A research into static traffic routing and resource optimization algorithm based on genetic and tabu search

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Abstract

In order to solve the issue of optical network's static traffic routing and resource optimization, this paper puts forward a hybrid genetic and tabu search virtual reconfiguration algorithm (HGTS-VRA) and designs the key elements. This algorithm could effectively integrate the large scale searching ability of genetic algorithm and the outstanding local searching ability of tabu search algorithm. The simulation comparison result and analysis result show that the HGTS-VRA put forward by this paper enjoys excellent advantages in the field of traffic routing and resource optimizing. In addition, it offers outstanding extendibility and robustness.

Keywords: Hybrid Genetic, Tabu Search, Static Traffic Routing, Resource Optimization

1 Introduction

The virtual reconfiguration of the SDH/OTN/DWDM three level networks is a NP-Complete issue, which needs a mathematical model to express it in terms of mathematical formula from the aspect of engineering optimization, so as to determine the target and limitations for optimization. For the solution for issues within small scale network, it's recommended to adopt integral linear programming or mixed integral linear programming. However, with expansion of network scale and increase of connection request, the linear programing model is hard to gain the optimized solution within polynomial time. For the solution to the issues in large network, we need to adopt heuristic algorithm to meet to limited time requirement. However, though heuristic algorithm is able to give a solution within given time, it cannot offer the most optimized solution. As a result, the choice of algorithm becomes extremely important.

This paper researches into the static traffic routing issue within SDH/OTN/DWDM three level networks. In other words, it researches into the routing and resource optimization of static traffic. It can be divided into two sub-issues: namely the routing issue and network resource optimization issue, which are interdependent with close relationship. In the aspect of routing issue, while selecting route for a large batch of traffic, we need to take network resource optimization into comprehensive consideration. Therefore, the network resource optimization is actually within the selection of routing issues. In the aspect of network resource optimization, we need to reconstruct the virtual topology gained from solution of routing issue for the sake of researching further into how to minimize resource consumption.

2 The Basic Elements of Genetic Algorithm (GA)

The basic operations of GA include encoding, appearance of initial population, fitness calculation, selection, crossover and mutation.

2.1 GENETIC CODE

According to the workflow of GA, when using GA in solving problems, a relationship should be established between the actual presentation of target problems and the bit-string structure of the chromosome in GA, namely the encoding and decoding operations should be determined. The encoding is to express the solutions with a code so as to make the problem state space corresponding to the coding space of GA, which relies heavily on the nature of the problems and which will affect the design of genetic manipulation. The optimization of GA is carried out in the code space corresponding to certain encoding mechanism instead of working directly on the parameters of the problems; therefore, the selection of the code is an important element affecting the algorithm performance and efficiency [1]. In function optimization, different code lengths and code systems place a great influence on the accuracy and efficiency of the problems. Binary encoding demonstrates the solutions to the problems with a binary string while decimal encoding presents the solutions with a decimal string. Obviously, the code length will affect the algorithm accuracy and the algorithm will give out larger memory space. Real-number encoding is to show

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the solutions with a real number and it has been extensively applied in high-dimensional and complex optimization space since it has solved the influence played by encoding on the algorithm accuracy and memory space. For the given optimization problem, the space formed by GA phynotype collection individuals is called problem space while that consisted by GA genotype individuals is called GA coding space. The genetic operators are implemented in the bit-string individuals in GA coding space [2].

2.2 GENETIC OPERATOR

The operators of the standard genetic algorithm often include three basic forms: selection, crossover and mutation, which make up the core that GA has strong search capacity and which are the main carriers of the reproduction, hybridization and mutation produced in the simulation of the natural selection and the genetic process. GA realizes the group evolution by using the genetic operators to reproduce a new generation of groups and the design of the operators is not only a key component of the genetic strategy, but also a basic tool to adjust and control the evolution process [3]. This paper will discuss the effect the genetic operators play on the convergence separately, which helps to learn about the characteristics and importance of genetic operators better.

(1) Selection Operator

Selection is to choose the individuals with high fitness value from the current group to produce the matingpool and it mainly includes fitness-proportionate selection, Boltzmann selection, rank selection, tournament selection and elite-preserving selection. In order to prevent the optimal individuals of the current group from losing in the next generation due to selection errors or the destructive effects of crossover and mutation, DeJong has come up with the elitist selection. In addition, Holland and others have also brought forth steady-state selection. The selections operators are mainly used to prevent gene delection and improve the global convergence and the calculation efficiency and the most commonly-used selection operators are fitness-proportionate selection operator and the elite-preserving selection operator.

Proportional model, also called Roulette wheel, is a method of playback random sampling and its basic idea is that the probability of every operator to be selected is directly proportional to its fitness. Because of random computation, the selection error of this method is so big that some individuals with high fitness fail to be selected; however, this is still one of the commonly-used selection operators.

Assume that the group size is M and the fitness of the individual i is Fi. Then the probability pi of the individual i to be selected is [4]:

$$p_i = \frac{F_i}{\sum_{i=1}^{M} F_i}, (i = 1, 2, \cdots, M) \tag{1}$$

In running GA, new individuals emerge continuously from such genetic operations as crossover and mutation on the individuals. Although more and more excellent individuals will appear in the group evolution, they may destroy the individuals with optimal fitness due to the randomness of selection, crossover and mutation. We hope that the individuals with optimal fitness can be preserved till the next-generation group as much as possible; therefore, we need to apply Elitist Model, meaning that the individuals with the highest fitness in the current group won't participate in the crossover and mutation but replace the individuals with lowest fitness produced by the current group after crossover and mutation.

(2) Crossover Operator

The so-called crossover operation in GA means that two matching chromosome individuals replace part of their genes in accordance with a certain way and form two new individuals. As a significant characteristic of GA, crossover operation plays a key role in GA and it is also a main method to produce new individuals.

Crossover operation is usually divided into the following several steps:

(a) Randomly take out a pair of mating individuals from the matingpool;

(b) Randomly take one or more integers k from [1, L-1] as the crossover position of the pair of mating individuals according to the bit string length L;

(c) Carry out crossover operation according to the crossover probability $p_c (0 < p_c \le 1)$; the mating individuals replace part of their contents and form a pair of new individuals at the crossover positions [5].

The most commonly-used crossover operator is One-point Crossover, which refers to set a crossover point randomly in the individual encoding string and replace some chromosome in these two mating individuals at this point. One-point Crossover has an important characteristic: if the relationship between the neighbouring loci can provide better individual character and higher individual fitness, then it will be less possible for this One-point Crossover to destroy such individual character and lower the individual fitness.

It will be faster to solve knapsack problem with and/or swap operation, the specific realization methods of which include:

(a) Choose two parent strings A and B according to the roulette wheel selection mechanism;

(b) Produce a substring A' from A and B according to logic and operation;

(c) Produce a substring B' from A and B according to logic or operation.

(3) Mutation Operator

As a local random search, mutation can avoid the eternal loss of some information caused by selection and crossover operators if combined with these operators. If mutation operation is conducted on the individuals with certain probability instead of single hybridization operation, mutation will randomly change the vectors of the individuals with small probability; in this way, it may result in some new and useful structures may appear and increase the probability to converge to the overall optimization. Mutation operation is a measure to prevent the prematurity of algorithm as well as non-mature convergence. Never take a big mutation rate in the mutation operation. If the mutation rate is bigger than 0.5, GA will degrade into random search and some important mathematic characteristics and search capability will no longer exist [6].

3 The Hybrid Algorithm Based on Genetic Algorithm and Tabu Search

3.1 THE IDEA OF HYBRID ALGORITHM

Theoretically, it has been proven that GA can find the optimal solutions to the problems in a random way from the significance of probability; however, the practical applications have also demonstrated that some unsatisfactory problems will appear in GA applications. The main problems include: easy to produce the premature phenomena; bad in local optimization and inefficient in running, which, however, are difficult to erase from GA. On the other hand, some optimization algorithms such as gradient method, hill-climbing method, simulated annealing algorithm and Tabu Search have strong local search capacity. Obviously, to mix the ideas of these optimization algorithms in GA search process and form a hybrid algorithm can enhance the running efficiency and the solution quality. The practice has shown that the improved GA is much better than the simple GA.

The hybrid GA blending the ideas of local search algorithm in the standard GA has the following two main characteristics:

(1) Introduce local search. Conduct local search based on the corresponding phenotypes to the individuals in the group and find the locally optimal solution to every individual in the current environment so as to improve the overall performance of the group;

(2) Add transcoding operation. Change the locally optimal solutions deduced from the local search process into new individuals through encoding to have a new group with better performance as the basis for the next-generation genetic evolution.

The basic constituent principles of the hybrid GA

The hybrid GA formed by the standard GA and other optimization algorithms shall abide by the following three principles:

(a) Adopt as much encoding of the original algorithm as possible;

(b) Use the advantages of the original algorithm;

(c) Improve the genetic operators. Design the genetic operators that can adapt to new encoding way and integrate the related inspirations to the problems in the operators; therefore, the hybrid GA cannot only preserve the global optimization of GA, but it can also improve its running efficiency.

On the basis of the above-mentioned three principles, mix the standard GA and Tabu Search into a hybrid genetic algorithm. In the following passage, I will briefly introduce Tabu Search first.

3.2 TABU SEARCH (TS)

The basic idea of TS is: give a current solution (initial solution) and a neighbourhood and determine several candidate solutions in the neighbourhood of the current solution; if the corresponding target value to the optimal candidate solutions is better than the current optimal solution state, then ignore its tabu, replace it with the current solution and the optimal solution state; add the corresponding object into the tabu list (which is used to record the tabu of the candidate solutions) and change the tenure of the object in the tabu list; if no such candidate solutions exist, choose the untabued optimal state from the candidate solutions as the new current solutions, ignore their advantages and disadvantages with the current solutions; add the corresponding objects into the tabu list and change the tenure of every object in the tabu list; repeat the above search process till it satisfies the stopping criterion. As a simulation of human’s thinking, Tabu Search can accept some solutions which are not so good through the tabu (which mean memory sometimes) of the locally optimal solutions so as to avoid local search [7, 8].

Since Tabu Search simulate the “memory” function in human’s intelligence , it can memorize some solutions which have been checked lately and make them to be the tabu of the next solution by setting a flexible memory structure; thus, it can effectively avoid the circuitous search, improve the search capacity of the algorithm in the solution space and enhance the optimization efficiency and performance by despising some criteria to remit some tabued best states so as to realize the global optimization [9].

The specific steps of Tabu Search are classified as follows [10]:

(1) Randomly choose some solutions to put into the tabu search collection T(s) according to a certain proportion;

(2) Take a solution si from the tabu search collection and set the tabu list and the optimal state as null;

(3) Produce several neighbourhood solutions si from the current solution, from which to determine several candidate solutions;

(4) Decide whether the candidate solutions have met the aspiration criterion. If they have, replace s- with the optimal state $S_{\max}$, which meets the criterion as the new current solution, namely, $s_i = S_{\max}$; put the corresponding tabu objects to $S_{\max}$ in the tabu list; release the objects which have satisfied the tabu length from the tabu list;

replace "the optimal" state with S_{max} and turn to Step (6); otherwise turn to Step (5);

(5) Decide the taboo attributes of the corresponding objects to the candidate solutions and choose the optimal state of the untabued objects in the candidate solution collection as the new current solution: put the corresponding objects in the tabu list and release those, which have satisfied the tabu length;

(6) If it meets the requirements of Tabu Search on si, finish the search on si and turn to Step (7); otherwise, return to Step (3);

(7) If every solution in the tabu search collection T has been conducted Tabu Search, finish this process; otherwise return to Step (2).

In Step (1), the selection proportion can be among 0-100%. When choosing 0, ignore the Tabu Search. The higher the selection proportion, the better the performance improvement of GA solutions; however, at the cost of calculation time, when the selection proportion reaches a certain degree, the proportion increase will not improve the performance of the solutions [11]. The selection proportion can be adjusted according to the practical requirements before running the procedures. From the above, it can be seen that the focal function (to realize local search), the tabu objects, the tabu list and the aspiration criterion are key to Tabu Search [12]. Among them, the focal function adopts the idea of local search and it is used to realize neighbourhood search; the setting of tabu list and tabu objects have demonstrated the characteristic that the algorithm avoids circuitous search and the aspiration criterion is not only an award of the excellent state, but also a relaxation of the tabu strategy.

It is found that TS is faster than GA in the search speed; however, it is also noticed that TS relies greatly on the initial solutions. A better initial solution can help TS to find better solution in the solution space while a bad initial solution will lower the convergence speed of TS and the solutions TS find are relatively bad [13]. Therefore, people will usually use a certain algorithm such as heuristic algorithm to get a satisfactory initial solution to improve the performance of TS. Another shortcoming of TS is that its search is single-single operation, namely there can be only one initial solution in the search and it can just move one solution to another solution in every generation without operation on several solutions (group) in every generation, just like GA [14].

4 Three Level Network Structure Model

The multi-level network defined by IEFT refers to an area that is controlled by the unified control panel and offers one or multiple exchanging ability, multiple data plane exchange and supports to traffic engineering. The concept of multi-level gives its focus to data plane and is normally classified into different groups in accordance with its data exchanging ability. The actual network topology researched in this paper consists of integrated network nodes and multi-wavelength fibre optic link, as indicated in Fig. 1. In actual network, some nodes may have already integrated OXC & ODUK electronic cross matric devices as well as DXC and corresponding layer interfaces, such as O3; some nodes only integrated OXC & ODUK electronic cross matric devices and corresponding layer interfaces, such as O4; some nodes are only equipped with OXC devices for traffic transmission and exchange, such as O6. After the actual network is divided based on logic, each integrated node will be classified as the corresponding node in different layers of the network and form the SDH/OTN/DWDM three-layer network structure. Here, the classification is the classification of logic sense, while different nodes in different layers of the network still have close interrelationship, which will be indicated by interlayer link. In fact, interlayer link is an abstract presentation of interlayer interface devices. The interlayer link mentioned in this paper include DWDM-OTN interlayer link, DWDM-SDH interlayer link and OTN-SDH interlayer link

SDH layer business is undertaken by SDH layer logic link and OTN layer business is undertaken by OTN layer logic link, while SDH logic link can be constructed by DWDM layer fibre optical link in terms of wavelength granularity or that the STM-N bandwidth granularity is constructed by OTN layer logic link. For example, in Fig.1, the SDH layer logic link could provide 2 kinds of resource transmissions: the first transmission is provided by the by O1→O7, O7→Os and Os→O5 fibre optical links from DWDM layer in terms of wavelength granularity; the second transmission is provided by D1→D5 logic link in OTN layer in terms of STM-N granularity, while the D1→D5 logic link is provided by optical path constructed by O1→O2, O2→O3, O3→O4 and O4→O5 logic links in OTN layer in terms of wavelength granularity. As a result, the R1→R5 link can be constructed by D1→D5 logic link in OTN layer, while the D1→D5 logic link in OTN layer can be constructed by O1→O5 optical link in DWDM layer. Therefore, there is a nesting relationship among the links in SDH, OTN and DWDM layer.

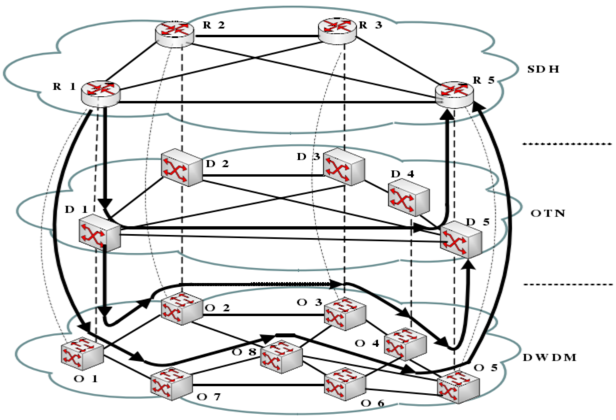

FIGURE 1 Multi-Layer Network Topology

5 Three Layer Optical Network

Under the circumstance of given network model parameters and a variety of limitations, setting the optimization target to request routing and resource configuration for traffic is the tyFigal integral programming issue. In order to verify the effectiveness of the algorithm put forward in this paper, we establish the static traffic routing issue optimization model named ILP. The accurate solution of this model could provide the theoretical upper performance limit of static traffic grooming algorithm.

5.1 MODEL PARAMETER

5.1.1 Symbol

1L, 2L, 3L: superscript or subscript, represent SDH layer, OTN layer and DWDM layer respectively.

i, j: the two points of SDH layer virtual topology edge.

u, v: the two points of OTN Layer topology edge

m, n: the two points of DWDM layer optical link

s, d: the traffic requests source node and host node of SDH layer and OTN layer

y: the band width granularity of traffic request. Here, both traffic in OTN layer and SDH layer are supposed to be fixed granularity:

OTN Layer Band Width Granularity $y \in \{ODU-1/2/3\}$, SDH layer bandwidth granularity $y \in \{STM-1/1/16\}$.

5.1.2 Known values

W: the maximum wavelength of each optical fibre

C^{2L-3L} : OTN Layer logic links is the maximum mapping link capacity that SDH layer can provide.

C^{1L-3L} , C^{1L-2L} : stand for OTN layer mapping link capacity and SDH layer mapping link capacity provided by DWDM layer wavelength links respectively.

$\Lambda_{2L}^{sd,y}$ and $\Lambda_{3L}^{sd,y}$: stand for the and width granularity traffic request number requested by OTN layer and SDH layer towards node (s, d).

R_j^{2L-3L} , R_j^{1L-3L} and R_j^{1L-2L} : standards for the Node J's interlayer link capacities from OTN layer to SDH layer, from DWDM layer to SDH layer and from DWDM layer to OTN layer.

T_j^{3L-2L} , T_j^{3L-1L} and T_j^{2L-1L} : stands for Node J's interlayer link capacity from SDH layer to OTN layer, from SDH layer to DWDM layer and from OTN layer to DWDM layer.

5.1.3 Variables

(1) DWDM layer topology variables

WOP_{mn}^{uv} : links from Node u to Node v within OTN layer and pass through Node M and Node N in DWDM layer mapping path.

WOP_{mn}^{ij} : links from Node i to Node j within SDH layer and pass through Node M and Node N in DWDM layer mapping path.

(2) OTN layer Topology Variables

$W_{uv,l}^{1L-2L}$ stands DWDM wavelength links mapped to DWDM layer by Node u's No. l link in OTN layer.

V_{uv}^{1L-2L} : stands for links from Node u to Node v in OTN layer and are mapped from DWDM layer to OTN layer

$SP_{uv}^{ij,y}$: The link group from Node i to Node j in SDH layer passes through Node u and Node v in OTN layer.

(3) SDH layer Topology Variables

$SP_{uv}^{ij,y}$: The link group from Node I to Node j in SDH layer and pass through Node u and Node v in OTN layer.

$W_{ij,k}^{1L-3L}$ stands for the DWDM wavelength that No. k link from Node I to Node j in SDH layer is mapped to DWDM layer.

V_{ij}^{1L-3L} and $V_{ij,y}^{2L-3L}$ stand for the links that locate in Node i in SDH layer and are mapped from DWDM layer (in terms of wavelength granularity) and OTN layer (in terms of y granularity) to SDH layer.

(4) Traffic Request Varibles

$O\_\theta_{sd}^{yt}=0 : O\_\theta_{sd}^{yt}=1$ indicates that, in Node (s, d) in OTN layer, the request of traffic Y of No. t granularity is accepted, otherwise, $O\_\theta_{sd}^{yt}=0$

$O\_\theta_{uv}^{sd,y,t} : O\_\delta_{uv}^{sd,y,t}=1$ indicates that, in Node (s, d) in OTN layer, the request of traffic Y of No. t granularity is accepted, otherwise $O\_\theta_{sd}^{yt}=0$

$O\_\theta_{sd}^{y,t} : O\_\theta_{sd}^{y,t}=1$ indicates that, in Node (s, d) in SDH layer, the request of traffic Y of No. t granularity is accepted, otherwise $S\_\theta_{sd}^{y,t}=0$

$S\_S_{uv}^{sd,y,t} : S\_\delta_{uv}^{sd,y,t}=1$ indicates, in Node (s, d) in SDH layer, the request of Traffic Y of No. t granularity is undertaken by links between Node (I, j) in SDH layer, otherwise $S\_\delta_{uv}^{sd,y,t}=0$

5.2 OPTIMIZATION TARGET

The optimization modes are a target function that takes minimizing the network resource consumption as its target:

$$Min: \{[\sum_{i,j}(C^{1L-3L}\times V_{ij}^{1L-3L})+\sum_{u,v}(C^{1L-2L}\times V_{uv}^{1L-2L})+\sum_{i,j,y}(C^{2L-3L}\times V_{ij,y}^{2L-3L})]\}. \quad (2)$$

Formula 2 stands for the interlayer link bandwidth consumed by traffic. Each new OTN layer logic link or SDH link needs assigned capacity from interlayer links and lower layer network links in accordance with granularity. In addition, the consumed interlayer links are in terms of pair, including one downward interlayer link and one upward interlayer link. Therefore, the total consumed link width is the twice of total virtual topology logic links in OTN layer and SDH layer.

6 Adopt Three-layer Optical Transmission Network Static Topology in HGTS-VRA to Reconstruct

6.1 THE HYBRID ALGORITHM COMBINING GENETIC ALGORITHM AND TABU SEARCH

To genetic algorithm, once the individuals in the group are the same, no new genes can be introduced by selection and crossover algorithms and only mutation can transfer the group. When the mutation probability is small, the algorithm will linger on the old state for a long time; the search is inefficient and it is easy to converge in advance. Additionally, the selection operators make it more probable for the individuals with higher fitness value to survive; however, excessively-strong selection will over-attract the search process to the local minimum point, which makes it easy to converge in advance. The algorithm to define the target function by randomly taking the weights can find the approximate non-inferior solutions of various types, but the group will converge near several non-inferior solutions. Therefore, improvements should be made to the basic GA. Having flexible memory function and aspiration criterion and accepting inferior solutions in the search, Tabu Search has strong hill-climbing capacity and it can step out of the locally optimal solutions and turn to the other regions in the solution space in the search so as to increase the probability to obtain the better globally optimal solutions. Therefore, it is very necessary to introduce Tabu Search in GA; in the meanwhile, GA has the characteristic of global optimization and the final result does not depend on the selection of the initial value. On the other hand, Tabu Search searches along a line from a pint and the quality and convergence speed of the final solution are closely related to the initial solution. Besides, Tabu Search can only have one initial solution in the search and it only transfers one solution to another solution in every generation without operating on the solution collection (group) like GA. Therefore, the hybrid strategy to combine genetic algorithm and Tabu Search can remedy each other's shortcomings and get a better optimization result.

This paper puts forward a Hybrid Genetic and Tabu Search Virtual Reconfiguration Algorithm (HGTS-VRA), which firstly adopts genetic algorithm for global search to determine to major areas with targeted individuals and secondly adopts tabu search algorithm in local search to improve individual quality. This algorithm adopts genetic algorithm in large-scale search. After the target area is narrowed to certain degree while all individuals' locations are fixed, the tabu search method is adopted for local search. In this way, we can significantly reduce the times of calling tabu search algorithm and the amount of calculation. In addition, we can effectively integrate the genetic algorithm's advantage in large-scale search and tabu search algorithm's advantage in local search. The Fig.2 has presented the flow of this algorithm:

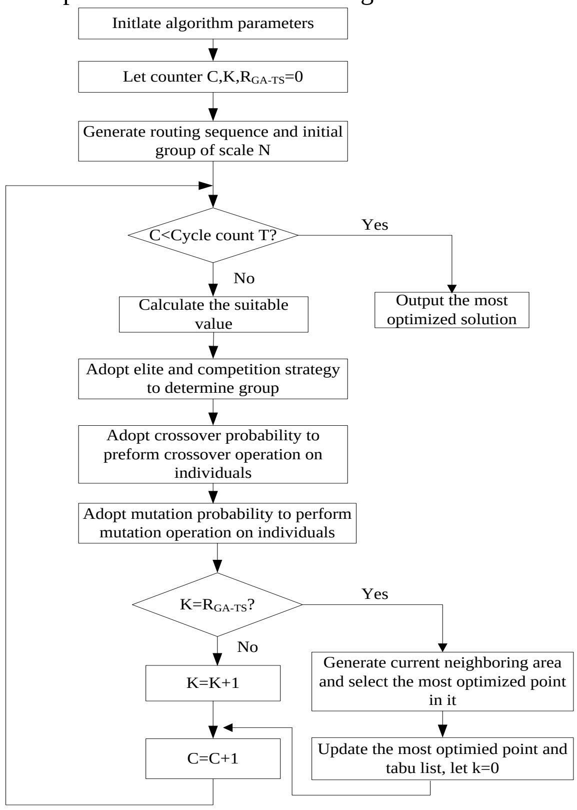

FIGURE 2 HGTS-VRA Algorithm Flow

6.2 ROUTING STEPS AND AUTHENTICATION SETTING

Static traffic routing is an issue global optimization and needs to request routing for batch static traffic of diversified bandwidth granularity. Such traffic request will be stored in terms of array. In regard to traffic request from OTN layer and SDH layer, this paper follows the sequence of requesting routing for traffic in OTN layer before routing SDH traffic and establishing logic links.

Step 1: For the routing of Traffic Ti (the No. i traffic request of OTN layer of SDH layer) in the virtual topology of current layer, we shall try to use rest bandwidth of logic links in current layer. In case of that, it fails in routing procedure, which we can turn to Step 2.

Step 2: Make comprehensive use of network resource in lower layer. The logic links that undertake Ti(s, d, r) can adopt the mixed choice of current exited optic fibres and newly established optical fibre. In case that this routing fails, system will reject this traffic.

When a traffic request Ti (s, d, r) is request routing in the three levels network, the weight value of Edge e (W (e)) in topology of DWDM layer, OTN layer and SDH layer shall be set as:

$$W(e)=\begin{cases}1 & C(e)\geq r\\ \infty & C(e)\prec r\end{cases}. \quad (3)$$

C(e) stands for the maximum rest band within e Links, C(e) guarantees that it will select the minimum tick for link among DWDM layer, OTN layer and SDH layer.

In regard to the traffic whose routing needs to take network resource in both upper layer and lower layer into comprehensive consideration, in case that they need to set different weight value to indicate the difference between link difference in different layers, the weight value of link i (W (i)) shall be set as:

$$W(e)=\begin{cases}\alpha\times C & C(i)\geq r\\ \infty & C(i)\prec r\end{cases}. \quad (4)$$

C stands for the link width of interlayer links, while α stands for integrals larger than 1 to guarantee that W(i) >> 1

6.3 FITNESS FUNCTION

The fitness function is a reference to evaluate individuals in solved space's fitness in their environment. It has normally indicated or determined by target function, expense function or other method. We can set that, in the initial topology of SDH/OTN/DWDM, $G(V^1,E^1)$, $V^1=\{v_i^1\,|i=1,2,\dots n\}$ and $E^1=\{v_{ij}^1\,|v_i^1,v_j^1\in V^1\}$ stand for that node collection and optical link collection, while $e_{ij}^1=1$ or 0 indicates that $G(V^p,E^p)$ layer (2,3) virtual topology built by $G(V^1,E^1)$ respectively, $V^p\in V^1$ and E^p is the link grow of Layer p; set $L_{ij}^{pq}=\{l_{ij}^{pq}\,|v_i^p\in V^p,v_j^q\in V^q;p,q=123;p\neq q\}$ stands for the link number array between layer p and layer q, while l_{ij}^{pq} stands for link number between Node i in layer p and Node j in Layer q. the fitness value is as below:

$$\varphi_f=I_{\max}-1\text{n}\left[\sum_{p,q(p\neq q),i,j} l_{ij}^{pq}\right]. \quad (5)$$

In this formula, $I_{\max}$ is large enough figure to make $\varphi_f>0$, while $\sum_{p,q(p\neq q),i,j} l_{ij}^{pq}$ stands for the interlayer resource usage situation.

6.4 CODING AND INITIAL GROUP GENERATING

One of the basic tasks of genetic algorithm is the coding of solution, which is also known as that the coding of one solution is a chromosome, while the elements that build coding is known as gene. The purpose of coding is to optimize the solution presentation, so that it will be suitable for being calculated by genetic algorithm. The coding way of this paper: based on current network state of Topoi-1, in order to guarantee that traffic could select Topoi-1 shortest ways in Ti(s, d, r), it will randomly select one of the path to service as the path of this traffic and update Topoi-1 to be $Topo_i\,(i=1,2\dots m)$, while m stands for the total gene number in chromosome.

Generate the routing sequence for traffic in OTN layer and SDH layer respectively; select a rout for each traffic Ti(s, d, r) so as to form a chromosome; the mark for the path of each traffic is a gene from chromosome.

Repeat Step 2 N time to gain initial group of N.

6.5 GENETIC OPERATOR

Genetic operator is the main method to simulate group evolution. The genetic operation includes crossover operation, mutation operation and select operation. This paper introduces these three operations in details:

1) Crossover Operation

The crossover is the process in which two parent chromosomes produces new chromosome, while the crossover pattern of SDH layer traffic and OTN layer traffic is similar. Here, we cite OTN layer for example. Assuming that the capacity of new optical fibre is ODU-3 and the rest capacity of parent generation 2 A→B optical fibre 1 is ODU-2 while the rest capacities of other optical fibres are all ODU-2, the optical fibre A→E→D→C only undertakes Ti(A,C,ODU-2)and in Parent Generation 1, there are two optical links, namely optical fibre A→B and optical fibre B→C. In Parent Generation 2, there is a single fibre A→E→D→C. the crossover is the process of exchanging different chromosomes within the path selected by the same traffic based on current topology status. After performing crossover operation to the traffic, this business is undertaken by the new optical fibre A→E→D→C in Child generation 1. In Child generation 2, since the rest capability ODU-1 of optical fibre 1 between A→B is inferior to the bandwidth requested by Ti, the rest capacity of optical fibre 1 between A→B is not sufficient to undertake this traffic. However, the rest capacity of optical fibre 2 between A→B is larger than the band width requested by Ti and the rest capacity of optical fibre 1 between B→C is larger than the band width requested by Ti, this traffic will be undertaken by the optical fibre 2 between A→B and optical fibre 1 between B→C. since the optical fibre A→E→D→C in Child generation 2 does not undertake any traffic after crossover, the resource of this optical fibre will returned.

2) Mutation Operation

Mutation operation is to change a gene's path with steps as below:

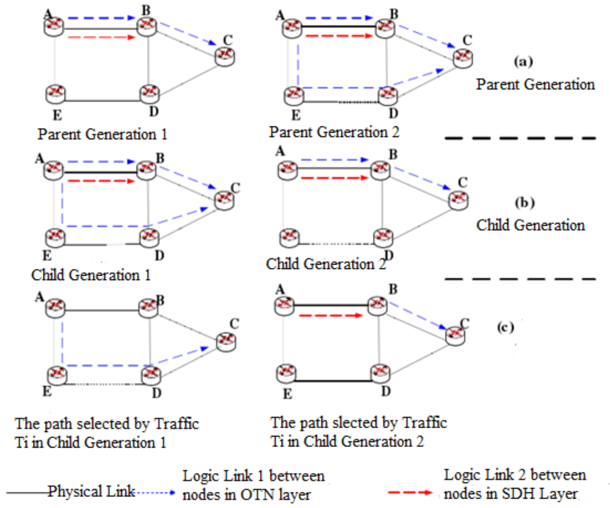

FIGURE 3 Crossover Operation

(1) Mutation based on traffic's tick in DWDM layer: since the logic links in SDH layer and OTN layer are undertaken by SDH layer and OTN layer, when a certain gene from chromosome take up less physical links in DWDM layer than this chromosome's average gene undertaking links, the significant mutation probability will be adopted, otherwise the small mutation probability will be adopted.

$$P_m^{(i,DWDM)} = \begin{cases} P_{mut} & (h_i \geq h_{avg}) \\ P_{mut} \times (h_{avg} - h_i)/(h_i + h_{avg}) & (h_i < h_{avg}) \end{cases} \quad (6)$$

P_{mut} is the initial value of mutation probability and hi is the total physical links consumed by No. i gene in DWDM layer. $h_{avg} = \sum_{j=1}^{m} h_j / m$ is chromosome gene's average undertaking links in DWDM layer and m is total gene number in chromosome.

(2) Mutation based on the average logic link utilization ratio in SDH layer or OTN layer: when the utilization ratio of logic link in SDH layer or OTN layer virtual topology is not large than average utilization rate of logic links in virtual topology, the large mutation probability will be adopted so that the traffic in this link will re-choose path, otherwise, the small mutation probability will be adopted.

uj is the utilization ratio of No. J logic link in virtual topology. $h_{avg} = \sum_{i=1}^{q} u_i / q$ is the average utilization rate of logic link, and q is the total logic link number.

3) Select Operation

Select operation is to select some outstanding individual from the current group. The standard of judging whether an individual is outstanding or not is their fitness value. This algorithm adopts the most popular tournament algorithm and saving best result algorithm. It can copy the individual solution of best fitness from current group to next group for comparison. In this algorithm, the tournament algorithm steps are as below: randomly select 2 individuals from the group; compare the fitness of these two individuals; save the individual of highest fitness value to the next generation; repeat the above procedures until the individuals saved to next generation equals group number N.

7 Algorithm Simulation Result

We adopt NSFnet as the experimental network for comparing the performance of HGTS-VRA and LCBRF-StraGPP. The Fig4 below offers the performance comparison result between HGTS-VRA and LCBRF-StraGPP under the circumstance of different traffic distribution. LCBRF-StraGPP algorithm is an initial solution that takes LCBRF algorithm as tabu algorithm by using tabu node to achieving the most optimal algorithm.

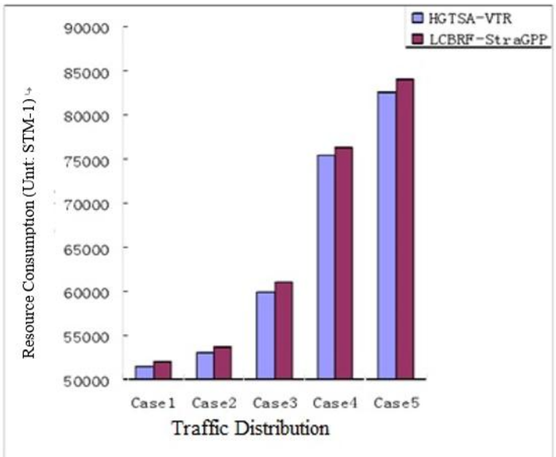

FIGURE 4 The Comparison of Network Resource Consumption between 2 Algorithms

Judged from Fig4, HGTS-VRA has better performance in the aspect of resource consumption compared with LCBRF-StraGPP. In addition, with the increase of traffic, this performance gap increases. HGTS-VRA's operation time is related to traffic volume, group quantity and frequency of calling tabu search. Since it adopt genetic algorithm and tabu mechanism at the same time, its operation time is around 3-5 times as that as LCBRF-StraGPP consumes. However, since it could the static traffic routing can be calculated offline, the decrease of resource consumption overtake the increase of operation time.

8 Conclusions

This paper puts forward a new optical fibre routing and resource optimization algorithm, which is known as the Hybrid Genetic and Tabu Search Virtual Reconfiguration Algorithm (HGTS-VRA). It can effectively integrate the large scale searching ability of genetic algorithm and the outstanding local searching ability of tabu search to help static traffic routing and resource optimization.

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