Germany network and NSFNET, a US network as shown in Figs. 2 and 3, respectively, are taken into consideration, to investigate distance adaptive modulation and routing using GA. For the different network topology, different modulation formats are applied in accordance with transmission distance. The performance of modulation formats is affected by ISI, attenuation, noise, and several other factors, restricting the optical reach of the transmitted signal [27]. Higher-order modulation schemes may be applied to shorter routes while lower-order modulation techniques are usually applied to longer paths, this concept is referred to as distance-adaptive spectrum allocation, for example, BPSK modulation technique is taken into consideration when the maximum length of the path is 2000 km, QPSK modulation technique is adapted when the maximum length of the path is 1000 km and 8PSK is considered for 500 km path-length. The reference distance is predicated on an assumption. Once

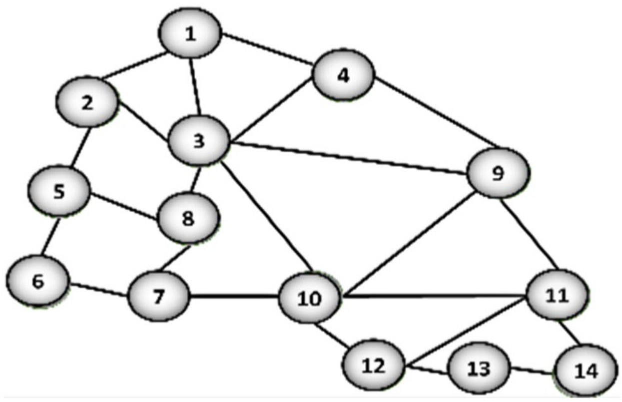

Fig. 2 DT14

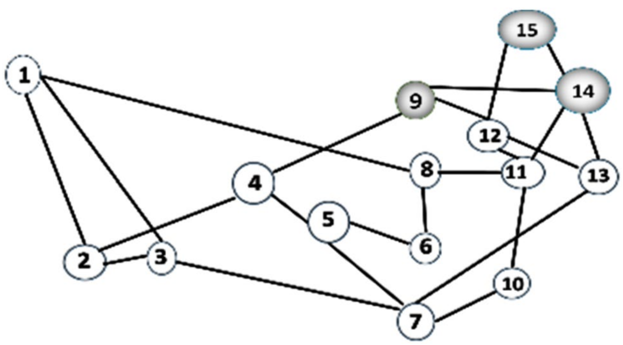

Fig. 3 NSFNET

the link distances are specified, the routing algorithm evaluates the network's distance-adaptive modulation formats. Symbol rate, spectrum efficiency, and tolerance to optical defects are all properties of different modulation formats. The routing algorithm considers these characteristics, as well as link distances, to determine the best modulation format for each link. Then for routing, shortest path is calculated among multiple paths using Dijkstra's algorithm. Routing considers some assumptions: all the channels should have the same wavelength, all connection requests should arrive by the Poisson process, and the holding time of all source–destination pairs should be the same. As there is no spectrum conversion available, hence spectrum continuity constraint is considered. Once the routing paths and modulation formats are selected then using GA, a gene is formed which comprises of route and the modulation format, i.e., (R_s, M_a). Then more such genes are identified and then the chromosomes are formed and finally a population is generated. Crossover is a multi-point gene-level operation in which a set number of genes are chosen and switched at random sites of parents based on the crossover rate. Pairs from the parents are randomly selected and crossover is applied to them. The crossover produces new offspring individuals. Then the fittest individuals from the entire population pool are chosen. The chosen individuals are next subjected to a mutation phase in which a set number of genes are modified at random depending on a mutation rate mentioned in Table 1.The factors mentioned in Table 1 are taken into account while utilizing GA:

Genetic algorithm applied to find multipath route along with adaptive distance modulation formats, finds the optimal solution based on the fitness function. Fitness function is defined as finding the shortest routing path (Fd) and the path with minimum number of blocked request (Fm) when the traffic is high. The fitness function (F) used in the simulation is given below:

$$F = Fd + Fm \tag{1}$$

where Fd is defined as the ratio of shortest distance between the two neighboring nodes and Fm as the distance between the source and destination nodes. The selection method, preferred here is Elitism as it limits the number of routes with the best fitness value and other routes are discarded hence the computation in crossover and mutation steps reduces thereby minimizing the computation complexity. The performance of the two networks are assessed by blocking probability (BP), which is considered to be a vital parameter and given as:

$$\text{BP} = \frac{\text{total number of blocked requests}}{\text{total number of arrival requests}} \tag{2}$$

The results of BP are plotted against the traffic load (in Erlang), which is represented by λ/μ. In all the simulations λ is set to 10^{-1}, and μ ranges from 10^{-6} to 10^{-1}, where λ is the arrival rate of light path requests and μ is the parameter of exponential distribution. As a result, the range of traffic load is [1, 10^5].

Results

The performance of multipath routing using genetic algorithm is evaluated by considering two networks for simulation out of which one is NSFNET and the other is DT-14. Figure 4 shows the comparison of blocking probability

Table 1 Parameters used for GA

S. No	Parameters	Values
1	Size of the population	100
2	Elite Size	20
3	Rate of Crossover	0.9
4	Mutation Rate	0.01
5	Number of generations	50

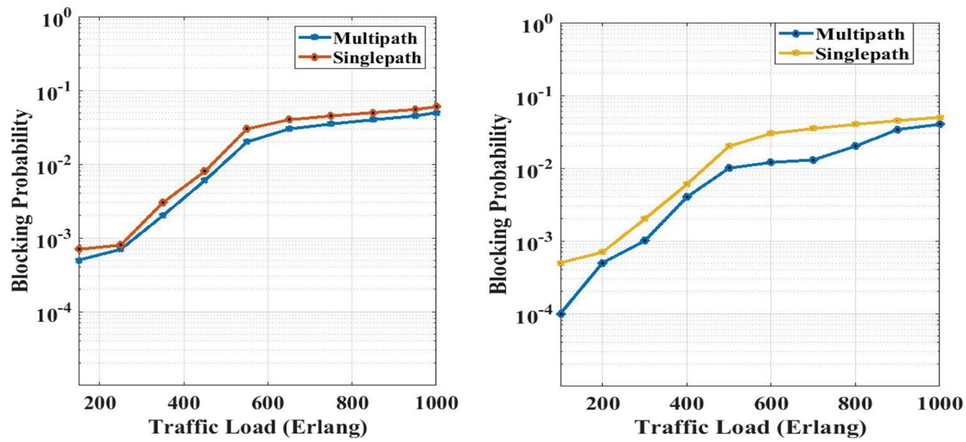

Fig. 4 Blocking probability versus traffic load for **a** DT-14, **b** NSFNET

due to multipath routing using GA and single path routing for NSFNET and DT-14 topologies. It is observed from Fig. 4 that there is approximately a reduction of 10% in BP in case of DT-14 and a reduction of about 20% in BP in case of NSFNET while using multipath routing using GA as compared to single path routing. The reduction in BP in NSFNET is more as compared to DT-14 since NSFNET is a sparse network hence the traffic congestion reduces in this network. To achieve even greater spectrum efficiency, distance adaptivity is applied by constantly modifying modulation schemes, as higher order modulation schemes are applied to shorter routes and lower order modulation formats to longer routes.

Conclusion

This research recommends a multipath routing strategy for elastic optical networks based on genetic algorithms in order to find the shortest path and decrease network blocking probability throughout the routing process. Then, while taking into account the distance parameters between the various kinds of nodes in the network, an effective fitness function is generated. The blocking probability and the various routes between the sending and receiving nodes are among these features. The shortest distance is determined via simulation analysis, which is also used to assess the blocking probabilities of multipath and single path routing. When compared to single path routing, multipath routing based on evolutionary algorithms minimizes the blocking probability significantly in both simulation networks, NSFNET and DT14. It is observed that there is approximately a reduction of 10% in BP in case of DT-14 and a reduction of about 20% in BP in case of NSFNET while using multipath routing using GA as compared to single path routing. Additionally, different modulation formats are used in accordance with the transmission distance to achieve distance adaptivity and greater flexibility in EON.

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