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RSA algorithm of EON based on coloring theory

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***Abstract*—Traditional wavelength division multiplexing networks use fixed grids to meet the needs of today's rapidly evolving networks. The elastic optical network with OFDM as the core can divide the spectrum resources into finer granularity, thereby improving the utilization of network resources and reducing the bandwidth blocking rate in the network. this paper considers risk avoidance to improve the elastic optical network routing and wavelength assignment algorithm based on spectrum coloring theory: First, define the network The routing risk coefficient, starting from the power communication service flow, analyzes the resource status of nodes and links, and establishes a route optimization model. Secondly, based on the characteristics of power communication network, based on the graph coloring theory and considering the spectrum fragmentation problem, the risk equilibrium model is designed. Finally, the joint transfer hops and the network risk value are jointly balanced, and a mixed integer linear programming model of the RSA problem with the minimum transfer hop and the lowest risk balance is jointly established. The spectrum is based on the coloring number. Equally divided blocks, the spectrum is allocated by block. The simulation results show that compared with the typical algorithm, the proposed algorithm alleviates the problem of uneven distribution of risk and spectrum fragmentation in the power communication network in the prior art, and comprehensively considers routing and spectrum, and balances the number of hops. Balance the risk with the effect of improving resource utilization.**

Keywords—Elastic optical network; coloring theory; risk balance

I. INTRODUCTION

The traditional wavelength division multiplexing (WDM) optical network divides the spectrum into different channels. According to the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) standard, the channels in the WDM optical network are The minimum interval is "50GHz" or "100GHz". Since the interval between the channels is fixed and the spacing is large, when the channel carries only the service of the lower bandwidth, a large amount of unused frequency slots are left, which causes a large amount of waste of spectrum resources. The Elastic Optical Network (EON), which utilizes spectrum efficiency, can overcome the limitations of traditional WDM optical networks in bandwidth utilization.

In the elastic optical network, the above sub-problems can be separately studied and solved in order for different business needs, or combined and researched and solved at the same time. For example, in the literature [1], Z. Zhu et al. proposed a dynamic RSA algorithm based on multi-path routing based on single-path routing, which divides large services into multiple small services and transmits them on different paths.[2]L. Delvalle et al. designed a simulator that can run and compare the performance of various RSA algorithms to comprehensively study RSA problems in elastic optical networks. Literature [3] et al. proposed a spectrum defragmentation algorithm for spectrum fusion, which re-routes existing services in the network, creates enough spectrum space to complete blocked requests, and optimizes the use of network resources. , effectively reducing the blocking rate of the business. In the literature [4], Sunny Shakya et al. proposed a defragmentation scheme, which reduces the spectrum in the network into multiple independent sets and integrates spectrum resources when the degree of network fragmentation is high. Due to the typical industry specificity of the grid business, once the fiber breakage in the power communication network fails, it will have a major impact on the safe production and stable operation of the power system. At the same time, sudden congestion is no longer the source of business communication risks. The excessive concentration of services on several paths is a new source of risk. Traditional routing algorithms cannot avoid such risks.

Therefore, this paper proposes an elastic optical transmission RSA algorithm based on coloring theory. First, the classic Dijkstra algorithm-based ksp algorithm is used to determine the routing alternative set. Secondly, through the graph vertex coloring theory, the routes are colored and classified, and the distribution of the service transmission spectrum is completed, so as to solve the problem of uneven distribution of risk and spectrum fragmentation in the power communication network in the prior art, and comprehensively consider routing and spectrum, and balance the transition. The number of hops and risk balance are improved to improve the utilization of resources.

II. PROBLEM MODEL

In an elastic optical network, in order to adapt to dynamic and variable service bandwidth requirements through flexible spectrum bandwidth, the traditional RWA algorithm is no longer applicable. Similar problems in elastic optical networks are extended to routing and spectrum allocation problems (RSAs). The routing problem in the RSA algorithm is consistent with the routing problem in the RWA algorithm, and the appropriate transmission path is searched according to the requirements of the service and the source node and the destination node. The WDM network uses a fixed grid. Therefore, the spectrum allocation problem in the RSA algorithm is different from the wavelength allocation problem in the RWA algorithm. The RWA algorithm in a WDM network needs to meet the wavelength consistency constraint, that is, uniformly allocate wavelengths on each link on the working path. Similarly, the RSA algorithm in an elastic optical network also needs to meet the following three restrictions:

(1) Spectrum continuity restrictions: The frequency slots allocated to each service bandwidth request must be contiguous and continuous.

(2) Spectrum Consistency Limitation: The spectrum resources allocated for each service bandwidth request on each link of the optical path must be in the same location.

(3) Spectrum non-overlap limitation: Each frequency slot is only allowed to be occupied by one service, and different services cannot have overlapping on the spectrum.

In an actual network environment, a large number of randomly arrived service connection requests are allocated corresponding working connection paths and idle spectrum resources in a certain order or priority, and the establishment and removal of service paths corresponding to service connection requests frequently occur in the network. Distribution and release of spectrum resources. Moreover, the elastic optical network allocates spectrum on the sub-carrier frequency slot of the link, and the size of the link sub-carrier frequency slot can be elastic, and the spectrum allocation in the elastic optical network must satisfy the constraints of spectrum continuity and spectrum consistency. condition. Therefore, dynamically allocating and tearing down links in the network will result in a large amount of spectrum fragmentation, and the number of spectrum fragments will increase as the network load increases. Paths in the spectrum domain may cause misalignment of available frequency slots. Or the phenomenon of not being adjacent to each other, so that the subsequently arrived services in the network cannot find a suitable path or spectrum resource to complete the transmission of the service, causing service congestion and network performance degradation, as shown in Figure 1.

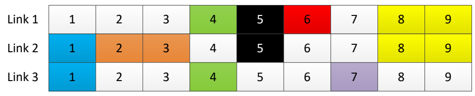


Fig. 1. Spectrum fragmentation diagram

III. RSA ALGORITHM MODEL BASED ON GRAPH COLORING THEORY

A. Spectral graph coloring analysis

The figures mentioned in this paper refer to the undirected simple diagrams of finite, acyclic, and no heavy edges. The vertex and link sets of graph G are typically represented by V(G) and E(G), respectively. The vertex coloring problem of Figure G refers to coloring each vertex of the graph G and assigning any two adjacent vertices to different colors. The edge coloring problem of Figure G refers to coloring each edge of the image G and assigning any adjacent two edges to different colors

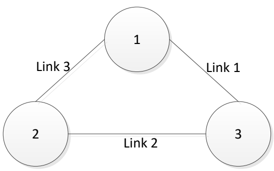


Fig. 2. Network topology

Considering the widespread spectrum fragmentation problem in EON, the edge coloring theory can realize the block transmission of services on the spectrum, and achieve the effect of improving network resource utilization and reducing the blocking rate.

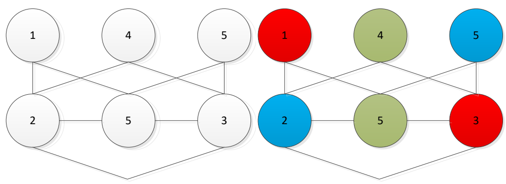
We set up a route set for each pair of source destination nodes. At the same time, two concepts "shared link set" and "non-shared link set" are defined, which respectively refer to different service sets having the same link and different service sets without any same link. We have to divide the entire spectrum into several parts. The routes occupied by different services allocated by each part do not contain any identical links. The next consideration is how to reduce the number of spectrum blocks.

For each pair of node pairs, assuming that the route selected by it has been determined, each point represents a route, and if two routes share at least one link, then the connection is made between the two points. In the process of coloring each point, the constraint of "different color of adjacent points" must be satisfied. Each color corresponds to a spectrum block, and a policy of performing traffic allocation by block is implemented. The length of the spectrum block is determined by the number of routes. Therefore, the minimum number of colors means the least number of spectrum blocks. After the number of color categories is obtained, the routes of the same color are arranged into the same spectrum block for transmission, and the length of the spectrum block is determined according to the number of routes.

TABLE I. ROUTING TABLE

Label	Source node	Destination node	routing
1	1	2	1-2
2	1	3	1-2-3
3	2	1	2-3-1
4	2	3	2-3
5	3	1	3-1
6	3	2	3-1-2

To better understand the coloring process, use an example to explain. As shown in Table I, in this simple network topology, there are three nodes and three edges. The routing table is shown in Figure 3. The coloring process can be obtained as shown in Figure 3(a). When two routes share at least one link, they are wired between two points representing the two routes. The routes of labels 1, 2, and 6 share the link 3. Therefore, the points representing the three routes are connected to each other. Second, follow the principle of "there are shared links, different colors" to color each point. The effect after coloring is shown in Fig. 3(b). Routes of the same color will be allocated to transmit traffic in the same spectrum block, which reduces the effect of spectrum fragmentation, improves resource utilization, and reduces blocking rate, as shown in Figure 4 and Figure 5.



(a) (b)

Fig. 3. coloring effect diagram

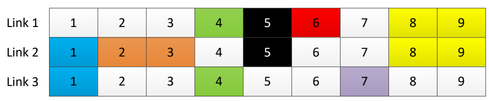


Fig. 4. Spectrum allocation effect diagram before applying coloring

theory

Fig. 5. Spectrum allocation effect diagram after applying coloring theory

TABLE II. VARIABLE AND ITS DESCRIPTION

variable	description
CAPEX	Optical path total transfer hops
p	Number of nodes through which the route passes
N	The total number of colors assigned to the spectrum
V	Vertex collection of the network
E	Network link set
Re	Risk standard deviation of the whole network
Ratio	Blocking rate

B. Algorithm Description

First, the classic ksp algorithm is used in routing. According to the route hop hop CAPEX, the number of transit hops is analogized to the link weight indicator to determine the route candidate set of the m-th power communication network node pair. The formula is as follows: Shown as follows:

$$CAPEX(m) = \sum^{v} p \tag{1}$$

Where p is the number of nodes passing through;

Further, the determining the coloring of the routing candidate set according to the hop count of the routing node and the total number of spectrum colors, and reducing the risk balance of the entire network is specifically: using the same link color or the same link color, establishing the following objectives function:

$$Min\ Q = CAPEX + N \tag{2}$$

Where N is the total number of spectral colors and Q is the optimal equalization number;

The constraints are:

$$\sum_{o \in O} x_v^o = 1, \forall v \in V_1 \tag{3}$$

$$x_v^o + x_{v'}^o \le y_o, \forall (v, v') \in E_1, \forall o \in O \tag{4}$$

$$y_o \ge y_{o'}, if o' \ge o, \forall o', o \in O \tag{5}$$

$$y_o = \{0,1\},\ \forall o \in O \tag{6}$$

$$x_v^o = \{0,1\}, \forall v \in V_1, \forall o \in O \tag{7}$$

$$N = \sum_{o \in O} y_o \tag{8}$$

Where p is the number of nodes through which the route passes, V_1 is the route set, E_1 is the connection set, O is the color set, x_v^o and y_o is the binary quantity, if the point v uses the color o,$x_v^o = 1$ otherwise $x_v^o = 0$, if the color o has been used at least， Once, $y_0 = 1$, otherwise $y_0 = 0$.

Further, according to the total number of colors allocated and the number of route classes allocated by each color, the spectrum is divided into proportions according to the ratio, specifically:

The spectrum block size St(i) of the i-th color distribution is determined according to the following formula:

$$St(i) = ratio(i) \times num \tag{9}$$

Where num represents the total number of spectral lattices, ratio(i) represents the ith color ratio, and the spectrum is partitioned according to the size ratio of the spectral blocks allocated for each color.

Further, according to the communication service to be transmitted, the transfer hop count and the risk balance value of the entire network are comprehensively considered, and the optimal solution is selected from the route candidate set as follows:

The optimal solution is selected from the set of routing alternatives according to the following objective function, thereby determining the route for performing the service allocation:

$$Min\, M = CAPEX + R_e \tag{10}$$

The constraint function is:

$$CAPEX(m) = \sum^{v} p \tag{11}$$

$$R(i,j) = n \times \frac{FS_{ij} - FS_{ij}^{idle}}{FS_{ij}} \times im \tag{12}$$

$$\mu = \frac{1}{S} \sum R(i,j) \tag{13}$$

$$R_e = \sqrt{\frac{1}{S} \sum [R(i,j) - \mu]^{\wedge}2} \tag{14}$$

In the formula, it represents the comprehensive optimization goal, CAPEX represents the number of transit hops of the m-th route, im represents the initial probability of failure, n represents the importance of the service, p represents the number of nodes through which the route passes, and R(i,j) represents the risk value on the link ij, N represents the color type, S represents the number of the total network links, FS_{ij} represents the total number of spectrum grids on the link ij, FS_{ij}^{idle} represents the number of idle spectrum grids on the link ij,μ represents the average network risk value, and R_e represents the standard deviation of the whole network.

IV. Simulation analysis

A. Simulation condition

In order to verify the performance of the RSA algorithm based on coloring theory, this paper carried out simulation experiments in matlab. The network topology has a total of 14 nodes, 48 links, and 600 spectrum grid capacity per link. In the simulation experiment, a static business model is adopted, and the source node and the destination node of each connection request are randomly generated and subject to uniform distribution. The spectrum requirements of each connection request and the traffic importance of the transmission are randomly generated and subject to uniform distribution. In order to verify and compare the performance of the RSA algorithm, the most commonly used network blocking rate, number of transition hops, and risk balance are used as performance indicators.

In order to verify the advantages of the RSA algorithm based on coloring theory, we also used the traditional RSA algorithm for comparison in the simulation. In the traditional scheme, the routing problem is solved by a fixed selection routing strategy. Among them, the routing scheme adopts the widely used Dijkstra algorithm to find the shortest path between the source destination nodes, and the wavelength assignment algorithm uses the first adaptive allocation algorithm (FF), the best adaptive allocation algorithm (BF), and the random adaptive allocation. Algorithm (RF). In the FF algorithm, the available spectrum of the optical path is first numbered, then traversed sequentially, and finally the spectrum with the smallest index value is selected. The BF algorithm selects the most suitable spectrum block to complete the allocation through the global information of the system. The RF algorithm randomly selects a block of spectrum to complete the allocation.

B. Result analysis

In order to prove the superiority of the algorithm, the risk balance degree, the average number of service hops and the service blocking rate are used as the evaluation basis. The rationality of resource allocation can be investigated by the average number of hops of the integrated service and the risk balance of the whole network. . At the same time, according to route coloring, the spectrum is allocated in blocks, which reduces the blocking rate and improves the resource utilization. The simulation results show that the proposed algorithm has better performance in risk balance and lowering the blocking rate.

It can be seen from figure 6 that when the number of services is small, the average algorithm has the highest average number of hops, the FF and BF algorithms are the second, and the lowest is the RF algorithm. This is because the proposed algorithm PSA considers the risk-wide balance of the whole network. The risk balance function is designed to effectively reduce the risk equilibrium value of the whole network, while the FF, BF, and RF algorithms do not consider the situation where the service is excessively concentrated on a certain number of links. When the number of service requests is less than 500, the proposed algorithm PSA and FF and BF algorithms rarely block, and the RF algorithm is more likely to block due to the principle of “random allocation”. The number of hops is low. When the number of requested services is greater than 500, the blocking rate of the FF and BF algorithms increases, resulting in a decrease in the average number of hops. The algorithm proposed in this paper is stable because the blocking rate has not changed greatly. . Compared with the comparison algorithm, the average number of hops of the service will increase by 3.7% to 4.4%. When the network transmission traffic is large and the number of services is large, the average forwarding hop count of the service is reduced due to the increase of the blocking rate of the comparison algorithm.

Figure 7 compares the network-wide risk balance of each algorithm under different service requests. It can be seen from the figure that the algorithm proposed in this paper has the lowest risk balance of PSA, while FF, BF and RF are higher, and with the increase of the number of requested services, the risk-equalization index of each algorithm shows an upward trend, compared with the previous one. The average transfer hop count of the business, the algorithm proposed in this paper is slightly higher than the comparison algorithm by 3.7% to 4.4%. However, in terms of the risk balance of the whole network, the proposed algorithm is reduced by about 60% compared with the comparison algorithm. This shows that the proposed PSA algorithm and the comparative FF, RF, and BF algorithms are basically equivalent in routing, but greatly reduce the blocking rate, and consider that a large number of services are excessively concentrated on certain links, resulting in increased network risk. The problem is that the spectrum coloring method is adopted to reduce the network risk balance. In the case of a large number of services, more spectrum space can be planned to complete resource allocation, thereby reducing the blocking rate and improving resource utilization.

Figure 8 shows the comparison of the blocking rates of the algorithms for different service requests. It can be seen from the figure that when the number of requested services is less than 500, the PSA blocking rate of the proposed algorithm is the lowest. As the number of requested services increases gradually, when the number of requested services is greater than 500, the blocking rate of FF, BF, and RF algorithms is fast. Elevated, and the proposed algorithm PSA is stable, because the PSA algorithm adopts the method of reducing the effect of spectrum fragmentation through the coloring theory. In the case of a large number of services, more spectrum space can be planned. Resource allocation, which reduces the blocking rate and improves resource utilization.

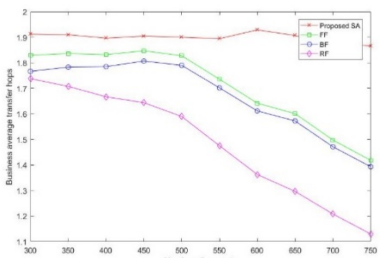


Fig. 6. Relationship between the average number of hops and the number of requested services

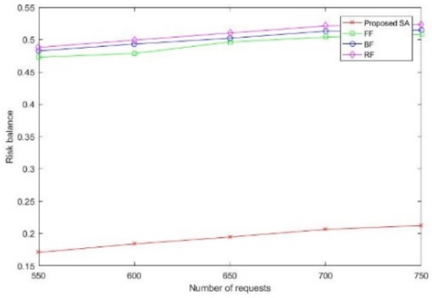


Fig. 7. Relationship between risk balance of the whole network and the number of requested services

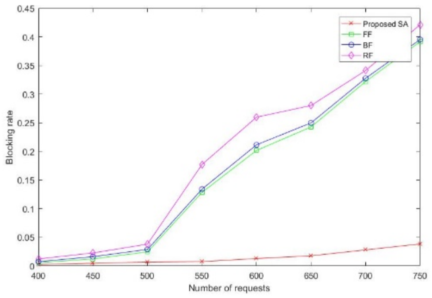


Fig. 8. Relationship between blocking rate and number of requested services

Since the traffic distribution and transmission risk are the two main characteristics of the power communication network, and the algorithm designed in this paper aims to balance the resource allocation and risk of the power communication network, it is necessary to separately allocate the effect from the resource and the risk balance effect. In some aspects, its performance is tested and compared. In short, compared with the classic FF, RF, BF and other algorithms, the proposed algorithm slightly improves the number of routing transition hops, but greatly reduces the blocking rate, while considering a large number of services are excessively concentrated in certain chains. The road, which leads to the problem of increasing network risk, adopts the method of spectrum coloring, which increases the network risk balance and reduces the impact of spectrum fragmentation.

V. CONCLUSION

With the increase of the amount of network data and the increase of the types of services, it is an urgent problem to achieve efficient routing and wavelength allocation calculation in complex networks and to balance network risks with services of different importance. In this paper, an RSA algorithm based on coloring theory is proposed for elastic optical networks. According to different business importance and occupied transmission links, the source destination node pairs are colored and classified to achieve the effect of block transmission and improve the whole network. Risk balance, reduced blocking rate, and optimization. Through a large number of simulation experiments in the NSFNET network topology, the results show that the algorithm has obvious advantages for the traditional scheme, which can effectively improve the risk balance and reduce the blocking rate.

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