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Modified Multiobjective Metaheuristics for Sparse Traffic Grooming in Optical WDM Mesh Networks

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Abstract

Now days the number of users that use data networks has increased tremendously and this demand will keep on increasing. This has made an increase of bandwidth necessary. Our current data networks are unable to support this growth, so better solution is to use optical data networks, in which the bandwidth is over 50Tbps. Data network provides also provides a huge bandwidth but the maximum speed for an end user is only a few Gbps which is speed of their devices. So if we use wavelength division multiplexing, maximum bandwidth utilization will be done because of simultaneous transmission of data. Traffic grooming problem is a NP-hard problem, so we need to use metaheuristics. DEPT and MOVNS have been proved to provide most optimal solutions. But these were implemented earlier on full grooming network. This paper proposes variants of DEPT and MOVNS using sparse grooming network which will provide better results in terms of throughput and propagation delay.

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Keywords: Traffic grooming, Optical Network, sparse grooming, WDM, Metaheuristics, Multiobjective optimization.

1. Introduction

To exploit the bandwidth of optical networks is required as it is huge in a single optical strand. To serve this purpose wavelength division multiplexing (WDM) is used. It allows concurrent transmission of traffic on many non-overlapping wavelengths. These wavelengths support traffic demands in Gbps but most of the applications require a bandwidth of Mbps only. This leads to wastage of bandwidth. To solve this problem we need to multiplex a number

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of low-speed traffic demands (Mbps) onto a high-speed wavelength channel (Gbps). This is known as the Traffic Grooming problem. In an optical WDM network, two nodes communicate over a wavelength channel. This wavelength channel is called as a lightpath which may span multiple fiber links and be routed by the intermediate optical switches between a given node pair.

Traffic grooming in WDM networks is classified into two types, static and dynamic. In static request the originating traffic source, destination of traffic data and bandwidth requirement are known in advance.

On the other hand, if these are not known in advance, it is dynamic request. In this case virtual topology has to be reconfigured according to the request either on the arrival or on the departure of traffic [4]. To test the results, we have considered the dynamic nature of traffic generation.

Grooming network is of two types according to the number of nodes having grooming capability: full grooming network and sparse grooming network. In full grooming all the nodes are grooming nodes; if only few nodes of the network are grooming then it is a sparse grooming network. The grooming node is able to multiplex and de-multiplex the data as well as wavelength conversion.

Consider an optical network topology which has a fixed number of transmitters and receivers per node. There are fixed number of wavelengths per optical fiber. The wavelength capacity of each wavelength band is fixed. Set of low speed traffic requests are also important as need to multiplex. Traffic grooming problem can be divided up into three subproblems:

- The lightpath routing subproblem: - This consists of the establishment of lightpaths over the physical topology.
- The wavelength assignment subproblem: - This consists of assigning an available wavelength to each established lightpath.
- The traffic routing subproblem: - This consists of establishing each low-speed traffic request through a lightpath or many concatenated lightpaths, depending on whether traffic grooming is single-hop or multi-hop.

Thus the main goals of Traffic Grooming problem are: maximization of the number of requests established successfully (total throughput) or minimizing the number of requests failed (total blocking), minimization of the number of lightpaths created in order to minimize the number of transmitters and receivers used at each node, and minimization of the amount of time taken for a request to travel from the source node to the destination node over each established lightpath (average propagation delay).

The purpose of our work is to use multiobjective evolutionary algorithms to solve the Traffic grooming problem by considering sparse grooming network. We aim to solve the above mentioned Traffic Grooming problem by using a sparse grooming network for dynamically generated requests. We have selected the MultiObjective Evolutionary Algorithms Differential Evolution Pareto Tournaments (DEPT) [9] and MultiObjective-Variable Neighborhood Search (MO-VNS) and proposed variants of them for a sparse grooming network and thus using wavelength conversion at the grooming nodes.

We compare these two algorithms with DEPT and MO-VNS on full grooming network. We have also compared our algorithms with algorithms for multi-objective optimization: the Non- Dominated Sorting Genetic Algorithm (NSGA-II [5]) and the Strength Pareto Evolutionary Algorithm 2 (SPEA2 [6]).

2. Related Work

In [1], Zhu and Mukherjee propose mathematical formulation of the traffic grooming problem by using two fast heuristics viz. Maximizing Single-hop Traffic (MST) and Maximizing Resource Utilization (MRU) for a WDM Mesh Optical Network.

In [7], Konda and Chow deal with the traffic grooming problem by the aim of reducing the number of transmitters and receivers. In [8], the authors handle the traffic grooming problem for minimizing number of transmitters and receivers by decomposing it into two smaller problems - the traffic grooming and routing problem, and the wavelength assignment problem - solving them separately. Li et al. [9] give a heuristic for finding an optimal wavelength assignment and grooming such that the number of wavelengths required in the network is minimized.

In [4], De et al. deal with the traffic grooming problem with the objective of maximizing the network throughput for wavelength-routed mesh networks and map this problem to the clique partitioning problem. They compare their work with the well-known heuristics proposed in [1], MST and MRU.

A´ lvaro Rubio-Largo et. al. [9] proposed Multi-objective Evolutionary Algorithms (MOEA). In this paper, authors have made comparison with the well-known Fast Non-Dominated Sort Genetic Algorithm (NSGA-II), Strength Pareto Evolutionary Algorithm 2 (SPEA2). The selected algorithms are multi-objective variants of the standard Differential Evolution with Pareto Tournaments (DEPT) and Variable Neighborhood Search (MO-VNS). They are highlighting in particular the performance of the DEPT algorithm. The MOEA solution used in the modified algorithm simultaneously maximizes the throughput of a given optical network, minimize the number of transceivers per node and minimize the average propagation delay. But they have implemented these algorithms on full grooming network. Also they have used first fit method for channel selection and considered static traffic generation. They have considered only low speed requests less than OC-48 where bandwidth of an OC-x channel is $x \times 51.84$Mbps.

Hence we propose variants of DEPT and MO-VNS implemented on a sparse grooming network with best fit method for channel selection and dynamic traffic generation. The grooming nodes have the capability of multiplexing, demultiplexing and wavelength conversion.

3. Problem Formulation

3.1. General Problem Statement

In this work, a NSFNET topology for WDM Mesh optical network has been designed as a graph G (V, E), where V is the set of nodes and E is the set of physical links connecting to nodes i.e. the edges of graph. We consider there has an equal number of fibers joining two nodes in both directions. Wavelength continuity has some constraints which are resolved by wavelength conversion. So a lightpath established over a link may use different wavelengths between any two physical links as per the availability. We consider higher speed traffic requests upto OC-192.

A connection traverses different light paths because of Multi-hop grooming facility. So, we have to consider an NSFNET optical network topology. The number of transmitters and receivers at each node are fixed. The wavelengths per fiber are fixed, also the capacity of each wavelength is fixed. The set of connection requests with different bandwidth are generated. The problem of traffic grooming may be stated as a Multiobjective Optimization Problem (MOOP). In this problem the objectives are, first maximizing the throughput or minimizing blocking, second minimizing the cost of the network in terms of the number of transmitters and receivers, and third reduced the average propagation delay.

3.2. Constraints

- Number of lightpaths between any node pair (i,j) should be less than or equal to the number of transmitters at node i.
- The number of lightpaths between any node pair (i,j) is less than or equal to the number of receivers at node j.
- Lightpaths between any two nodes consists of lightpaths on distinct wavelengths between nodes i and j.
- For any intermediate node k of the lightpath (i,j) the total incoming lightpaths is equal to total outgoing lightpaths on a wavelength w.
- There are no incoming streams in source node i of the lightpath (i,j) on a wavelength w.
- On a lightpath (i, j) over a given wavelength w no outgoing stream exists at destination node j
- For any source node i the total outgoing lightpaths are equal to total available lightpaths between the source and destination node pair.
- Total incoming lightpaths at node X is equal to the total lightpaths between node pair (i,j) on wavelength w for source node i for destination node j.

3.3. Objective Functions

- Maximize the traffic throughput (f1): Maximize the total successfully routed traffic requests on virtual topology or in other words minimize the total failed requests from[9].

$$Max \sum_{s=1}^{|N|} \sum_{d=1}^{|N|} \sum_{t=1}^{R_{sd}^{d}} x * S_{sd}^{x,t} \tag{1}$$

- To Minimize the transmitters and receivers (f2) at node X: Minimize the total number of transmitters and receivers used or in other words minimize the number of light paths established over a virtual topology[9].

$$Min \sum_{i=1}^{|N|} \sum_{j=1}^{|N|} \sum_{m=1}^{|N|} \left((D_{mn}) * \left(\sum_{w=1}^{w} L_{mn}^{ij,w} \right) \right) \tag{2}$$

- Minimize the average propagation delay (f3): Minimizing the average propagation delay or in other words minimize the average hop count of established lightpaths[9]. Assume Dmn=1.

$$\frac{Min \sum_{i=1}^{|N|} \sum_{j=1}^{|N|} \sum_{m=1}^{|N|} \left((D_{mn}) * \left(\sum_{w=1}^{w} L_{mn}^{ij,w} \right) \right)}{\sum_{i=1}^{|N|} \sum_{j=1}^{|N|} \sum_{w=1}^{|N|} V_{ij}^{w}} \tag{3}$$

Where,
V: - the set of nodes.
W: - number of wavelengths that can be multiplexed on a single fiber. All fiber-links support equal number of wavelengths.
T: - number of transmitters at node i; Ti ≥ 1.
R: - number of receivers at node i; Ri ≥ 1.
K: - number of shortest paths
Lmn: - number of fibers interconnecting nodes m and n. If Lmn = Lnm = 0, there are no physical links between m and n, otherwise Lmn=Lnm=1.
C: capacity of each channel.
R: - traffic demand matrix

3.4. Algorithms

The proposed algorithm presents the variants of multiobjective metaheuristic algorithms DEPT and MO-VNS for a sparse traffic grooming with wavelength conversion capability and by considering dynamically generated requests.

Algorithm 1: Proposed Algorithm
1. Start
2. Generate a NSF Network
3. Nodal degree algorithm is used to select grooming nodes.
4. Accept number of transceivers, number of requests N
5. WDM is performed according to number of transceivers
6. For all N requests

a. Randomly select source and destination
b. Generate random data at each source
c. Find k shortest paths using Yen's algorithm
d. Perform DEPT as follows:
i . Generate new individual X
ii. while time stopping criterion do
1. Evaluate the size of population as P
2. Select 3 random individuals R1 R2 R3
3. Generate a new individual Xtrial by using selection scheme Rand/1/Binomial (S=7)
4. By comparing MOfitness function of Xtrial with Xtarget we execute the Pareto Tournament and do selection accordingly.
iii. end while
e. Perform MO-VNS as follows:
f. while time stopping criterion do
i. Generate new individual X
ii. By removing those individuals dominated by X the Pareto Front is updated
iii. Initialize the neighborhood degree n =1
*iv. While n < Maxneighborhood Calculate mutation factor as F= n * 0.15*
v. Generate random X from neighborhood of X which is nth element.
vi. Apply a local search with X' as the initial solution to get X''
vii. Take 'move or not' decision as
1. if X'' dominates X then
a. X = X''
b. n=1
2. else
a. n= v + 1
3. end if
g. end while
h. Perform the standard NSGAII and SPEA2 algorithms[5],[6]
i. Calculate fitness values for all three objectives
j. Assign the wavelength channel by using best fit strategy
k. If sparse grooming is selected
i. If the node is a grooming node
1. Do multiplexing/ demultiplexing
2. Do wavelength conversion if required
ii. End if
l. End if
7. End for
8. Fitness of algorithms will be compared with sparse as well as full grooming
9. End

The MOfitness function is given as[9]:
*Mofitness(X) = |isDominated(X)| * PopSize + |Dominates(X)*
isDominated: is the set population which dominate X.
Dominates: set of individuals dominated by X

In genetic algorithms, an individual is one of the solutions to the problem. In our case it is the optimal path.
Algorithm 2: Generating Individual
1. Start
2. Check transmitter availability
3. if isPossibleToEstablish

*a. w=Wfij * Traffic(i,j)*
b. Assign wavelength by Best Fit
c. Calculate objective functions
4. End if
5. End

A nodal degree algorithm is used for selection of grooming node in sparse traffic grooming, i.e. the nodes with maximum connectivity will be selected as grooming nodes.

Algorithm 3: Grooming node selection
For network topology G (V, E)
1. Start
2. Assign grooming nodes count V
3. Create a class SparseGroomingNode
4. Declare variables for incoming and outgoing edges of node as members of class.
5. For each node (V) do
a. If edge is found between nodes i and j, increment incoming and outgoing variables of I and j both.
b. Create object o of class SparseGroomingNode.
c. Calculate value as (o.incoming+o.outgoing)-(incoming+outgoing)
6. End For
7. Sort in descending order according to the value.
8. Select top V nodes as grooming nodes.
9. End

4. Experimentation and Evaluation

We implemented all the four algorithms on full grooming as well as sparse grooming networks. We compared the algorithms on the basis of success ratio and throughput. We observed 20% improvement in the success ratio. DEPT with sparse grooming gives most optimal results as seen in the graph. We get maximum throughput for DEPT with sparse grooming which is 85%.

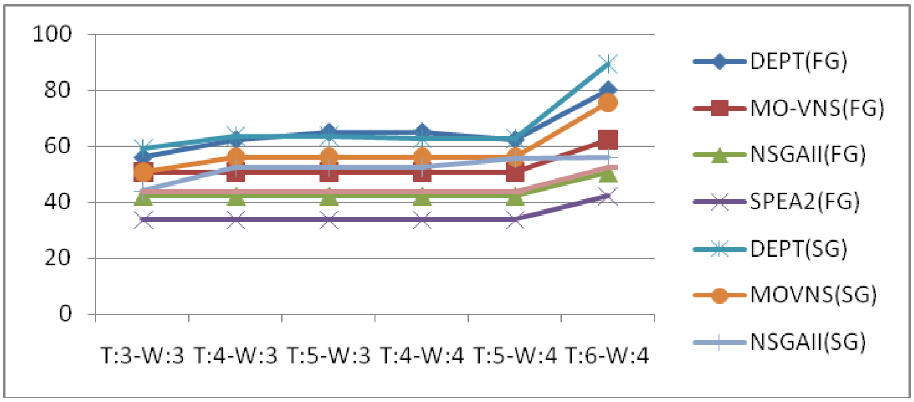

Fig. 1. Success ratio

The success ratio is the combined value of fitness function of all three objectives. Lesser the value of fitness function more is the success ratio. We observe best success ratio for the pair T: 6 and W: 4.

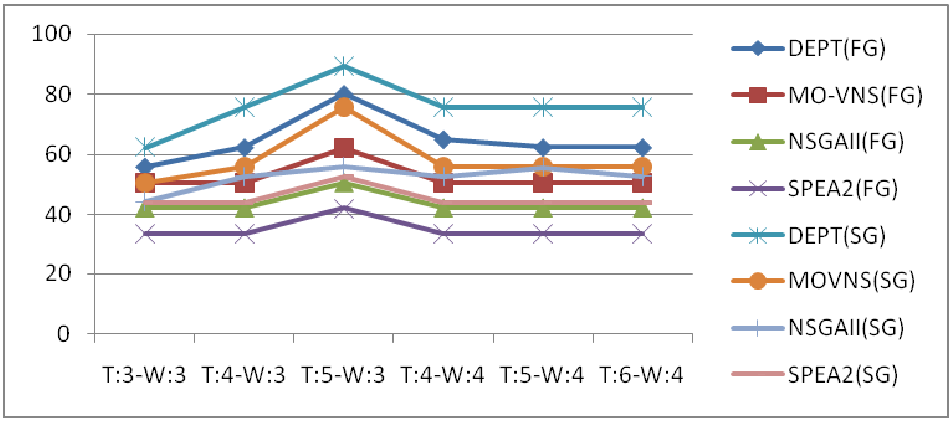

Fig. 2. Throughput

Throughput is calculated as number of requests successfully routed over the network. For all algorithms, we achieve better throughput for sparse grooming network. We tested our algorithms by varying the number of sparse grooming nodes. We observed that for 3 grooming nodes, best result is achieved.

5. Conclusions

With our proposed system, we achieved better success ratio for the three objectives of traffic grooming. With sparse grooming nodes, grooming capability applied to only few nodes. It reduces the number of resources used and hence the network cost. Multiplexing and demultiplexing can be done at grooming nodes only. This reduces propagation delay as well as cost. Proposed algorithm uses Best Fit method for wavelength assignment rather than First Fit. That yields better throughput. Also wavelength conversion at grooming nodes is done because of which maximum utilization is done so the success ratio increases.

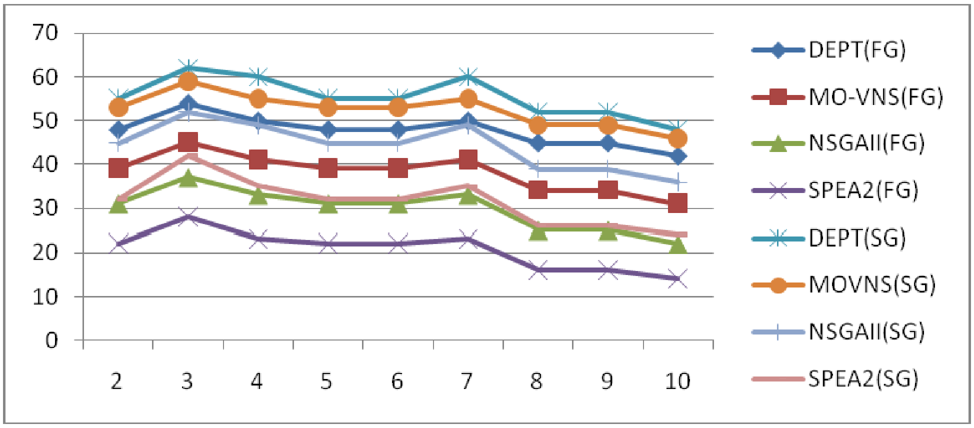

Fig. 3. Performance by Varying number of G-nodes

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