Optimization of Optical Network using Genetic Algorithm

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Abstract—The increasing importance of telecommunications for applications such as the internet and video on demand leads to a requirement for a high bandwidth network made of optical fibers. The design of an optimal optical fiber based network is a complex comprehensive task. Some of the problem domains are the topology, connectivity and routing decisions. This work explores an optical network design tool based on Genetic Algorithms (GA) and compares it with Simulated Annealing (SA). A solution has been proposed based on GA that minimizes the cost of fiber ducts and installs a minimum net present cost of Optical Network and satisfies the customer demand criterion. The average GA solution cost less than the average SA solution.

Key Words: Genetic, algorithm, optimization, optical, network, planning.

1. INTRODUCTION

Telecommunication networks today, utilize fiber optic cable as their medium of choice to carry large quantities of data over long distances. Fiber optic cable provides a way to multiplex multiple digital channels together to carry voice, real time video and large volume of still images in addition to the growing volume of computer data. This allows a multitude of new services to provide bandwidth on demand, variable bandwidth, high bandwidth, user control, measurement of traffic performance and rapid service provisioning. The Optical Network planning problem is defined as finding shortest paths between the nodes, as in installing a new network most of the money is spent on digging the cable ducts. These networks can be implemented in several topologies. One such configuration is a ring structure where the OLT (Optical Line Termination) in the central office can be seen as the root and the ONU (Optical Network Units) as the nodes in the ring. Ring architecture is considered as it is cost effective and offer high network survivability in the face of node failure and provides greater bandwidth sharing [3]. Customer access points are connected to the ONU in a star topology. These devices take an optical fiber as input and split the signal carried on this fiber over a number of fibers on the output. Signal attenuation constraints require that the signal is only split at a maximum of two points between the exchange and customer. The first splitting point in the network is called the primary node. The second point at which the signal is split is called the secondary node. The diagram Fig. 1 shows a ring of fiber connecting the primary nodes and the method of connecting the end-users to these primary nodes.

![Fig. 1: Schematic for a network planning](image-url)

2. PROBLEM DESCRIPTION AND OBJECTIVE

While planning optical network design there are two sets of customers to be considered, the user who would be using the services through the network and the company that will be building the network and maintaining it. Therefore while planning the networks there are two principal objectives to be considered. One, the network should meet the end-users needs in terms of quality of service and cost. Two, for the network operator it should be as cost effective as possible to install and maintain the network. The second objective has traditionally been examined as reducing the first installed cost of the network. Minimizing the total cost is mainly a matter of finding shortest paths between the nodes, as in installing a new network most of the money is spent on digging the cable ducts. These networks can be implemented in several topologies. One such configuration is a ring structure where the OLT (Optical Line Termination) in the central office can be seen as the root and the ONU (Optical Network Units) as the nodes in the ring. Ring architecture is considered as it is cost effective and offer high network survivability in the face of node failure and provides greater bandwidth sharing [3].
In this work we have considered the case where there is a single connection from the primary to secondary node and from the secondary node to customer. This is likely to be the most common installation strategy for the network as back-up links are very expensive. When installing a new network in the access area, the majority of money has to be spent on digging the cable ducts. Thus, minimizing the total cost is mainly a matter of finding the shortest street paths which interconnect all ONUs with the OLT. A city map can be represented by a graph where the streets are the links, and the street junctions together with the ONUs and the OLT make up the nodes. Here, we have taken the location of the exchange, location of potential end-users, and a forecast of these end users’ demand in terms of number of lines and year. Variables are the primary and secondary node locations, cable sizes and routes, duct capacity and routes, assignment of end-users to secondary nodes, and the assignment of secondary nodes to primary nodes. The network must be implemented subject to the constraints of - attenuation, maximum distance between a node and lastly a customer and planning rules. The aim of the planning is to satisfy both the network’s end-users and the network operator, by producing a reliable cost-effective network.

The objective of the optimization is to install a minimum net present cost network that satisfies the customer demand criterion. This problem can be classified as a dynamic network optimization problem with a discontinuous link cost function [4]. Let the graph G=(V,E) be a set of V nodes and a set of E edges. A ring is a sequence of vertices with n number of nodes v1, v2,…vn, such that {vi,vi+1}, for all 1<=i<=V, is a link, and that v1=vn.

The objective function used to optimize the backbone network has been taken as:

Objective fun = min \( \sum \sum (x_i - x_{i+1})^2 + (y_i - y_{i+1})^2 \)  \( (1) \)

Where,

\[ x_i, y_i = \text{co-ordinates of the nodes} \]
\[ x_0 y_0 = x_0 y_0 \]

3. NETWORK DESIGN METHODOLOGY USING GENETIC ALGORITHM

The problem has been divided into two phases. In the first phase Genetic Algorithm has been used to design the backbone network using the ring topology. The configuration string has been taken as the integer value by assigning a pseudo link weight to the respective link which is not correlated to the real cost value of this edge. The pseudo link weights are only auxiliary parameters. Link has been defined as the connection between two nodes. The cost function has been calculated based on objective function given in (1). The position of the primary and secondary nodes and the associated split-levels can be represented using a simple bit string. An individual is therefore a combination of two types of genome; a list for representing allocation and a bit string for representing split level and secondary and primary node positions. The two can be evolved in parallel and the fitness score of the individual depends on the performance of both the genomes. Thus the initial problem is solved wherein the primary nodes are optimally connected to the local exchange in the ring topology. The second stage is then to optimize the allocation of end-users to the secondary nodes and assigning secondary nodes to the primary nodes. For encoding of the problem the following methodology has been considered.

There are m end-users and p secondary nodes a matrix of \( p^m \) is taken. A constant k is chosen based on the condition of fiber optics i.e. the maximum possible distance the signal can be transmitted without getting attenuated. Initially the configuration string is taken at random based on the constraint that the distance between the end-node and the secondary node will be less than or equal to k. Also to optimize the time at which cable is installed into the network to create a network that uses the above allocations, split levels and positioning. A heuristic method has been used to achieve this installation strategy. Heuristic used is:

Step 1. Set year, \( y = 0 \)
Step 2. For each customer with demand in \( y \), connect it to the secondary nodes to which it is assigned by the shortest route through the duct network.
Step 3. For each secondary node connected in the previous step connect it to the primary node to which it is assigned.
Step 4. If \( y \) is the final year of the planning period then finish else increment \( y \) and go to Step 2.

This heuristic has been included in the objective function of a genetic algorithm so that iteration is not required between the two stages. Costing of the installation is based on the net present worth of the plant in the year it is installed.

A. Network Optimization Using GA

Step 1. Initialize population with \( n \) solutions.
Step 2. Evaluate fitness of each solution. Save best solution.
Step 3. Repeat \( \text{max} \) times { 
Step 4. Select solutions for next generation using tournament selection of size \( s \)
Step 5. After a specified number of generations, copy the best member \( n \) times, and delete exactly one distinct node location from each solution.
Step 6. Pick two solutions with probability \( P_c \) and exchange genetic material with x-point segmented crossover operator
Step 7. Mutate solution with probability \( P_m \) by randomly adding, deleting, or exchanging node locations.
Step 8. Evaluate fitness of each solution (i.e (1)).
Step 9. Replace worst solution of present generation with best solution found.)

The parameters were established empirically from a series of test runs using MATLAB.

4. EXPERIMENTAL RESULTS

Genetic Algorithms has been used to find an optimum connection, using ring topology, between nodes in the backbone network. Number of experiments was conducted with varying parameters. For all the experiments the results were recorded based on the terminating condition of GA. The objective function in (1) has been considered. These parameters were established empirically from a series of test runs. Fig. 2 shows the best network configuration obtained by GA for the connection of Primary nodes to the exchange. The graph, Fig. 3, shows the comparison between the average costs.
and the best cost of the individual in the solution space. Table 1 summarizes the best cost and time required using GA, with varying nodes size, to generate the solution comparison chart for Average Cost and Best Cost.

![Fig. 2: Optimum network with 50 nodes using GA.](image)

![Fig. 3: Comparison chart for Average Cost and Best cost with 50 nodes.](image)

### Table 1: Results obtained in phase I

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Nodes</th>
<th>Phase I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>GA Time</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
<td>1 min 30 secs</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>4 min</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>8 min 40 secs</td>
</tr>
</tbody>
</table>

### Table 2: Results obtained in phase II

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Nodes</th>
<th>Phase II GA Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>4 min</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>9 min 11 secs</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>18 min</td>
</tr>
</tbody>
</table>

The allocation of end-users to secondary and primary nodes can be treated as an ordering problem. The approach taken is to represent the problem using an ordered list of end-users. The first n end-users from the list are assigned to the first secondary node, the second n end-users to the second node, etc. Unlike many optimization techniques, GA works effectively with discontinuous cost functions. The cost of assigning a customer to a node is calculated by finding the shortest path from the customer through the network of ducts to the node. The constraint that has been considered for assigning the end-users to the secondary nodes is that no more than 8 end-users can be connected to a single secondary node. The best results are shown for end-user networks using GA, Fig. 4. In the figures a network with 100 end-users has been considered. It can be observed from the resultant network, the majority of the nodes in the network obtained by GA supply nearby clusters of end-users.

![Fig. 4: End-users connected to secondary nodes and secondary nodes connected to primary nodes in star topology using GA.](image)

### A. Comparison with Simulated Annealing

Results obtained using Genetic Algorithm is compared to same problem [5] solved using simulated annealing; this problem explores an ATM network design tool based on Simulated Annealing (SA). Here solution has been proposed based on SA that minimizes the cost of fiber ducts and installs a minimum net present cost of PON (Passive Optical Network) ATM, which satisfies the customer demand criterion. Also a comprehensive ATM design tool has been proposed in which the backbone network is connected using ring topology and the end-user connectivity is provided using star topology. Results are compared on the basis of execution time and obtained cost. Results are summarized in Table 3 and Table 4.

### Table 3: Results obtained in phase I

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Nodes</th>
<th>Phase I</th>
<th>SA Time</th>
<th>SA Cost</th>
<th>GA Time</th>
<th>GA Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td></td>
<td>2 min</td>
<td>2435</td>
<td>1 min</td>
<td>2336.50</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td></td>
<td>4 min</td>
<td>4677.43</td>
<td>4 min</td>
<td>4498</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td></td>
<td>10 min</td>
<td>8997.78</td>
<td>8 min</td>
<td>8534.67</td>
</tr>
</tbody>
</table>

### Table 4: Results obtained in phase II

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Nodes</th>
<th>Phase II SA Time</th>
<th>Phase II GA Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>5 min</td>
<td>4 min</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>9 min 11 secs</td>
<td>9 min 11 secs</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>20 min 45 secs</td>
<td>18 min</td>
</tr>
</tbody>
</table>

This result leads to the conclusion that Genetic Algorithm works better than Simulated Annealing. The average GA solution cost less than average SA solution. It is more probable that SA may discard potentially “good” solutions than GA because SA retains a single solution and GA retains a population of solutions.

### 5. CONCLUSION

A Genetic algorithm based optimization system for optical network has been designed, implemented and tested. From the simulation results it can be concluded that GA based optimization provides a good network design tool for the network design problem. Firstly GA has been used to connect the primary nodes in ring topology and secondly the end-users have been connected to the secondary nodes in star topology using GA and then the secondary nodes are connected to the...
nearest primary node. An optimization system such as the one described here will enable a planner to evaluate a large number of scenarios under different conditions.

REFERENCES


