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A Simulated Annealing Based Approach for ATM Network Optimization

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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 such as Asynchronous Transfer Mode (ATM). The design of an optimal ATM network is a complex comprehensive task. Some of the problem domains are the topology, connectivity and routing decisions. Given the complexity of ATM design problem, computer based network design tools can be very effective in solving such type of problem. The important aspect of design tool is the usage of meta-heuristics as the optimization algorithm. Large scale optimization problems comprise of many local maxima and minima, moving out of local minima are very important to get global optima. ATM network design being a large scale optimization problem simple heuristics alone are not sufficient enough to solve the problem. This paper explores an ATM network design tool based on Simulated Annealing (SA). A new solution has been proposed based on SA that minimizes the cost of fiber ducts and installs a minimum net present cost PON (Passive Optical Network) ATM that satisfies the customer demand criterion. 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.

Keywords: Asynchronous Transfer Mode, Passive Optical Network, Simulated Annealing, Meta-heuristics.

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]. Given the complexity of ATM network design problem, network design tools can be very effective in solving such problem. A large number of network optimization problems do not have any standard algorithm that can guarantee an optimal solution in real time. Mainly in large scale optimization problems which consist of many local optima but one global optima the general heuristics fail to give a satisfactory solution, as the general heuristics are not capable to find the global optima but only the local optima. So the most important aspect of having design tools is the usage of the meta-heuristics based optimization algorithms. These meta-heuristics based optimization techniques give better results in shorter time period than the manual based designs. As ATM network design problem [Liu, 2003, Carello, 2002] is a large scale network design problem Simulated Annealing has been chosen as the optimization algorithm. One of the important advantages of using SA - it does not prematurely converge to the local optima as is the case with genetic algorithm. So SA has been chosen for the study. Meta-heuristics like SA [Rios et. al., 2005] and GA has been used to solve the ATM network related problems [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. Boorstyn et. al. [Boorstyn and Frank, 1977] compared the performance of the GA to results obtained from Lagrangian relaxation (LR). For uncapacitated problems [Balakrishnan et. al., 1989], LR finds better solutions than the GA. ATM network design 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 above literatures is the requirement of expensive exchange based equipments. [Thomson, 2000] Compared the meta-heuristics GA and SA to solve the design problem of ATM but their approach to ATM design suffers from the abovementioned limitation. In this paper we have proposed Passive Optical Network as 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 and solved using Simulated Annealing the comprehensive ATM network design 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.

Simulated Annealing

The method was proposed by Kirkpatrick et al.(1993) and has since been used extensively to solve large-scale problems of combinatorial optimization. SA is based on the annealing of metals. If a metal is cooled slowly, it forms into a smooth piece because its thermal mobility is lost and molecules have entered a crystal structure. This crystal is the state of minimum energy can also be termed as the optimal solution for the system. On the other hand at high temperatures, the molecules of a liquid move freely with respect to one another and if a metal is cooled too fast, the metal will form a rough piece. So the effectiveness of the simulated annealing algorithm lies in slow cooling of the temperature [Sheshadri]. One of the features of SA is its ability to come out of local minima as worst moves are allowed in the algorithm based on some probabilistic condition. In large scale optimization problem, which comprises of many local maxima and minima, moving out of local minima is very important to get global optima. The major steps involved in SA are- Initialization: defines how to get the initial feasible solution. The next step is the Iteration: defines the neighborhood, temperature schedule, how many iterations per temperature, and criteria for reducing the temperature. Last step Termination: defines a terminating condition.

Problem Description

While planning ATM 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 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.

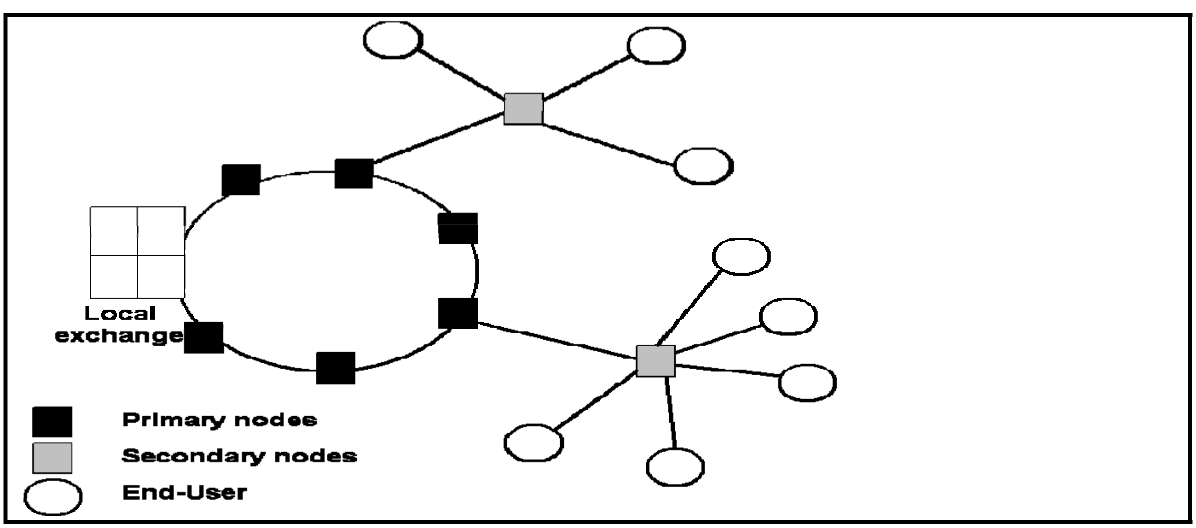

Figure 1: Schematic for an ATM planning

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. 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 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. 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 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 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. This problem can be classified as a dynamic network optimization problem with a discontinuous cost function [Minoux, 1987]. 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,… 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:

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

Where,

x_i, y_i = co-ordinates of the ATM nodes

$x_n y_n = x_0 y_0$

ATM Network Design Methodology using Simulated Annealing

The problem has been divided into two phases. In the first phase Simulated Annealing has been used to design the backbone ATM 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 Equation [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:

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 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.

Network Optimization Using SA

```
Begin
        Generate an initial solution p_i
        Compute the objective function to find the cost of f (p_i)
        Set the effective temperature, t, to the initial value, t_0
        While t <> t_n do
                Randomly select a neighbor,
                Compute the objective function i.e. Cost f (p_j)
                Find the difference d=f (p_j)-f (p_i)
                If d<=0 then
                p_i=p_j (for minimization problems)
                Else
                Based on probability e^(-d/t), p_i=p_j
                (selection of worst move based on the probability function)
                End if
           Change the temperature t
            End of while loop
  End
```

The initial temperature has been taken as 1000 and cooling coefficient has been taken as 0.9. The terminating condition has been taken as either 100 iterations without improvement in the solution or a constant 500 generations, whichever criteria is fulfilled first. These parameters were established empirically from a series of test runs. The worst moves have been selected on the basis of the probability function given in the algorithm above.

Experimental Results

Simulated Annealing has been used to find an optimum connection, using ring topology, between ATM 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 SA. The objective function in Equation [1] has been considered. These parameters were established empirically from a series of test runs. Figure 2 show the best network configuration obtained by SA for the connection of Primary nodes to the exchange. The graph [Figure 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 SA, with varying nodes size, to generate the solution.

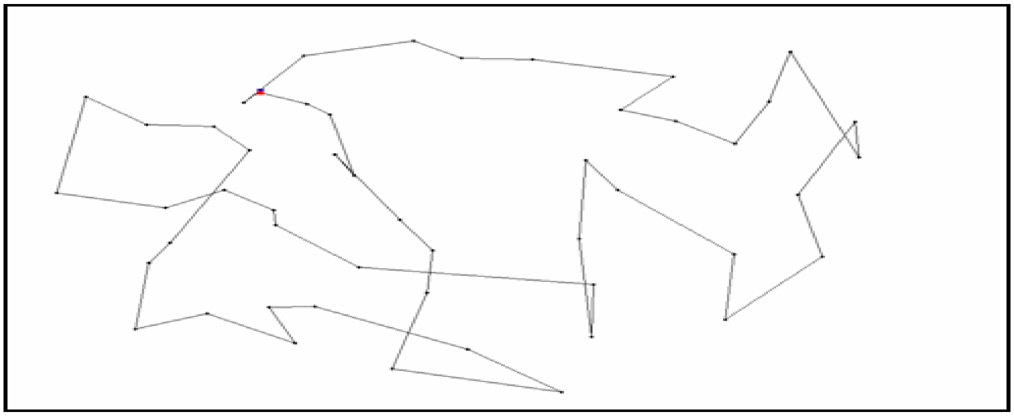

Figure 2: Optimum network with 50 nodes using SA

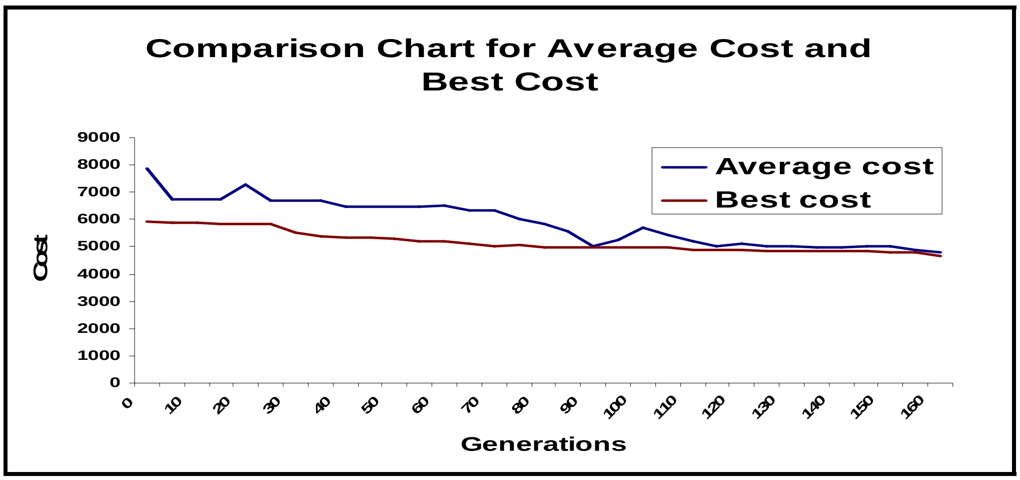

Figure 3: Comparison chart for Average Cost and Best cost with 50 nodes.

Table 1: Results obtained in phase I

ATM nodes	**Phase I**	
	SA time	**SA cost**
30	2min	2435
50	5min	4677.43
100	10min 30secs	8997.78

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, SA 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 SA (Figure 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 SA supply nearby clusters of end-users. But one of the limiting factors of SA is the time. The time taken by SA is considerably higher (Table 2). As slow cooling is very important to generate near optimal solutions in SA, we have taken a cooling factor of 0.9 based on the outcome of series of test run. It has been observed, if the cooling factor is taken as higher the results obtained are not satisfactory as fast cooling schedule is equivalent to the greedy algorithm [Sheshadri].

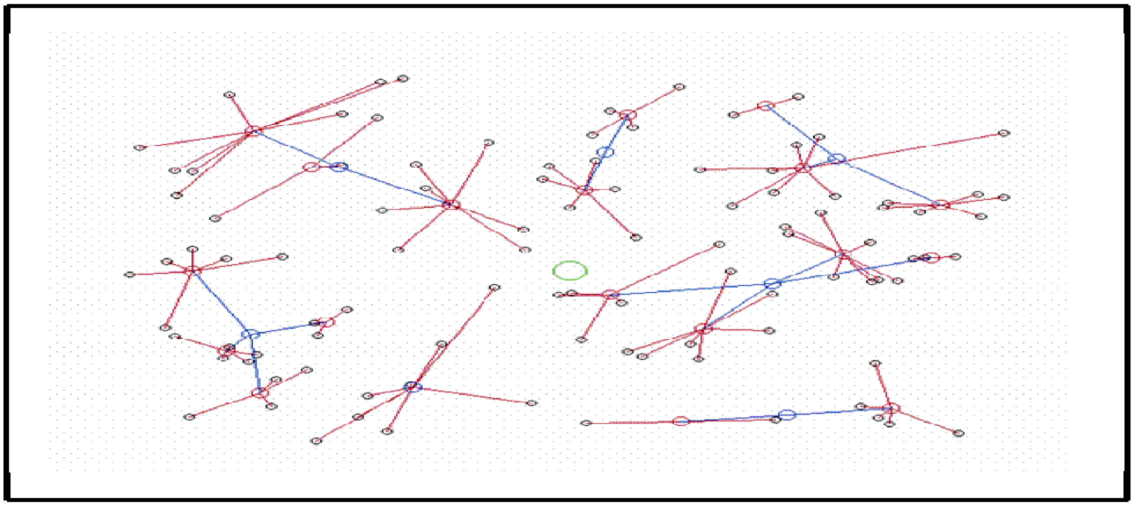

Figure 4: End-users connected to secondary nodes and secondary nodes connected to primary nodes in star topology using SA.

Table 2: Results obtained in phase II

ATM nodes	**Phase – II SA time**
30	5min
50	9min 10 secs
100	20min 45secs

Conclusion

A Simulated Annealing based optimization system for ATM network has been designed, implemented and tested. From the simulation results it can be concluded that SA based optimization provides a good network design tool for the ATM design problem. Firstly SA 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 SA and then the secondary nodes are connected to the nearest primary node. Though one of the limiting factor that can be inferred from the simulation results in the design of ATM network using SA is the time required. The time required to generate the results are quite high but 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. So it can be inferred that computer based technique using meta-heuristic like SA 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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