ATM NETWORK PLANNING: A GENETIC ALGORITHM APPROACH

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ABSTRACT

The Asynchronous Transfer Mode (ATM) network is expected to become a backbone network for high speed multimedia services as the demand for applications such as internet and video on demand increases. One of the major issues in ATM network is the design. The design of an optimal ATM network is a complex comprehensive task. ATM network based on Passive Optical Network (PON) is one such solution. The deployment of optical fiber in the local access network is an essential step towards the provision of advanced ATM network services to the end user. Considering the strategic and financial implications for communications providers, it is clearly very important that fiber networks are implemented in a cost-effective manner. This paper demonstrates an optimization based approach using Genetic Algorithm (GA) for network planning. The optimal backbone ATM network design is characterized by the requirement to minimize the cost of fiber ducts. The objective of the optimization is to install a minimum net present cost network that satisfies the customer demand criterion. In this paper GA has been used to optimize the ATM backbone network. In addition GA has been used to provide end user connectivity. From the results obtained it can be inferred that computer based technique using genetic algorithm is a powerful tool for reducing the complexity of the planning task and ATM network based on PON provides a cost effective solution to ATM design.

Keywords: *Asynchronous Transfer Mode, Passive Optical Network, Genetic Algorithm.*

1. INTRODUCTION

ATM is a packet switched, connection oriented transfer mode based on asynchronous time division multiplexing. ATM is considered to reduce the complexity of the network and improve the flexibility of traffic performance [1]. In ATM, information is sent out in fixed-size cells. Each cell in ATM consists of 53 bytes. Out of these 53 bytes, 5 bytes are reserved for the header field and 48 bytes are reserved for data field. ATM is Asynchronous as the recurrence of cells sent by an individual user may not be necessarily periodic. ATM integrates the multiplexing and switching functions and allows communication between devices that operate at different speeds [2]. The objective of ATM network planning is to design the network structure to carry the estimated traffic and also to minimize the cost of network [3][4]. Over the last decade, many programming models have been developed [5][6] which deals with telecommunication network planning [7]. A large number of network optimization problem do not have any standard algorithm that can guarantee an optimal solution in real time, based on the different constraints. As the models for the design of ATM networks are quite complex, and involve generally a very large number of integer and continuous variable, meta-heuristics like GA has been used to solve the design problem [8] – [10]. Abuali et. al. [11] presented a GA based algorithm for the capacitated concentrator location problem and develop a permutation-based representation. The resulting algorithm out-performed a greedy heuristic on larger problems. Elbaum & Sidi, [12] considered the problem of designing local area computer networks which corresponds to the minimum spanning concentrator location problem. Chardaire *et a*l. [13] have also used GA and applied it to uncapacitated and capacitated versions of SS-CLP. The paper does not describe how they assign end-users if there are capacity constraints. One of the limiting factors in the design of the ATM network as can be deduced from the literatures cited is the requirement of expensive exchange based equipments. Passive Optical Network is a solution to the problem. It provides a way to gradually introduce fiber optic technology into access networks while still deploying parts of the traditional copper line or co-axial cable systems. These networks allow many different configuration options and as such will place new demands on network planners. Most of the literatures available with respect to PON ATM's pertain to the Steiner tree topology implementation. This paper addresses the comprehensive ATM network planning problem which deals with the backbone network design using the ring topology. Ring architecture is considered cost effective as they offer high network survivability in the face of node failure and greater bandwidth sharing [14]. And also the problem of end-user connectivity with the backbone network has been addressed.

2. GENETIC ALGORITHM

GA is a non-traditional based optimizing technique [15] which can be used to optimize the ATM network. GA operations [16, 17] can be briefly described as Coding, Initialization, Evaluation, Reproduction, Crossover, Mutation and Terminating condition. Coding-This step is to represent the variables of the optimization problem in the form of genes. Initialization-Chromosomes with different genes are randomly selected as the initial chromosomes. These random chromosomes constitute the population, the size of which is equal to the random number of chromosomes. Evaluation-Each chromosome in the population is assigned a specific value associated with the gene arrangement called fitness. Due to the differences of gene arrangement, the fitness value of the chromosome in the population is used to evaluate the chromosome for its survivability. Reproduction-from Evaluation chromosomes with different gene arrangements have different fitness values. Reproduction is to increase the number of the good chromosomes and decrease the number of the poor chromosomes in the next generation. Crossover-This procedure exchanges genes between the father and the mother chromosomes. Two chromosomes are randomly selected from the population as parent chromosomes. The crossover points are chosen to be less than the number of genes in the chromosome and then the genes are swapped between the crossover points. Two new chromosomes with the genes from both the parent chromosomes are obtained. This procedure is called two-point crossover. There are other methods as well such as single-point crossover. Mutation-In order to have a new chromosome which differs from the chromosomes in the population, a mutation operation is used. A chromosome is randomly selected as the mutated chromosome. The mutating gene is randomly selected from the number of genes in the mutating chromosome and then the value of this gene is flipped into another value. The operation repeats until the variation of the mean fitness of the population is very small. Finally, the best chromosome in the population is decoded as the solution of the optimization problem. GA has been used in previous studies to optimize the ATM network and also in the design of ATM network [18 – 20].

3. PROBLEM DESCRIPTION

While planning ATM network there are two sets of customers to be considered, the user - using the services through the network and the company - building the ATM network and maintaining it. Therefore while planning the ATM 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 ATM nodes, as in installing a new network most of the money is spent on digging the cable ducts.

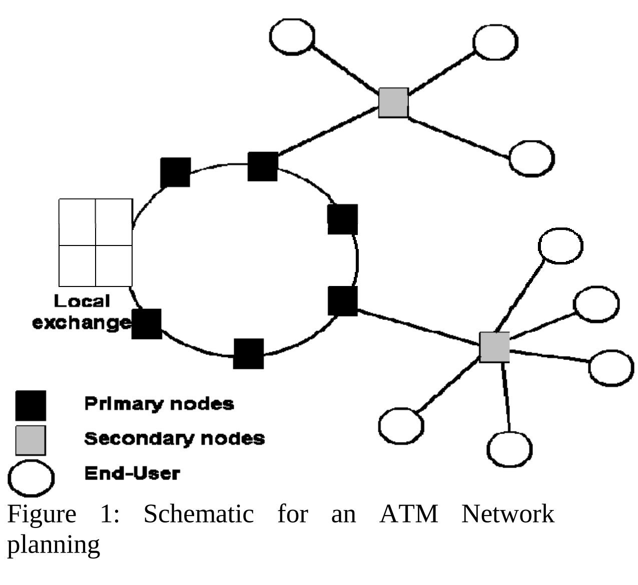


Figure 1: Schematic for an ATM Network planning

PON ATMs 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. Customer access points are connected to the ONU in a star topology [21]. 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. Typically 32 ONU's [21] can be connected to one OLT. The diagram [Figure 1] shows a ring of fiber connecting the primary nodes and the method of connecting the end-users to these primary nodes. This paper consideres 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 ATM 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.

4. PROBLEM FORMULATION

The problem has been formulated as –

Given:

- The location of the exchange.
- The location of potential end-users.
- The number of primary nodes.
- The number of secondary nodes.
- The number of end-users.

Variables:

- Primary and secondary node locations.
- Cable sizes and routes.
- Duct capacity and routes.
- Assignment of end-users to secondary nodes.
- Assignment of secondary nodes to primary nodes.

Constraints:

- 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 ie. the maximum possible distance the signal can be transmitted without getting attenuated.
- A maximum of eight end-users can be connected to a single secondary node.

The following objective function is used in this paper:

Objective: 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 cost function [6]. 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 $v_1, v_2, \ldots, v_n$, such that$\{v_i, v_{i+1}\}$, for all $1<=i<V$, is a link, and that $v_1=v_n$.

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

Objective function =

$$\text{Minimize } \sum_{i=1}^{n}\sqrt{\left(x_i - x_{i-1}\right)^2 + \left(y_i - y_{i-1}\right)^2} \qquad [1]$$

Where,

x_i, y_i = co-ordinates of the ATM nodes

$x_n y_n = x_0 y_0$

Along with the objective function - to optimize the time at which cable is installed into the network and to create a network that uses the above allocations, split levels and positioning, a heuristic method has been used to achieve the installation strategy. Heuristic used is:

1. Set year, y=0
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.
3. For each secondary node connected in the previous step connect it to the primary node to which it is assigned.
4. If y is the final year of the planning period then finish else increment y and go to 2.

This heuristic has been included in the objective function 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.

5. METHODOLOGY

Encoding: The integer value is assigned to the respective link as a pseudo link weight which is not correlated to the real cost value of this edge. The pseudo link weights are only auxiliary parameters. The fitness has been calculated based on objective function given in [Eq.1]. The position of the primary and secondary nodes and the associated split-levels can be represented using a simple bit string. An individual in the population 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 ie. 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. The following algorithms along with the parameters specified have been used to optimize the network:

Network Optimization Using GA:

```
pop = makeRandomPopulation
    while (not done)
     for each p in pop
          p.fitness = evaluate(p)
          for i = 1 to size(pop) by 2
          ## select parents for reproduction
      [parent1, parent2] = select two random solutions from pop
    [child1, child2] = crossover (parent1, parent2)
       mutate child1, child2
    replace old population with new population
```

Selection: The selection mechanism chosen is the Roulette wheel selection. In roulette wheel selection individuals are assigned a probability of being selected based on their fitness, $p_i = f_i / \Sigma f_j$, Where pi is the probability that individual i will be selected, f_i is the fitness of individual i, and Σf_j represents the sum of the fitness of all individuals in the population. Similar to using a roulette wheel, fitness of an individual is represented as proportionate slice of wheel. Wheel is then spun and the slice underneath the wheel when it stops determines which individual becomes a parent.

Crossover: Two standard crossover operators are chosen for manipulating the above representation. These are the edge recombination crossover and the partial match crossover [15]. These operators are designed to manipulate permutations. Standard crossover and mutation operators can manipulate this.

Mutation: A mutation rate of 0.01 was taken for GA. The number of generations considered in the algorithm was 500.

Terminating Condition: The terminating condition has been taken as a constant with 500 generations.

6. EXPERIMENTAL RESULTS

Genetic algorithm has been used to find out an optimum connection using ring topology to connect the ATM nodes. The population size has been considered with 30 nodes and 50 nodes, and the results were recorded after a fixed number of 500 generations in our experimental data. The objective function in [Eq. 1] has been considered. The crossover rate of 0.6 and a mutation rate of 0.01 have been considered in the algorithm. These parameters were established empirically from a series of test runs. Fig. 2 (a & b) show the best network configuration obtained by GA for the connection of Primary nodes to the exchange. The graph [Fig. 3] shows the average normalized cost of the best individual in the population at each generation for each operator. Also plotted is the cost of the best known solution found for these problems with 50 nodes.

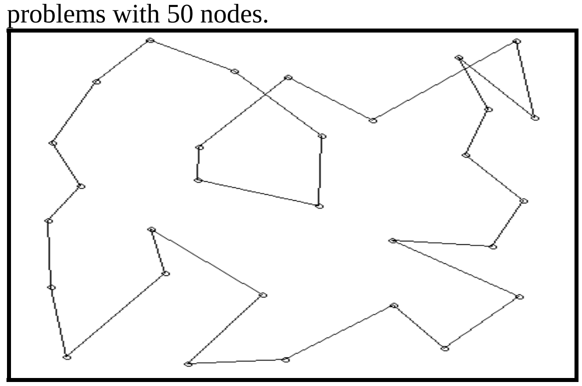


Fig.2. (a).The optimum network with 30 nodes

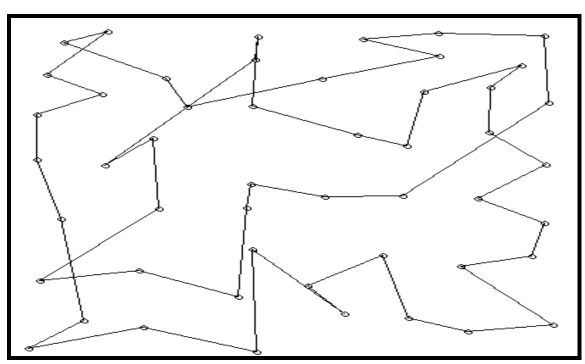


Fig.2. (b). The optimum network with 50 nodes

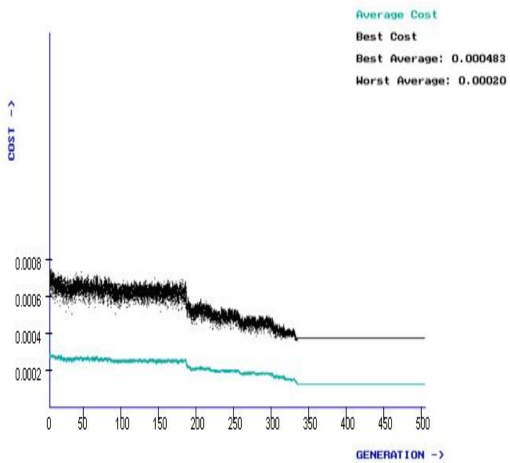
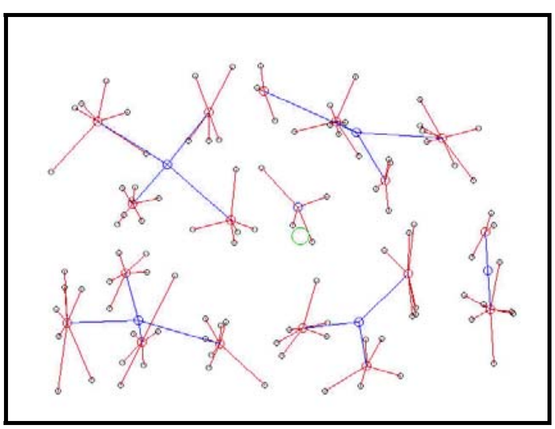


Fig.3. The comparison chart for the Best cost average and the worst cost average for 50 nodes over 500 generations.

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, genetic algorithms work effectively with discontinuous cost functions. The best results obtained for two different end-user networks are shown in Fig. 4 (a & b). It can be observed from the network that the majority of the nodes supply nearby clusters of end-users. 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.



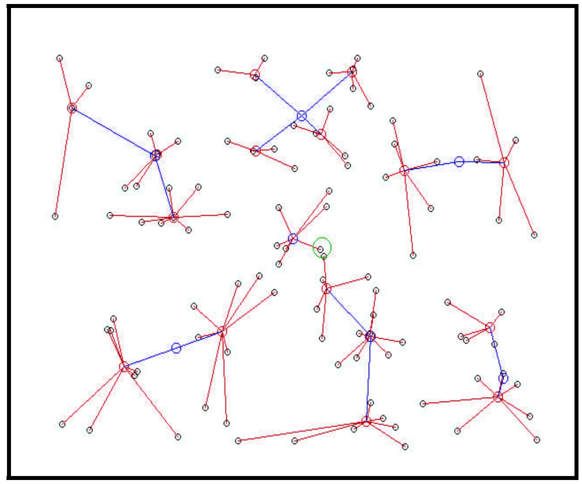


Fig. 4. (a). & Fig. 4. (b). – End-users connected to secondary nodes and secondary nodes connected to primary nodes in star topology.

7. CONCLUSION

A GA-based optimization system for ATM network has been designed, implemented and tested. In this paper we have designed an ATM network using genetic algorithm approach. We have firstly used GA to connect the primary nodes in ring topology and have then connected the end-users to the secondary nodes in star topology using GA. As the results demonstrates that an optimization based approach to network planning produces good network plans. Considering the strategic and financial implications for communications providers, cost is very important factor in network planning. So it is very important that fiber networks are implemented in a cost-effective manner. Minimizing the total cost is mainly a matter of finding shortest paths between the ATM nodes, as in installing a new network most of the money is spent on digging the cable ducts. In this paper we have found the optimal paths to connect the primary nodes in the ring topology and also connected the end-users optimally with the secondary nodes in a star network and then the secondary nodes are connected to the nearest primary node. So it can be inferred that computer based technique using genetic algorithm is a powerful tool for reducing the complexity of the planning task and allows more flexibility in the management of uncertain data. An optimization system such as the one described here will enable a planner to evaluate a large number of scenarios under different conditions.

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