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QoS Routing Optimization Strategy Using Genetic Algorithm in Optical Fiber Communication Networks

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Abstract This paper describes the routing problems in optical fiber networks, defines five constraints, induces and simplifies the evaluation function and fitness function, and proposes a routing approach based on the genetic algorithm, which includes an operator [OMO] to solve the QoS routing problem in optical fiber communication networks. The simulation results show that the proposed routing method by using this optimal maintain operator genetic algorithm (OMOGA) is superior to the common genetic algorithms (CGA). It not only is robust and efficient but also converges quickly and can be carried out simply, that makes it better than other complicated GA.

Keywords genetic algorithm, optimal maintain operator (OMO), optical fiber communication network, QoS routing

1 Introduction

With the development of the optical fiber technology, data communication has been speeded up from 56 Kbps (ARPANET) to 1 Gbps (modern optical communication). Meanwhile, the error rate went down from 10^{-5} per bit to almost zero[1]. In addition, fiber can handle much higher bandwidths than any other transmission media[2], with the advantage of not being affected by power surges, electromagnetic interference, and power failures. In the future, fiber will become more and more popular.

Almost all communication networks including optical fiber communication networks require that the route should support QoS request. To support the requirement of extensive QoS, routing algorithms need rather complicated matrix to characterize the network with several indexes, such as delay, bandwidth, packet loss rate, and cost[3,4]. Thus, the routing problem based on QoS can be converted to the optimum-searching problem satisfying several constraints simultaneously. This kind of routing problem is proved to be an NP-problem[5].

Genetic algorithms have been applied to the optimization of the network topology structure[6–8], and obtained some beneficial results. Recently, GA was found to be well suitable for routing problems[4,9,10]. And some researchers solved routing problem with their improved genetic algorithms and the approach was proved to be feasible. However, the localization of GA search, especially in the large-scale network with complicated topology structure, makes it perform badly, which may lead to premature convergence without optimal solution. In this paper, the genetic algorithm with optimal maintain operator (OMOGA) is applied to solve the QoS routing problem in optical fiber networks. The simulation results show that the proposed routing method using the OMOGA is not only easy to execute compared with other GAs, but also feasible and efficient and superior to the common genetic algorithms (CGA). Further, by selecting genetic constraints it can eliminate the circulating routing. This routing optimization method can be applied to arbitrary optical fiber communication networks with complicated topology.

The rest of the paper is organized as follows. In Section 2, we introduce OMOGA based on CGA. In Section 3, we state the QoS routing problem in optical fiber communication networks formally. Section 4 describes coding method and the problem of QoS in fiber networks and proposes a strategy for routing optimization based on OMOGA. In Section 5, we analyze the feasibility of the proposed OMOGA and compare it with CGA. Finally, Section 6 gives the conclusion of this paper.

2 The Genetic Algorithm with Optimal Maintain Operator (OMOGA)

Common Genetic Algorithm (CGA) is a kind of

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random global optimization method developed recently, based on the principle of natural selection and genetics. It is quite simple and robust, and very easy to be implemented. so that it has been applied to solve large-scale problems successfully[6−8].

OMOGA is the improvement of CGA. The common genetic operators of OMOGA are the same as those of CGA. However, in OMOGA the best one of every generation is used in the next generation directly. The best one of every generation is compared with the best one of the previous generation, and the better one is used in the current generation.

It can be seen from the above definition that elitist model[11,12] is adopted in OMOGA as the selection operator. It has been proved that elitist model based GA could finally converge to the global optimal solution[11]. In OMOGA, there are N selected mothers which cross and mutate to produce the new generations just as the CGA. It makes OMOGA different from the sole elitist model based GA which selects $N-1$ mothers[12].

Therefore, we employ OMOGA to solve the routing problem in the optical fiber communication networks. The results verify that there is no immature convergence in OMOGA.

3 QoS Routing Problem Presentation

We model the topology network structure with undirected graph $G=(V,E)$, where network nodes are represented by vertexes and links are represented by edges. V is the set of network nodes and E is the set of links in the graph. Every edge $l_i \in E$. The aim of routing selection is to search for the optimal path while satisfying the QoS requirement between the source nodes and the end nodes.

Routing in optical fiber communication networks is a little different from other communication networks because of the characters of the fibers. QoS routing is composed of several factors, such as cost, bandwidth, packet loss rate, delay and so on[4]. In optical fiber communication networks, we may not consider the bandwidth constraint because of the unique character of optical fibers, which have the bandwidth wide enough to transmit almost any signal[5]. But the nodes (computer or server) have the finite bandwidth. Therefore, if there are many requests at the same time some requests must wait till the nodes have free time to deal with. Sometimes the delay is short enough to satisfy the request of users. Because different operations have different requests of delay and loss rate, and the request is represented in real time, the routing algorithm must be dynamic.

The routing request q of a single destination consists of source node, destination node and QoS request including error rate Lu, cost Wu, delay Du, and the number of nodes from end to end. In general, the error rate is almost zero and the delay is very small when the signals transmit in the optical fibers because the speed of light is supreme. But we should consider the error rate and the delay of the nodes. So the routing algorithm should find a path that satisfies the QoS required by routing request q. The following conditions must be satisfied:

Delay constraints by the mid nodes between source node and destination node:

$$\textstyle\sum_{l_{ij}\in Eu} D(l_{ij}) \leqslant Du \ (j = \text{ mid nodes, including destination node}). \tag{1}$$

Error rate constraints from end to end:

$$\textstyle\prod_{l_{ij}\in Eu}(1-L(l_{ij})) \geqslant 1-Lu \ (j=\text{mid nodes, including destination node}). \tag{2}$$

Cost constraints from end to end are limited within Wu:

$$\sum_{l_{ij}\in Eu} W(l_{ij}) \leqslant Wu \tag{3}$$

where $l_{ij}\in Eu$, Eu is the selected route, $Eu \subset E$. $D(l_{ij})$ is the handling delay of the node j, $L(l_{ij})$ is the loss rate of node j and $W(l_{ij})$ is the cost of link l_{ij}. In (1) and (2), j should represent all mid nodes. Here, j is set to include destination node in order to simplify computing.

4 Strategy for Routing Optimization Based on OMOGA

4.1 Coding and Decoding Mechanism of OMOGA

We take $\lfloor v_{ij}\rfloor_{N\times N}$ as the coding mechanism of genetic algorithm, construct the topology network matrix $\lfloor l_{ij}\rfloor_{N\times N}$, and assume that the optical fiber communication network has N nodes, so the topology network matrix model has $N\times N$ elements. Except diagonal elements, each element corresponds to the likely existing link l_{ij}, evidently, here $l_{ij}=l_{ji}$. Then the element l_{ij} located in the matrix corresponds to the link l_{ij} from node i to node j,

$$l_{ij}=\begin{cases}1, & \text{if link } l_{ij} \text{ from node } i \text{ to node } j \text{ exists in the topology network;}\\ 0, & \text{otherwise.}\end{cases}$$

The routing problem can be described by N-dimensional binary routing evolution matrix

$[v_{ij}]_{N\times N}$, where the elements on rows represent all start nodes of the network, the elements on columns represent all destination nodes (vice versa, the row and column are equivalent).

Each element of the evolution matrix corresponds to the link v_{ij} from node i to node j, located on row i and column j.

$$v_{ij} = \begin{cases} 1, & \text{if the optimal route includes link from node } i \text{ to node } j; \\ 0, & \text{otherwise.} \end{cases}$$

Similarly, the link elements that are not located in the selected route are set to constant zero. And we design the value of the diagonal elements as zero, thus the value of v_{ij} indicates whether the link l_{ij} from i to j is selected. When $v_{ij} = 1$, the link l_{ij} is the selected route leading to destination. While $v_{ij} = 0$, it shows that the link l_{ij} is not included in the route leading to destination, or other instances.

It is obvious that the decoding of this genetic algorithm maps the N-dimensional matrix to the representation of binary array. Therefore, the optimal state in the genetic evaluation routing matrix straightly represents an optimal path from the initial source nodes to the final determination nodes. For example, there are 6 nodes in the topology of the optical fiber communication networks; the matrix A can represent a route from a_1 to a_6. The route is $a_1 \to a_2 \to a_4 \to a_3 \to a_5 \to a_6$.

Here

$$[l_{ij}]_{N\times N} = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1N} \\ l_{21} & 0 & \cdots & l_{2N} \\ \cdots & \cdots & 0 & \cdots \\ l_{N1} & l_{N2} & \cdots & 0 \end{bmatrix},$$

$$A = \begin{matrix} a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \end{matrix} \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}.$$

Evidently, we can get the constraints of the optimal path as follows:

(i) only if it includes link l_{ij} in the network topology structure, i.e., $l_{ij} = 1$, the element v_{ij} in the evaluation routing matrix may take 1, i.e., $v_{ij} = l_{ij} \times v_{ij}$;

(ii) every element in the evaluation routing matrix can but take 0 or 1;

(iii) in the binary coding evaluation routing matrix, no more than one element in each row takes 1, i.e., $\left(\sum_{j=1}^{N} v_{ij} - 1\right) \leqslant 0$;

(iv) in the binary coding evaluation routing matrix, no more than one element in each column takes 1, i.e., $\left(\sum_{i=1}^{N} v_{ij} - 1\right) \leqslant 0$;

(v) intermediate elements (except source and destination nodes) of the binary coding evaluation routing matrix will be the inceptive node of the next link, if it is the arriving node, i.e., $\sum_{i=1}^{N} v_{ij} - \sum_{i=1}^{N} v_{ji} = 0$ (j represents all the intermediate nodes along the optimal path).

Obviously, if the route includes the circulating links, one of the nodes belonging to the route must be the destination node twice. And in evaluation routing matrix, there must be more than one element in each column taking 1. Then the route cannot satisfy the constraints (iii), (iv) and (v). Therefore, the constraints (iii), (iv) and (v) avoid circulating links.

4.2 Evaluation Function Establishment

According to the above mechanism of coding, decoding and several constraints, we design the evaluation function as follows:

$$\begin{aligned} E_0 = {} & \frac{A}{2}\sum_{j=1}^{N}\sum_{i=1}^{N}(v_{ji} - l_{ij}v_{ij})^2 + \frac{B}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} v_{ij}(1 - v_{ij}) \\ & + \frac{C}{2}\sum_{j=1}^{N}\Big(\sum_{i=1}^{N} v_{ij} - 1\Big)^2 + \frac{D}{2}\sum_{i=1}^{N}\Big(\sum_{j=1}^{N} v_{ij} - 1\Big)^2 \\ & + \frac{E}{2}\sum_{j=2}^{N-1}\Big(\sum_{i=1}^{N} v_{ij} - \sum_{i=1}^{N} v_{ji}\Big)^2 \\ & + \Big(\frac{F}{2}\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}v_{ij} - Wu\Big)^2 \\ & + \frac{G}{2}\Big[\sum_{i=1}^{N}\sum_{j=1}^{N} t_{ij}v_{ij} - (Du - d_0)\Big]^2 \\ & + \frac{H}{2}\Big[\prod_{i=1}^{N}\sum_{j=1}^{N}(1 - v_{ij}\mu_{ij}) - (1 - Lu)\Big]^2. \end{aligned} \quad (4)$$

Here t_{ij}, μ_{ij} and w_{ij} denote the delay, signal error rate and cost respectively, that can be obtained by measuring network as the vital index of routing. Du, Lu, Wu, d_0, and b_0 are designated by QoS. Every item in (4) corresponds to an item of constraints (i) to (v) mentioned above and QoS requests (1) to (3) respectively.

Consider that the first five constraints (i) to (v) of the elimination function are strong constraints, and a route cannot be optimal if not satisfying any of them. Therefore, in the realization of particular algorithm, we define the five constraints as chromosome constraints, and only the filial generation satisfying genetic constraints can exist.

Five genetic constraints ψ_1, ψ_2, ψ_3, ψ_4 and ψ_5:

$$\begin{cases} \psi_1 \equiv v_{ij} - l_{ij} \times v_{ij} \equiv 0, \\ \qquad\qquad (i = 1, 2, \ldots, N,\ j = 1, 2, \ldots, N) \\ \psi_2 \equiv v_{ij}(1 - v_{ij}) \equiv 0, \\ \qquad\qquad (i = 1, 2, \ldots, N,\ j = 1, 2, \ldots, N) \\ \psi_3 \equiv \sum_{i=1}^{N} v_{ij} - 1 \leqslant 0, \\ \qquad\qquad (i = 1, 2, \ldots, N,\ j = 1, 2, \ldots, N) \\ \psi_4 \equiv \sum_{j=1}^{N} v_{ij} - 1 \leqslant 0, \\ \qquad\qquad (i = 1, 2, \ldots, N,\ j = 1, 2, \ldots, N) \\ \psi_5 \equiv \sum_{i=1}^{N} v_{ij} - \sum_{i=1}^{N} v_{ji} \equiv 0, \quad i = 1, 2, \ldots, N : j \\ \quad \text{represents all the intermediate nodes along} \\ \quad \text{the optimal path.} \end{cases}$$

Only three optimization targets are involved when choosing elimination function E_1.

$$\begin{aligned} E_1 = {} & \frac{F}{2}\Big(\sum_{i=1}^{N}\sum_{j=1}^{N} w_{ij}v_{ij} - Wu\Big)^2 \\ & + \frac{G}{2}\Big[\sum_{i=1}^{N}\sum_{j=1}^{N} t_{ij}v_{ij} - (Du - d_0)\Big]^2 \\ & + \frac{H}{2}\Big[\prod_{i=1}^{N}\prod_{j=1}^{N}(1 - v_{ij}\mu_{ij}) - (1 - Lu)\Big]^2 \end{aligned} \tag{5}$$

The selected fitness function is

$$E = \frac{1}{E_1 + 1} \tag{6}$$

When E_1 tends to 0, E comes to 1 approximately. The optimal route is the matrix or two-dimensional array that corresponds to the one with fitness 1.

4.3 Realization of OMOGA

Perform specific routing algorithm as follows.

I. Select matrix colony $\{v_{ij}\}$ from current matrices, and evaluate its evolution matrix (chromosome) which creates the initial of evolution routing matrix according to the preceding four strong constraints. Simultaneously, present route delay matrix $\{t_{ij}\}$, cost matrix $\{w_{ij}\}$ and loss rate matrix $\{\mu_{ij}\}$ as the information of delay, cost and loss rate of the current link, respectively.

II. By using fitness function E, evaluate the fitness of all solutions in the colony, label the best one and compare it with the former best one if there is a former generation, then select the better one as the best one of the current generation.

III. According to five genetic constraints, process the new colony using CGA.

IV. Rule of stopping testing. If it is satisfied, then stop; otherwise turn to II.

5 Simulation Analysis

Carry out computer simulation experiment with Matlab 6.1 on a PC Pentium Ⅲ 1G. The number of running times is set to 50.

Figs.1 and 2 show the topology of network systems. Fig.1 consists of six nodes and eight edges. Fig.2 consists of thirteen nodes and several edges connecting the nodes. Each of the nodes and edges is denoted by the parameters. The elements in the parentheses are error rate and delay, respectively. Cost is marked on the side of edges.

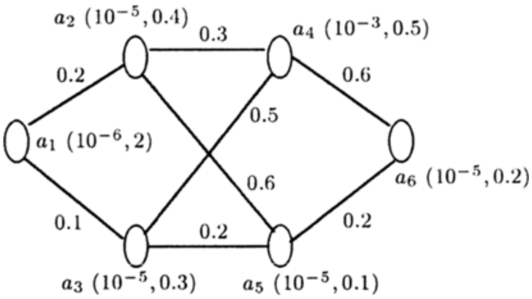

Fig.1. Network topology structure and its parameters of Example 1.

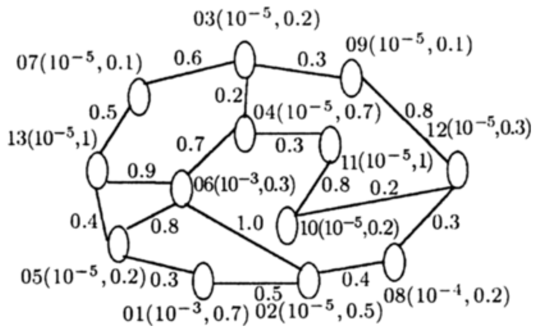

Fig.2. Topology structure and its parameters of Example 2.

Example 1. Employing the network topology structure shown in Fig.1. Perform routing from source node a_1 to destination node a_6. Population dimension is set to 10, $P_{\text{crossover}} = 0.95$, $P_{\text{mutation}} = 0.03$, coefficient $F = G = H = 100$. To conduct simulation by employing the OMOGA proposed above, the mean genetic era is 4. We can obtain the global optimal solution when passing down to the third generation. While simulation with CGA the mean genetic era to obtain the optimal path is 62.

Example 2. Employing the network topology structure shown in Fig.2. According to above algorithm flow, draw up procedure to perform routing from node 01 to node 10, and the size of population is set to 40. $P_{\text{crossover}} = 0.95$, $P_{\text{mutation}} = 0.03$, coefficient $F = G = H = 100$. By simulating with this OMOGA, we can obtain the optimal path, and through several simulations the mean number of generations to gain optimal solution is 15. While simulating with CGA, the mean number of generations to gain optimal solution is 627. Compare with CGA, OMOGA requires less retries.

Table 1 shows some experimental results obtained with CGA and OMOGA. The data clearly indicate that the mean genetic era of OMOGA is less than that of CGA.

Table 1. Simulation Results of CGA and OMOGA

Example	1	2
Population	10	40
Running times	50	50
Mean genetic era (OMOGA)	4	15
Mean genetic era (CGA)	62	627

The shortcoming of GA is the extra use of computational resources; more time and computing power are required to execute GA. But given a reasonably powerful processor, time requirement for even thousands of GA iterations can be only a few milliseconds, thus making it suitable for real time scenario. Alternatively, the execution of GA can be carried out off-line and the results can be used to on-line execution.

The results of simulation validate that this model can always converge to a stable state. Therefore, the optimal state in the genetic evaluation routing matrix represents an optimal path from initial source nodes to final determination nodes. And from the two cases, it is obvious that OMOGA is not only easy to carry out but also superior to CGA.

To make an in-depth analysis, the simulation experiments of OMOGA are also implemented in large-scale network having more than 100 nodes. This algorithm can find the optimal routing under limited time. The simulation results demonstrate that the time complexity function polynomially changes along with the increasing of the input loading of examples. It shows that this algorithm is a polynomial time algorithm. It is proved that the polynomial time algorithm is a practical and valid algorithm[13]. The fact that the time complexity function of OMOGA is a polynomial time algorithm proves its efficiency.

6 Conclusion

By using OMOGA, we can obtain the optimal solution of single-destination routing problem through simulation. This method is of low computational complexity, and can be realized with software. Compared with the CGA, it reduces calculation time, and eliminates premature convergence. This algorithm can also be applied to multi-destination routing in the optical fiber communication networks. Alternatively, the execution of OMOGA can be carried out off-line and the results can be used to on-line execution.

The proposed method in this paper solves the routing problem in optical fiber communication networks that have several QoS constraints. The results of simulation verify its superiority. This algorithm covers QoS parameters entirely, and it can be carried out simply and converges quickly. This algorithm is independent, that is, it does not rely on any specific network, which endows it with extensive applicability in network systems.

References

[1] Andrew S Tanenbaum. Computer Networks. 3rd ed., Tsinghua University Press, 1998.

[2] Govind P Agrawal. Fiber-Optic Communication Systems. New York: John Wiley & Sons, Inc. (US), 1997.

[3] Shigang Chen, Nahrstedt Klara. An overview of quality of service routing for next-generation high-speed networks: Problems and solutions. *IEEE Network*, 1998, 12(6): 64–79

[4] Xiang Fei, Junzhou Luo, Jieyi Wu *et al.* QoS routing based on genetic algorithm. *Computer Communications*, 1999, 22(15-16): 1392–1399.

[5] Wang Zheng, Jon Crowcroft. Quality-of-service routing for supporting multimedia applications. *IEEE J. Selected Areas in Communications*, 1996, 14(7): 1228–1234.

[6] Chou Hsinghua, Premkumar G, Chao-Hsien Chu. Genetic algorithms for communications network design — An empirical study of the factors that influence performance. *IEEE Trans. Evolutionary Computation*, 2001, 5(3): 236–249.

[7] Berna Dengiz, Fulya Altiparmak, Smith Alice E. Efficient optimization of all terminal networks using an evolutionary approach. *IEEE Trans. Reliability*, 1997, 46(1): 18–26.

[8] Sayoud H, Takahashi K, Vaillant B. Designing communication networks topologies using steady-genetic algorithms. *IEEE Communications Letters*, 2001, 5(3): 113–115.

[9] Wang Zhengying, Shi Bingxin, Erdun Zhao. Bandwidth-delay-constrained least-cost multicast routing based on heuristic genetic algorithm. *Computer Communications*, 2001, 24(7-8): 685–692.

[10] Cedric Davies, Pawan Lingras. Genetic algorithms for rerouting shortest paths in dynamic and stochastic networks. *European J. Operational Research*, 2002, 144(1): 27–38.

[11] Guoliang Chen, Xufa Wang, Zhenquan Zhuang *et al.* Genetic Algorithm and its Application. People's Post and Telecommunications Press, 1996. (in Chinese)

[12] Zhang Wenxiu, Leung Yee. Mathematical Foundation of Genetic Algorithms. Xi'an Jiaotong University Press, 1999. (in Chinese)

[13] Zhiping Ch, Zongben X. Computer Mathematics — Complexity Theories of Computing and the Solution of NPC, NP-Hard Problem. Science Press, 2003. (in Chinese)