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Optimization of the Placement of Wavelength Converters in WDM Networks

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ABSTRACT
The Routing and Wavelength Conversion are the two key techniques for improvement of the overall blocking performance in the wavelength routed all-optical networks. The Wavelength Converters are expensive, and thus the effective use of Wavelength Converters or more precisely the placement of minimum number of Wavelength Converter in appropriate nodes in the network is a challenge in the field of wavelength division multiplexing (WDM) optical networks. The performance of wavelength division multiplexing (WDM) network is highly dependent on Wavelength Converter allocation and routing problems. Typically treated as independent problems under dynamic traffic.

Keywords- Blocking Probability, Light Path, Optimization, Wavelength Converters, WDM.

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I. INTRODUCTION

Wavelength routed all optical networks have emerged as popular architectural solution for wide area networks and are being conceived for future broad band communications. Wavelength Division Multiplexing (WDM) technique is used to utilize the tremendous bandwidth of the optical fiber. WDM divides enormous bandwidth of an optical fiber into many non-overlapping channels (wavelengths), which satisfy the demand of the high-bandwidth applications in next generation networks.

Call connection probability in such networks depend on the number of WDM Wavelengths employed and on the capability for wavelength Conversion at network nodes. Wavelength Continuity Constraint degrades network performance in terms of blocking probability. In wavelength routed all-optical WDM network, two wavelength routers communicate with each other by setting up lightpath in between them. The number of WDM wavelengths employed determines the number of independently addressable lightpaths in a WDM network. This number may be sufficient to meet overall network bandwidth requirements but be inadequate to support the large number of nodes of a wide area network. Possibility for call blocking also arises due to wavelength contention when two calls at the same time are to be routed over same network link.

Without Wavelength Conversion, a call can be connected only if there is at least one wavelength available in common on each link of the call route. Therefore call blocking is possible in spite of all links on the requested route having free wavelengths but without a common one. If Wavelength Converters are present at every network node, a call can go through as long as any wavelength is free on each link of the route. A Wavelength Convertible network accepts more connections because of the relaxation of the wavelength continuity constraint.

A Wavelength Converter is a device which is capable of shifting the incoming signal from one wavelength to a different wavelength. When network node has Wavelength Conversion facilities, it is capable of switching data from an input port on one wavelength to an output port on another wavelength. Such node is defined as a wavelength converter node. When such node is capable of converting a wavelength to any other wavelength, the node has full conversion capability (full degree of Wavelength Conversion). When the node can convert an incoming wavelength to a subset of available wavelengths, the node has limited conversion capability.

1. Objective function

- Minimize blocking probability as a constraint, with use of specified number of wavelength.
- Optimization of Placement of Wavelength Converters.
- Maximize the sum of total utilizations (STU) of all the nodes, so that the overall utilization of FWC's can be improved. As a result, the overall blocking probability can be smaller and, hence, the mean quality of service is better.

II. ALGORITHMS

Genetic algorithms (GA) are robust algorithms for the global comprehensive optimum solution for an optimization problem. GA is repetitive optimization strategy, rather than to employ specific result in each iteration, it works with statistic solution in individual iteration. These are generally known as populations. In the lack of proficiency of problem domain, GA initiates search from arbitrary populations of solutions. They integrate survival of the fittest amidst string frameworks with framed yet arbitrary information transfer to form search algorithm with a few of ingenious ability of human search.

For each generation, unique series of simulated creatures (strings) is established using fits and starts of competent of the old; randomly new part is reliable for satisfactory measure. Three diverse procedures such as reproduction, crossover and mutation are enforced to amend the population of strings.

The individuals are comparable to the desired result of the problem. The tenacious individuals are related to the approximately optimal solutions. With respect to the Wavelength Converter placement issue, every individual in population symbolizes a desirable converter placement as a sequence of bits. The purpose is to obtain the placement that reduces the blocking probability. The GA is initiated by generating initial population. Approximately appropriate placement are preferred upon a number of generations. Crossover and mutation processes examine more possible placements.

Over a appropriate constraint management, the GA contains only possible placements. Just as the stopping criteria are convinced, an optimal converter placement is established. Genetic algorithm being enforced to discrete optimization problem, along with those in telecommunication field.

Primarily the GA mechanism uses a procedure of natural selection amidst of biology concept. This is an progression of individuals from one origination to the subsequent, depending on the eradication of fragile individuals and the replication of steady individuals. The individuals are comparable to the desirable result of the problem. The steady individuals are relevant to the approximately optimal solutions that are scrutinized in the optimization issues. These individuals will sustain upon the number of generations just before the substantial one only remains, specifically, an optimal result of problem is achieved.

In consequence of reproducing individuals in population, genetic operations like selection, crossover and mutation are used. Particular operators determine more solution for individuals that may lead to optimal result of the problem. The working procedure of Genetic Algorithm is as presented in Figure 1.

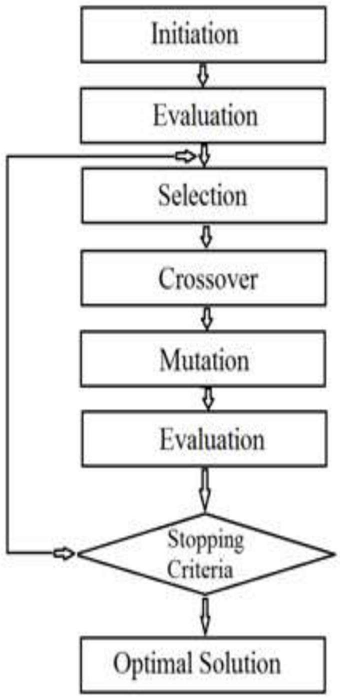

Figure 1: Flow Chart of the process of Genetic Algorithm (GA)

III. NETWORK ARCHITECTURE AND ASSUMPTIONS

- A WDM network is a connected graph. Accordingly, each node is reachable from any other nodes in the network.
- The links between the nodes are bi-directional. There are N nodes in the network labeled as 1, 2, 3, 4, 5 ,..., N.
- Each link between the nodes contains W different wavelength channels.
- A lightpath is characterized by a source-destination node-pair (s, d). For an N-node network, there exist $N \times (N - 1)$ distinguishable source-destination node pairs. So if we consider only shortest-path routing, there can be $N \times (N - 1)$ different possible lightpaths considering that only one shortest path is selected (even if there exist multiple shortest paths between a node-pair) depending on the flow of algorithm. Any Routing and Wavelength Assignment (RWA) algorithm can be applied but, the same algorithm should be applied while gathering the utilization statistics and after allocation Wavelength Converters (using utilization statistics).

- Full-range Wavelength Converters (FWCs) are assumed. FWCs can convert an input wavelength to any other wavelengths (at least, all the wavelengths corresponding to the different wavelength channels in the network). When a converter is in use, it cannot be used further until the conversion is completed.

IV. NETWORK MODEL

The network having directed graph G = (V,L) where V, vertices in graph, represents set of network nodes and L, directed edges in graph, represent the set of unidirectional optic fibre links in network. Let nodes be numbered 1,2, ..., N and let l_{ij} represent the directed link from node i to node j. There are F wavelengths on each link and each call requires a full wavelength on each link it traverses. Call requests arrive randomly at each source node and select any of the remaining nodes as their destination with equal probability. Each call uses a pre-specified shortest path. All the shortest paths in the network are assumed to satisfy the optimality principle.

The principle states that if node x is optimal shortest path from node y to node z then optimal shortest path from node x to node z follows same route of the path from y to z. If the pre-specified shortest path is available then light- path is established between source and destination nodes. If pre-specified shortest path is not available then call may not be routed through alternate path and is assumed to be blocked. Let A = [λ_{ij}] be traffic matrix where λ_{ij}, i ≠j denotes load node from node i to node j, and λ_{ii} = 0, F =The number of wavelengths per links, k=Number of nodes to equipped with converters, λ_{ij}= End to end traffic load from node s to node d.

It is the arrival probability of a call from s to d, λ_{ij}=0.05 for any node pair (i,j), Let link loads per wavelength be ρ_{ij} for link l_{ij}. Specifically, ρ_{ij} is probability that wavelength is occupied by lightpath on link l_{ij}. The link loads per wavelength per link can be obtained from load node by

$$\rho ij = \frac{\sum_{sd} \lambda sd}{w} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

such that path from s to d includes link l_{ij} provided λ_{sd} is small such that ρ_{ij} < 1. Assume that load on loads of other wavelengths and on other link wavelength on link is statistically independent of the link s.

Let the number of converter nodes to be placed be K. Let C = {c(l), c(2), ..., c(K)} be the converter placement vector such that 1 ≤ c(i) < c(i + 1) ≤ N, 1 ≤ i < K. The entries of C denote the placement of converters among the nodes 1,2, ..., N. Now consider the path p of an end-to-end call from a source node s to a destination node d in the network.

Define a segment to be the set of links on the path between two consecutive converter nodes or between the source (or destination) and a converter node. If the path contains no converter nodes, then it consists of a single segment between the source and destination. Then

$$f(i,j)=1-(1- \rho_{ii1}\ \rho_{i1i2}\ \ldots\ldots\ \rho_{ini}\ )^F \quad \ldots\ldots(2)$$

is the success probability in the segment from node i to node j on the path, where $\bar{\rho}_{xy}$ = 1 - ρ_{xy} for link l_{xy} and i_1,i_2, ..., i_n are the nodes in the segment between nodes i and j.

Let the number of converters placed on the nodes (not including the source and destination nodes) of the path p be k, where 0 ≤ k ≤ K. Given the converter placement vector C for the network, we have d_{sd} = (d(l),d(2),...d(k)) and d_{sd} C c, the converter placement vector for the path such that the entries of d(i), 1 ≤ i ≤ k correspond only to the node numbers of the path p which have converters on them. This divides the path p into k + 1 segments. Hence the success probability of the end-to-end call with the converter placement vector being C is given by

$$S_{sd}\,(C) = \prod_{i=0}^{k} f(si) \ \ldots\ldots\ldots..(3)$$

where f(s_i) = f(d(i), d(i + l)), 1 ≤i≤k-1 corresponds to the success probability of segment s_i between the converter nodes d(i) and d(i+1).

f(s_0) corresponds to the success probability of the segment between the source node and converter node d(1) and f(s_k) corresponds to the success probability of the segment between the converter node d(k) and the destination node. The blocking probability

$$P_{sd}(C) = 1- S_{sd}(C) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(4)$$

V. RESULT ANALYSIS

The 14 node NSFnet is considered, assuming 8 predefined node points where the converters are optimally placed. For each optimal placement combination with K , number of converters to be placed the corresponding blocking probability (P_{sd}) is calculated and tabulated as in TABLE I. The Blocking Probability for 10 nodes of NSFnet is calculated using Utilization matrix and is as in TABLE II

TABLE I
Optimal placement of 14 node NSFnet

K	Optimal Placement	Blocking Probability
1	5	2.20E-03
2	4,7	1.20E-03
3	3,5,7	1.00E-04
4	3,5,6,8	8.00E-04
5	3,5,6,7,8	6.00E-04
6	3,4,5,6,7,8	5.00E-04
7	3,4,5,6,7,8,9	4.10E-04

8	2,3,4,5,6,7,8,9	3.10E-03

TABLE II
Blocking probability calculated using Utilization Matrix

K	Optimal placement	Blocking Probability
1	0,1,2,3	4.71E-03
2	0,1,2,3,4	2.56E-03
3	0,1,2,3	1.92E-03
4	0,1,2,3,4,5	1.60E-03
5	0,1,2,3	1.28E-03
6	0,1,2	1.28E-03
7	0,1,2,3,4,5	9.60E-04
8	0,1,2,3,4	9.60E-04

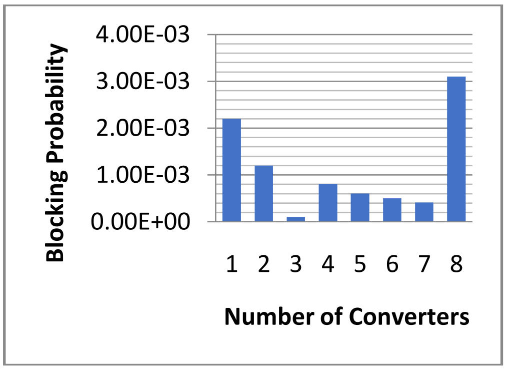

Figure 1: Blocking Probability vs Number of Converters for 10node of NSFnet using Auxiliary Graph Method.

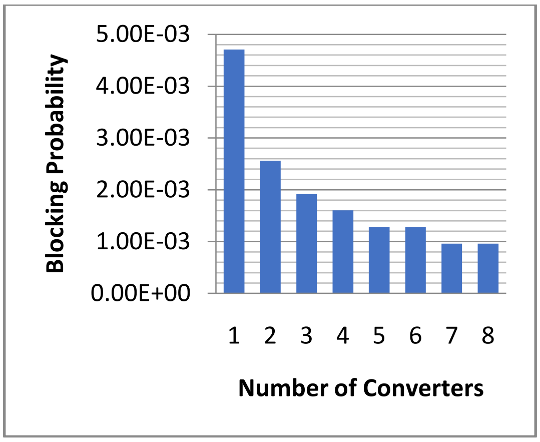

Figure 2: Blocking Probability vs Number of Converters of 14node NSFnet using Standard Utilisation Matrix

The following arbitrary values, F=3 , ρ=0.05 it is observed that as the number of Wavelength Converters placed optimally at each block , it will reduce the Blocking Probability. Further it is seen that if the number of nodes are more than 7 then there is drastic change in the behaviour of blocking probability and it shoots up and increases upto the value 0.0031(3.10E-03).

In Figure 2 , at each point in the 0,1,2,3 nodes 5 converters are to be placed . And for 0,1,2,3,4,5 node points 2 converters are placed.

VI. CONCLUSION

In today's world Blocking Probability is the bottleneck problem, for a 14 node NSFnet the optimal placement of converters is very important. It has a great role to play in high performance Optical Communications. In Figure 1, as the number of converter increases with the Optimal placement of nodes, it is always advisable to use 7 converters for traffic less communication i.e it is efficient to keep 7 Optimal converters for the 7 network nodes at points 3,4,5,6,7,8,9 for getting less congestion in the Optimal communication. In Figure 2, two converters in pair show the same call blocking capability. Thus in a 14 node NSFnet for 6 network nodes pair of Optical converters has to be placed at 0,1,2,3 and 0,1,2 , similarly at 7 network nodes pair of Optical converters has to be placed at 0,1,2,3,4,5 and 0,1,2,3,4

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