# An Enhanced Genetic Algorithm Approach to ATM Network Design

**Susmi Routray**

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**Abstract -** ***The world of telecommunications is booming the telecommunication infrastructures are becoming more complex, and consequently, interest in developing broadband integrated service of digital network technologies like Asynchronous Transfer Mode (ATM) and Wireless ATM (WATM) are gaining momentum. The changing traffic pattern and the new technologies used in ATM networks make the topological design of ATM network a major research issue. Most of the researchers dealt with the topological design problem suggested solutions based on requirement of expensive exchange based equipments. In this paper we have proposed a cost effective ATM network model. The design of ATM networks entail optimization of the network. We have proposed an Enhanced Genetic Algorithm (GA) based solution for the optimization of ATM network. The results of the study show a major improvement in the solutions generated by Enhanced GA over Simple GA.***

**Index Terms - Asynchronous Transfer Mode, Passive Optical Network, Genetic Algorithm (GA), Enhanced GA**

## 1.0 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 [Raychaudhuri and Wilson, 1994]. 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 necessarily be periodic. ATM integrates the multiplexing and switching functions and allows communication between devices that operate at different speeds [P. Wong and D. Britland, 1993]. 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 [Gerla, 1989, Gerla, Kleinrock, 1977, Routray et. al., 2006]. Over the last decade, many programming models have been developed [Kim et. al., 1995, Minoux, 1987] which deals with telecommunication network planning [Liu, 2003]. 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 simulated annealing [Rios et. al., 2005] and GA has been used to solve the design problem [Routray et. al., 2005, Davis et. al. 1993, Davis et. al., 1987]. Abuali et. al. (1994) present 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, 1995 consider the problem of designing local area computer networks which corresponds to the minimum spanning concentrator location problem. Chardaire *et a*l. (1995) also use a GA and apply it to uncapacitated and capacitated versions of SS-CLP. The paper does not describe how they assign end-users if there are capacity constraints. For uncapacitated problems [Balakrishnan et. al., 1989], LR finds better solutions than the GA. However, when tested against capacitated problems, a GA combined with local search performs more consistently than LR across a range of problems.

ATM network planning deals with determination of location for the switches and linking the switches [Hasslinger et. al., 2005]. 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. In this paper we have addressed the comprehensive ATM network planning problem which deals with the backbone network design using the ring topology. Ring architecture is considered cost effective in that they offer high network survivability in the face of node failure and greater bandwidth sharing [Wu, et. al., 1998]. And also the problem of end-user connectivity with the backbone network has been addressed.

## 2.0 GENETIC ALGORITHM

GA is a non-traditional based optimizing technique [Goldberg, 1991] which can be used to optimize the ATM network. GA operations [Srinivas et. al., 1994] can be briefly described as Coding, Initialization, Evaluation, Reproduction, Crossover, Mutation and Termination. 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

*Department of Information Technology, Institute of Management Technology, Ghaziabad, UP, INDIA*
*E-Mail: sroutray@imt.edu*

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. 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 with a different perspective and in parts to design ATM network, to optimize the bandwidth [Thompson , 2000, G. Carello et. al, 2003, Routray et. al., 2006]. Comprehensive ATM network planning problem using meta-heuristics has not been dealt with.

Genetic algorithms are based on evolution of genes. GA do not take into consideration the learning generated by cultural evolution. One of the limitations in GA based technique is quick convergence from local optima. Enhanced GA can be used to overcome this limitation. In Enhanced GA local search algorithms are implemented in the steps of GA to generate better solutions. The local search algorithm that has been considered in this paper is Hill climbing algorithm. In hill climbing the basic idea is to always head towards a state which is better than the current one. If such states are available the algorithm searches for those states and if there are no such states available then the algorithm terminates.

## 3.0 PROBLEM DESCRIPTION

While planning ATM network 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 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.

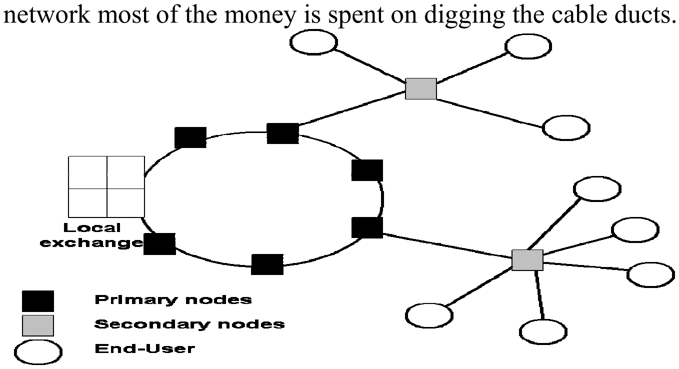


**Figure 1: Schematic for a ATM planning**

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 [en.wikipedia.org/wiki/GPON]. 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 [en.wikipedia.org/wiki/GPON] can be connected to one OLT. 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. In this paper 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 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. In this paper we have taken the location of the exchange, the location of potential end-users, and a forecast of these end-users' demand in terms of number of lines and year as given. Variables being - 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. The network must be implemented subject to the constraints of attenuation, maximum distance between a node and a customer and planning rules. The aim of the planner is to satisfy both the network's end-users and the network operator, by producing a reliable cost-effective network.

Objective: The objective of the optimization is to install a minimum net present cost network that satisfies the customer demand criterion. Let the graph G= (V, E) be a set of V nodes; V= {1,…,n} and a set of E customers as edges; E = {1,…,m}. The objective function [ Kratica] used to optimize the backbone network has been taken as:

Objective function = Minimize $\left( \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} x_{ij} + \sum_{i=1}^{m} f_i y_i \right)$ [1]

subject to,

$$\sum_{i=1}^{m} x_{ij} = 1 \qquad [2]$$

$\forall j \in J;$

$x_{ij} \in \{0,1\}$

$yi \in \{0,1\}$

xij =1 : when end node is connected to concentrator j; otherwise 0

yi = 1 : when secondary node is established else 0

fi = cost of secondary node connected to primary node

dij = $\sum_{i=1}^{n} \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2}$ [3]

Where,

xi, yi = co-ordinates of the ATM nodes

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 [Routray et. al.].

## 4.0 METHODOLOGY

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.

### 4.1 Encoding Mechanism

The position of the primary and secondary nodes and the associated split-levels can be represented using a simple bit string as in (Fig. 4.2). Standard crossover and mutation operators can manipulate this. 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 with 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 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 (CS) is taken at random. The CS is created by the mechanism shown in fig. 2. CS follows 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.

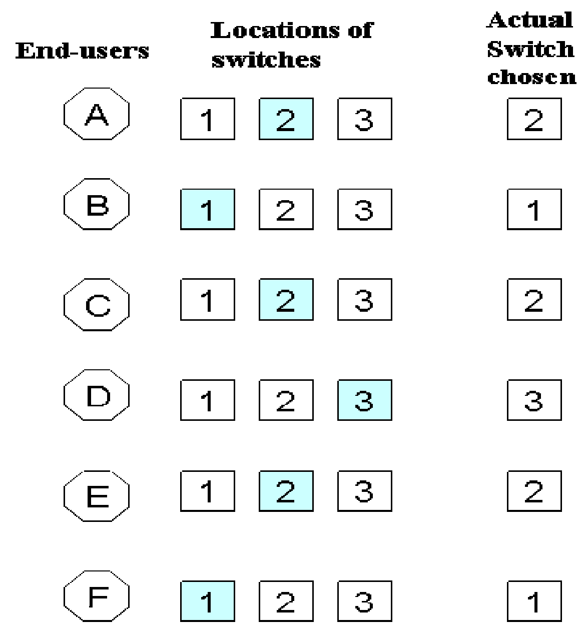


**Figure 2: Encoding Mechanism**

A heuristic method has been used to achieve this installation strategy. Heuristic used is:

4.1.1 Set year, y=0

4.1.2 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.

4.1.3 For each secondary node connected in the previous step connect it to the primary node to which it is assigned.

4.1.4 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 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.

**4.2 Network Optimization Using Ga**

The following algorithm is followed for the backbone network:

```
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
```

**4.2.1 Initial Population**

The approach taken is to represent the problem using an ordered list of customers. The first n customers from the list are assigned to the first secondary node, the second n customers to the second node, etc. Fig 4.1 shows an example of this: the first primary node connects to the first four secondary nodes, which in turn connect to the first thirty-two customers in the list. This representation means that the GA cannot generate genomes that correspond to illegal network configurations.

**4.2.2 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, fi is the fitness of individual i, and Σfj 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.

**4.2.3 Crossover**

Two standard crossover operators are chosen for manipulating the above representation. These are the edge recombination crossover and the partial match crossover [Goldberg, 1991]. These operators are designed to manipulate permutations.

**4.2.4 Mutation**

New genetic parameter is introduced by the mutation operator. The values of individual genes are changed and, hence, new solutions are chosen. Mutation becomes important when after some generations the number of different strings decreases because strong individuals start dominating. In a situation of strong dominance of a few strings, the crossover operator alone would not bring any changes and the search for an optimal solution would be ended. To partially shift the search to new locations in the solution space, the mutation operator randomly alters genes. A mutation rate of 0.01 was taken for GA. The number of generations considered in the algorithm was 500.

**4.2.5 Terminating Condition**

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

**4.2.6 Enhanced GA**

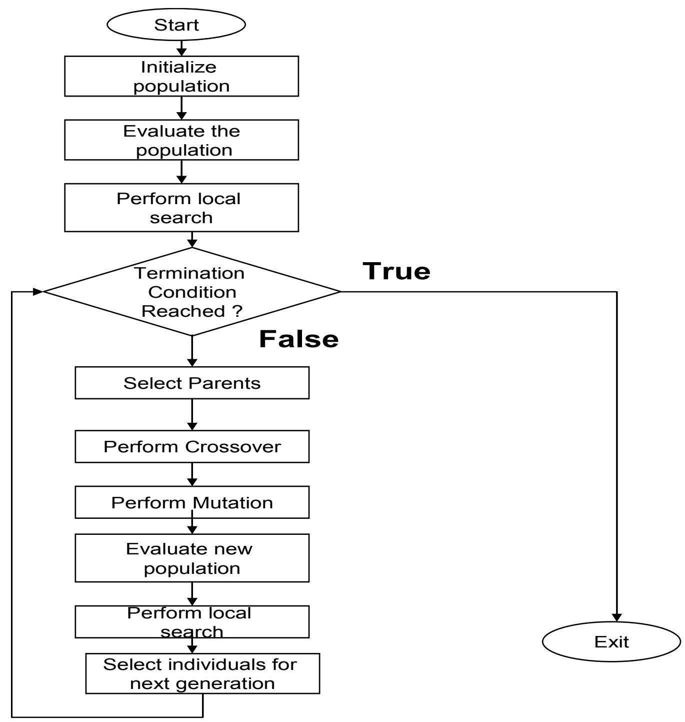


**Figure 3: Flowchart of Enhanced GA**

Initial Population Generation: Initial population is generated and then local search technique namely Hill Climbing algorithm is used to generate the initial solution string.

**5.0 EXPERIMENTAL RESULTS**

Enhanced Genetic algorithm has been used to find out an optimum connection using ring topology to connect the ATM nodes and to find end user connectivity. Numbers of experiments were conducted with varying population size. For all the experiments 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 for the base GA. These parameters were established empirically from a series of test runs. The graph [Fig. 4] shows the average normalized cost of the best individual in the population at each generation for each operator. In the first phase with 50 ATM nodes it has been observed, the solutions obtained by Enhanced GA were better than the solutions obtained by GA.

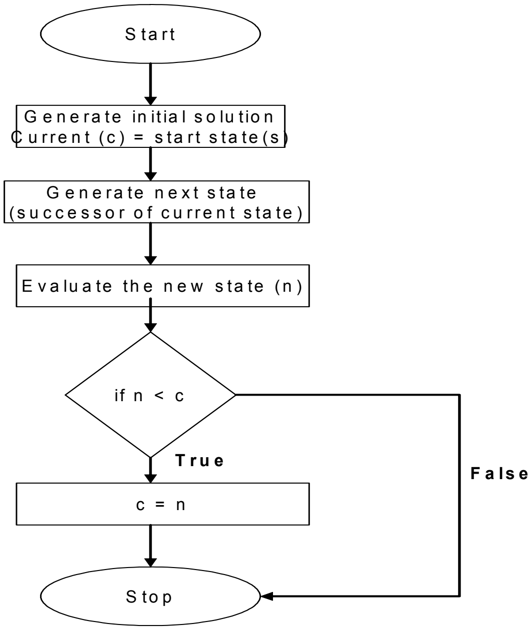


**Figure 4: Flowchart of local search method**

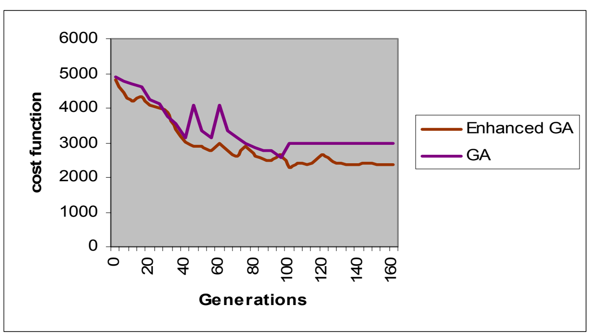


**Figure 5**

The comparison chart between GA & Enhanced GA for the Best cost average for 50 nodes. The cost of network design using Enhanced GA was 2986.53, which is better than GA. Also the time required to generate the solutions by Enhanced GA was much lesser than the time required by GA. It was also observed that with a smaller network size GA performed better than Enhanced GA but as the network size increased Enhanced GA performed better than GA (Table 1 & 2). The graph (Fig. 5) shows the average normalized cost of the best individual in the population at each generation for each operator. In the first phase with 50 ATM nodes it has been observed, the solutions obtained by Enhanced GA were better than the solutions obtained by GA.

| ATM nodes | Time (min) | |
|---|---|---|
| | GA | EGA time |
| 30 | 0.55 | 1.68 |
| 50 | 1.10 | 0.98 |
| 100 | 2.25 | 1.87 |

**Table 1: GA and EGA comparison for connecting primary nodes in ring topology**

| **ATM nodes** | **Time min** | |
|---|---|---|
| | **GA** | **EGA** |
| 30 | 1.25. | 2.19 |
| 50 | 2.30 | 2.65 |
| 100 | 5.10 | 3.97 |

**Table 2: GA and EGA comparison for network design**

It was also observed that the time required to generate the solutions by Enhanced GA was much lesser than the time required by GA. In some cases GA gave better results than Enhanced GA but the time required was very high in GA. In all the cases it was observed that GA was slower than Enhanced GA.

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, Enhanced GA work 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 Enhanced GA [fig. 6].

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 Enhanced GA supply nearby clusters of end-users. The time taken by GA is considerably higher than the time required by Enhanced GA. So for this specific problem of connecting the end-users with the secondary nodes it can be concluded that Enhanced GA works better than simple GA.

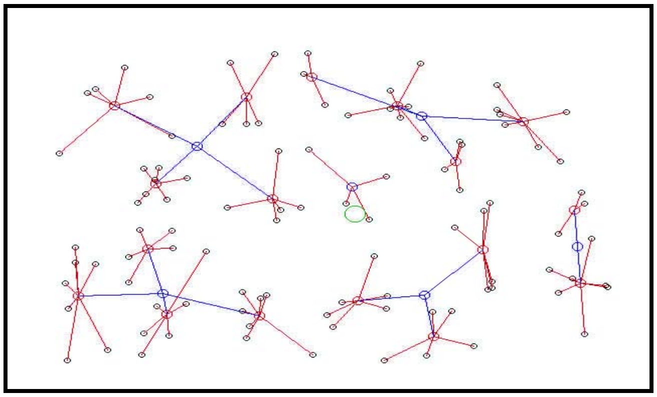

**Figure 6: End-users connected to secondary nodes and secondary nodes connected to primary nodes in star topology using Enhanced GA.**

**6.0 CONCLUSION**

An Enhanced GA based optimization system for ATM network has been designed, implemented and tested. In this paper we have designed an ATM network using Enhanced Genetic Algorithm approach. 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. We have firstly used Enhanced GA to connect the primary nodes in ring topology and have then connected the end-users to the secondary nodes in star topology using Enhanced GA. As the results demonstrates that a Enhanced GA based optimization approach to network planning produces good network plans as compared to simple GA based approach networks. 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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