

A Study Traffic Management, Involving Grooming and Conversion Devices

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Abstract- Effective traffic management is critical to ensuring the smooth flow of vehicles, enhancing road safety, and minimizing congestion. This study explores traffic management strategies with a specific focus on grooming and conversion devices. Grooming devices refer to technologies and systems that regulate traffic flow by optimizing lane usage, controlling signal timings, and managing vehicle speeds. Conversion devices, on the other hand, facilitate the transition between different traffic conditions or environments, such as urban to rural areas, or the incorporation of automated and semi-automated vehicles into existing road networks. This thesis aims to demonstrate a genetic algorithmic approach to the & wavelength assignment issue in WDM networks, specifically with respect to wavelength converters & traffic groomers.

Keywords- Traffic Management, Groomers, Conversion, Wavelength, WDM, Genetic

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INTRODUCTION

The wavelength division multiplexing networks which cover a span of thousands of kilometres called ultra-long haul WDM networks are characterised with traffic of heterogeneous data flows. The networks applied in wide area & urban area are characterised by the requirements to provision services of heterogeneous nature. The ever growing requirement in bandwidth necessitated by the increased use of online applications and data services for voice chat and video on demand traffic have led to advancement in WDM technology called IP over WDM technology (Chlamtac 1992). The SONET and ATM networks deployed widely in backbone networks carry IP traffic over the optical layer. The wide area networks WAN and metropolitan networks MAN, as they have to cater to the heterogeneous service requirements separate wavelengths are needed to carry individual services and this will lead to increase in the costs involved (Ramamurthy et al. 1998). The optical layer defined in this type of networks is based on Optical Circuit switching (OCs) technology. The setting up of a circuit called lightpath establishment, message transfer and release of the circuit of the three major phases in optical circuit switching technology. The optical layer by means of its circuit switched lightpaths provide services to the client layer such as SONET, ATM and IP.

In the existing backbone networks the ATM and SONET systems carry IP traffic (Wuwen Lai 2014). Even though the SONET systems were primarily

designed to carry voice signals, they are also increasingly used for transferring ATM and IP traffic. The SONET connections are called as Optical Carriers (OCs). The circuit switched services belonging to client layer are combined together in fixed time division multiplexing slots. The data rate of 51.48Mbps called Synchronous Transport Signal level (STS-1) is carried by an OC-1 connection. Each of the wavelengths have data carrying capability at the rate of gigabits per second and these resources may be utilized for transmission of the data rates OC-48, OC-192 and OC- 768 (Siva Ram Murthy 2011).

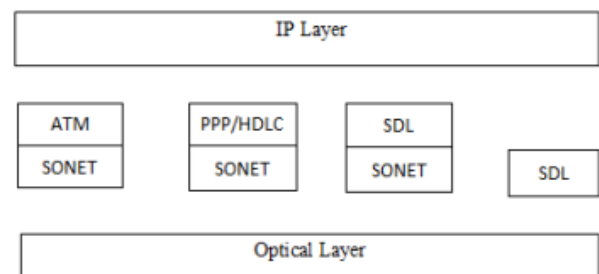


Figure 1 Possible protocol stack options for IP-over-WDM

Wavelength division multiplexing networks which offer services of varied granularity are referred to as WDM grooming networks. Figure 1 shows that possible protocol stack options for IP-over-WDM. The traffic grooming has its inherent efficiency to

improve wavelength utilization and reduce capital expenditure.

WDM – SONET RING NETWORK TABLES

A unidirectional ring network with four nodes labelled 0 through 3. Assuming that each node has two units of traffic (that is, two SONET OC-x connections) to every other node. The multiplexing factor is assumed to be 4 and therefore a wavelength can carry four OC-x connections. Routing all the OC-x connections on the unidirectional requires that each fiber link carry 12 OC-x connections. This means that minimum of three wavelengths are required to carry the traffic and we give below the different ways of grooming the traffic on to wavelengths.

Table 1 Traffic Aggregation (design 1)

	0	1	2	3
0		λ_1	λ_0	λ_1
1	λ_1		λ_2	λ_0
2	λ_0	λ_2		λ_2
3	λ_1	λ_0	λ_2	

Table 2 Traffic carried by wavelengths on different fibers (design 1)

	0	1	2	3
0		λ_1	λ_0	λ_0
1	λ_1		λ_2	λ_1
2	λ_0	λ_2		λ_2
3	λ_0	λ_1	λ_2	

Table 3 Traffic Aggregation (design 2)

	λ_0	λ_1	λ_2
0→1	< 0,2 > < 3,1 >	< 0,3 > < 0,1 >	< 2,1 > < 3,2 >
1→2	< 0,2 > < 1,3 >	< 0,3 > < 1,0 >	< 3,2 > < 1,2 >
2→3	< 1,3 > < 2,0 >	< 0,3 > < 1,0 >	< 2,1 > < 2,3 >
3→0	< 3,1 > < 2,0 >	< 1,0 > < 3,0 >	< 2,1 > < 3,2 >

Table 4 Traffic carried by wavelengths on different fibers (design 2)

	λ_0	λ_1	λ_2
0→1	< 0,2 > < 0,3 >	< 3,1 > < 0,1 >	< 2,1 > < 3,2 >
1→2	< 0,2 > < 0,3 >	< 1,3 > < 1,0 >	< 3,2 > < 1,2 >
2→3	< 2,0 > < 0,3 >	< 1,3 > < 1,0 >	< 2,1 > < 2,3 >
3→0	< 2,0 > < 3,0 >	< 3,1 > < 1,0 >	< 2,1 > < 3,2 >

WDM – SONET Ring Network

The grooming process has been extensively investigated on the ring topology, as many of the networks have SONET technology most often used in ring networks. The increase in number of nodes has given rise to the arrangement of networks as a mesh topology. The adoption of mesh topology has a cost advantage over ring network topology (Tanmay De et al. 2008). Figure 2 and Figure 3 shows that SONET 4-node grooming network and sparse grooming networks respectively. The traffic grooming applied to increase the efficiency is illustrated, considering a Unidirectional Path Switched Ring (UPSR) in a WDM network with 4 nodes interconnected by optical fiber links which carry 3 - wavelengths on each fiber. The wavelength is assumed to carry a capacity of 2.5 Gbps(OC-48).

Each pair of nodes in the network shown as ring topology is assumed to have a traffic requirement of 2 OC-12 circuits. The associated total traffic for the given configuration is 12 OC-12 circuits or 3 OC-48 rings involving 3-wavelengths. The following two assignments are considered for the traffic flow carried over the wavelengths in the ring network.

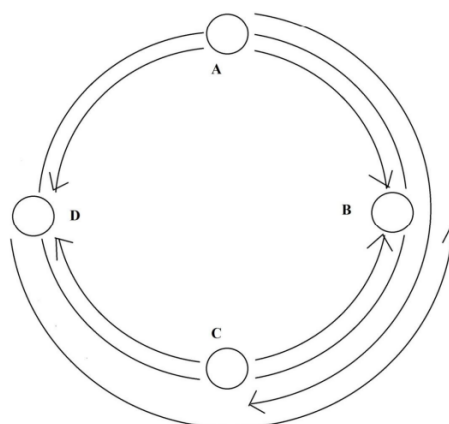


Figure 2 SONET 4- Node Grooming network

RWA Algorithm -1

$$\lambda_1 = A \leftrightarrow B, B \leftrightarrow C, C \leftrightarrow A \text{ (3 ADMs)}$$

$$\lambda_2 = C \leftrightarrow D, D \leftrightarrow E, E \leftrightarrow C \text{ (4 ADMs)}$$

$$\lambda_3 = F \leftrightarrow G, G \leftrightarrow H, H \leftrightarrow F \text{ (3 ADMs)}$$

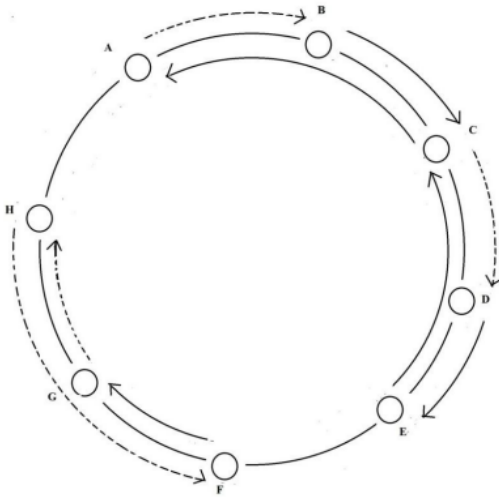


Figure 3 8-Node Sparse Grooming Network

RWA Algorithm -2

$$\lambda_1 = B \leftrightarrow C, C \leftrightarrow A, E \leftrightarrow C, D \leftrightarrow E, F \leftrightarrow G \text{ (8 ADMs)}$$

$$\lambda_2 = A \leftrightarrow B, C \leftrightarrow D, G \leftrightarrow H, H \leftrightarrow F \text{ (7 ADMs)}$$

Ten ADMs are required for the RWA Algorithm-1 to route the traffic on 3-wavelengths, whereas fifteen ADMs are required to route the traffic on only 2-wavelengths in Assignment-2. It can be observed that the RWA algorithm with a higher number of wavelengths uses fewer ADMs, whereas the algorithm with a higher number of ADMs reduces the number of wavelengths needed to route the traffic demands. This leads us to believe that adding more wavelengths is not always necessary for the classic RWA algorithm, which uses a larger number of ADMs.

Each lightpath in WDM grooming networks carry multiplexed lower data rate traffic. Data streams are multiplexed and demultiplexed by the OADMs located at the nodes. To perform grooming, OADMs adjust the wavelengths, whereas electronic ADMs multiplex or demultiplex the traffic streams based on those wavelengths. The cross connect provisioned at the nodes perform the operation of switching the data streams from one wavelength to another. This is accomplished by switching the traffic between different time slots on to a different wavelength on the successive fiber and this leads to increased cross connect complexity. When two or more packets are to be routed through the same output port, a situation of contention occurs. The techniques followed for resolving contention are i) buffering. (time domain) ii) wavelength conversion (optical domain) and iii) deflexion routing.

The process of wavelength conversion and time slot interchange are done in addition to space switching of wavelengths (Siva Ram Murthy & Mohan Gurusamy 2011). In this work, the resolution of contention in wavelength domain by usage of wavelength conversion is analysed. The contending packets can be carried over the wavelength converted to available free wavelengths and can be sent on the same link without delay (Osama Awwad et al. 2007).

GROOMING NETWORK MODEL

The WDM network may have the nodes equipped with wavelength selective cross connects (WSXc) or wavelength grooming cross connects (WGXC). Example node architectures using WSXc and WGXC are shown in the Figure 4.

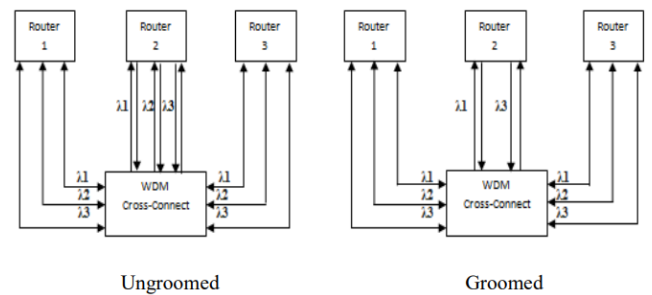


Figure 4 Grooming in an IP/WDM architecture

The fiber optic links interconnecting the network nodes may be either unidirectional or bidirectional. The wavelength from input port is switched to another wavelength at the output port by the Optical Cross Connects (OXC) present in the WSXc, the WSXc cannot switch traffic streams between different wavelengths. The time slot interchange technique is utilised in WGXC as an additional feature to the functionality of WSXc. The lower data rate traffic streams from a set of time slots carried over on a wavelength can be switched to a different set of time slots on another wavelength at the output port in a WGXC (Wang et al. 2001).

ANALYTICAL SCENARIO FOR CONSTRAINT GROOMING

It is presumed that the switching is completely non-blocking and can be executed across all wavelengths from any input port to any output port. A node is said to have maximum grooming capacity if it can convert wavelengths to their maximum extent. The node is stated to have limited grooming capabilities when it switches lower data rate traffic streams over a restricted number of wavelengths (Osama Awwad et al. 2007). A network which has only some of the nodes equipped with WGXC is referred to as sparse grooming network and the network equipped with WSXc at their nodes are termed as constraint grooming networks.

Connection Setup and Release

At the origin & destination, WSXc and WGXC nodes carry low-data-rate traffic. If one or more WGXC nodes are encountered in the path between source and destination, the traffic flow involves more than one lightpath. The lightpath establishment between the source and destination or between the intermediate WGXC nodes need to satisfy wavelength continuity constraint, i.e., the same wavelength has to carry the traffic on all constituent links of the path between the intermediate nodes or between the source to destination. It is possible to route lightpaths on different wavelengths among several WGXC nodes. Several wavelengths of low-data-rate communication can be carried on each of the lightpaths. Before establishing a connection, make sure the lightpaths have enough capacity and have been previously constructed. This will ensure that they can handle any new traffic sessions. To illustrate the connection setup and release, a part of the mesh network is considered and it is shown in Figure 5.

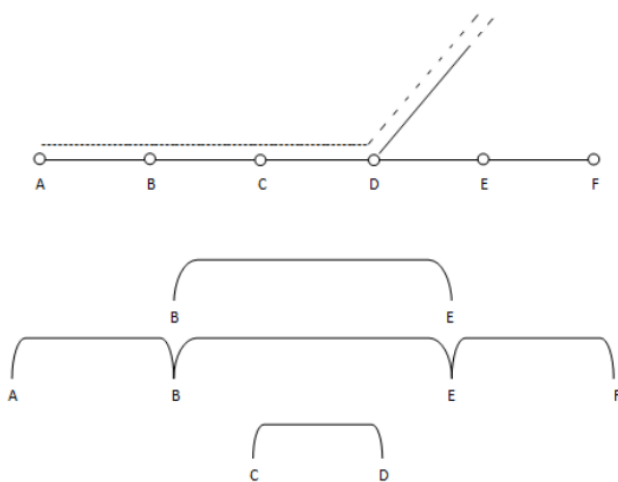


Figure 5 Connection Setup and Release

On the path from A to F, a single wavelength is considered to be available. The capacity carried by the wavelength is 'Cap'. And all the nodes are equipped with WSXc. A connection request for a capacity of $Cap/4$ between B to E arrives. The connection request can be promptly fulfilled on the available wavelength between nodes B & E by configuring the optical cross connect at nodes C & D and the optical adjacency modules at nodes B and E. Only at nodes B and E can wavelengths be added or dropped; at nodes C and D, this is not an option. Setting up light paths on similar wavelengths from A to B and from E to F can be utilized as well for establishing the second connection request between node A and F for a line capacity of $Cap/4$. Similarly, the lightpath from B to E can be established utilizing the same wavelengths or lightpath as the first connection. Here, four nodes—A, B, E, and F—add or subtract wavelengths. It is anticipated that the third request for a connection between A and G will be for a line capacity of $Cap/4$. Due to a request deviation at node D, which is equipped exclusively with WSXc, this connection request will be blocked &

cannot be served. Consider a fourth request for a connection between nodes C and D, with a line capacity of $Cap/4$. If a temporary disruption can be tolerated by the use of fast reconfigurable cross connections at the nodes or fast OADMs, the connection request can be fulfilled. Alternatively, the connection requests can be fulfilled if nodes C and D are equipped with WGXC.

Static Traffic Grooming

One definition of the static traffic grooming problem is the requirement for low-data-rate connections among pairs of sources & destinations. The number of SONET ADMs is considered when traffic is allotted to wavelengths. The establishment of lightpaths on the WDM network defines a virtual topology, which necessitates the discovery of solutions. To change the wavelength of a data stream, the electronic components at the nodes, like ADMs & digital cross connections, are employed.

Dynamic Traffic Grooming

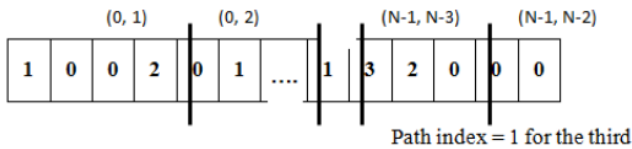
With (WDM, protocols like IP traffic can be transmitted without requiring SONET ADMs to handle traffic. This is achieved by having the IP layer multiplex traffic onto the wavelengths. According to Wuwen Lai et al. 2014, IP traffic requirements do vary more rapidly than SONET traffic, and WDM networks typically use a mesh topology to accommodate this.

GA APPROACH FOR RWA PROBLEM WITH CONSIDERATION OF GROOMING AND CONVERSION DEVICES

Genetic Algorithms are numerical optimization methods inspired by biological solution. These global search algorithms are optimization strategies based on certain assumptions about the search space. The possible assumption is a candidate solution that can be evaluated. The Genetic Algorithms have an advantage that the assumptions, i.e., the amount of heuristic knowledge on the problem can very well be adjusted for each case to the desired level. One more advantage of Genetic Algorithms is its ability to search larger problem spaces with minimal risk of getting trapped in local optima (Banerjee & Kumar 2007).

CHROMOSOME REPRESENTATION

A group of vectors that constitute chromosomes are encoded as follows. The vectors are coded as strings which contain path index. In this case, the path index is determined by the ascending order of the counts of intermediate hops. The indexing of routes represented as path index is shown in Figure 6.



transmitter of the lightpath (0, 2)

Figure 6 An example of genome encoding

The indexed routes are assigned wavelengths based on a wavelength assignment scheme. Chromosomes are constructed for $N(N-1)$ combinations, that is, for every conceivable combination of source or destination pairings in an N -node network, using the parameters of the number of grooming & wavelength conversion resources across all routes. The genomes constitute the lightpath representation for the source - destination pairs (Passakon Prathombutr et al. 2003).

INITIAL POPULATION

The sum of all potential connection requests for an N -node network is $N(N-1)$. A number of these $N(N-1)$ combinations are taken into account in order to construct chromosomes, & number of these sets of connection requests between source-destination pairings make up the initial chromosomal population. The grooming devices are taken into account at the end nodes, & mostly utilized wavelength scheme and the first-fit wavelength assignment method are implemented independently. The parts of the routes that connect the nodes that include wavelength converters execute the wavelength assignments. To determine how much it costs to convert wavelengths, the converters are only installed at the sparse nodes. By arbitrarily changing the location and quantity of converters, additional sets of chromosomes can be generated. Additional chromosomes are produced through an iterative process of changing the location of converters. Using a starting population of fifty chromosomes, this study examines the 14-node NSFNET network.

FITNESS FUNCTION

The following is an evaluation of the chromosome's fitness value with the only goal of lowering the number of wavelengths in a particular network:

Single Objective Fitness Function

$$Y_1 = 1 - \left(\frac{f_w}{|K|} \right), \text{ where } |K| \text{ is the set of lightpath}$$

Aside from the primary goal mentioned earlier, the secondary goal is to maximize the segment length among converters & minimize the cost of wavelength conversion.

Multi Objective Fitness Function

$$Y_3 = 1 - 0.9 \frac{f_w}{|K|} - 0.07 \sum_{i=1}^k \frac{\beta V_i (S_{Ra} - S_{R_{ai}}(v))}{S_{Ra}} - 0.03\alpha \sum_{i=1}^k \sum_{j=1}^{l_i} \sigma_{1ij}$$

Where f_w - the most overflowing segment uses the most wavelengths

K : the set of light paths.

β : the cost of single wavelength conversion device

V_i : the number of wavelength conversion devices in the route R_a

S_{Ra} : the segment length of route R_a

$S_{R_{ai}}(v)$: the maximum segment length after a converter is placed on node 'v'.

l_i : WDM links by i th light path traverses

SELECTION OF CHROMOSOMES

An absolute threshold is used to choose the chromosomes that will produce the next generation. One genetic operator that may be useful for recombination is the roulette wheel choosing, which is based on fitness proportional selection. The procedure is to find a fitness function which assigns a fitness value to the candidate solutions. The level of fitness determines the association of probability of selection of the individual chromosomes (candidate solution). In this method, the possible selections are assigned to portions of the wheel depending on the fitness value. A normalization procedure is performed to assign the fitness value of the chromosomes in relation to total fitness value of all the selections. A random selection is made in a similar way to that a Roulette wheel is rotated. The candidate solutions with higher values are generally not eliminated, but by the Roulette wheel method due to their association with probability of selection may get eliminated. In this study, each new generation of chromosomes is built from the ones with fitness values higher than a certain threshold. The threshold values are determined by the level of optimization that is necessary.

CROSS OVER

The cross over operation(recombination) resembles the biological cross over between chromosomes in an attempt to refine candidate solutions. A number of paths between each potential source & destination pair are considered, and a path index is assigned to each. To create new strings of potential solutions, the cross-over procedure involves exchanging the fractions of two parent strings at the common node. As the cross over is performed about common node, this is of the type one - point crossover. The process of cross over is illustrated as follows in the Figure 7.

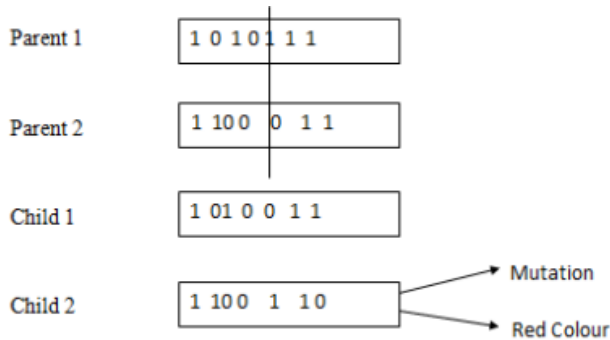


Figure 7 Parent String and Child String

MUTATION

In a generation selected, a chromosome is mutated with a particular mutation ratio. To calculate the mutation ratio, we look at the total number of source-destination lightpath requests. Every time a lightpath carries light from a source to a destination & includes a converter at an intermediate node, one converter is removed at random until half of the maximal count, or the number of converters in that lightpath, has been reached.

For each of the lightpaths $P_{ij} = [ni_1, ni_1, ni_2, \dots, ni_j]$ a converter node in the lightpath is selected randomly and it is removed. The minimum cost of the path between precedent node ni_j and successive $ni_{(j+1)}$, node to the converter node removed is calculated and the cost is substituted for the corresponding portion of the path P_i .

The Genetic operators predict the convergence characteristics of Genetic Algorithm. The solution for the formulated ILP has the following effects of the genetic operators which explains the convergence characteristics.

Roulette wheel selection attempts to improve the fitness of the populations through the successive generations. Statistically, the Roulette wheel selection has the effect of the best chromosomes getting copied most of the time than the average and the worst chromosomes get vanished. The cross over operator leads the GA to approach in the direction of suboptimal solution, for quick convergence. The mutation operator searches through the solution space randomly and avoids early convergence.

RESULTS AND DISCUSSION

The performance analysis of the proposed approaches is done for applying the algorithms to a backbone network namely the NSFNET mesh topology. The topology has the nodes connected together by undirected links meaning that the route from a node X to a node Y will have the same intermediate links for the route traversed from node Y to X. Random combinations of source & destination sets are considered in which all the nodes in the network act as source to every other node in the network. The traffic is assumed to be static and the genetic algorithm

approach is adopted. If a connection request is to be served, the resources are allocated for connection request using the K- shortest path routes already computed. The lightpath could not be established, if there is no free wavelength on any of the links in the route between source and destination pair. The lightpath establishment is done, considering link disjoint paths. The wavelength assignment is accomplished by employing the first fit assignment scheme or most fit assignment scheme, with an objective of minimization of number of wavelengths. Assuming the network is a CWDM network, the maximum variety of wavelengths that a fiber may carry is 16. With regard to the different quantities of traffic, the grooming devices are likely to be installed at sparse nodes.

Table 5 Comparison of wavelengths - mesh network

(S-D) Pair	Shortest Route	Commonly used wavelength assignment algorithms							
		Least used		Most used		First Fit		Random	
		λ No	No. of attempt	λ No.	λ No. of attempt	No. of attempt	λ No.	No. of attempt	λ No.
1-9	1-8-9	λ_1	1	λ_1	1	λ_1	1	λ_2	1
8-14	8-9-12-14	λ_2	1	λ_2	2	λ_2	2	λ_1	2
2-6	2-3-6	λ_1	1	λ_2	1	λ_1	1	λ_1	1
12-14	12-14	λ_1	1	λ_1	2	λ_1	1	λ_2	2
2-7	2-4-5-7	λ_2	1	λ_2	1	λ_1	1	λ_1	1
1-2	1-2	λ_1	1	λ_2	1	λ_1	1	λ_1	1
1-7	1-8-7	λ_2	2	λ_2	1	λ_2	2	λ_1	2
6-13	6-14-13	λ_1	1	λ_2	1	λ_1	1	λ_2	1
3-9	3-6-10-9	λ_2	2	λ_1	2	λ_2	2	λ_2	2
4-6	4-5-6	λ_2	1	λ_1	2	λ_2	2	λ_2	1
5-6	5-6	λ_1	2	λ_1	2	λ_2	2	λ_1	2
11-14	11-13-14	λ_2	1	λ_2	1	λ_1	1	λ_2	1

The Genetic Algorithm execution has the selection of parameters as given below.

- A fourteen-node NSFNET Requests for connections & structure of the network do not change.
- The segments between successive conversion devices satisfy the wavelength continuity constraint.
- A directed graph does not describe the network.

Figure 8 shows the number of wavelengths needed to fulfill the traffic request, namely traffic among S-D pairs, utilizing a GA technique with multiple fitness functions for the First Fit wavelength assignment.

Utilizing GA with the First Fit wavelength assignment technique, we optimize the number of wavelengths.

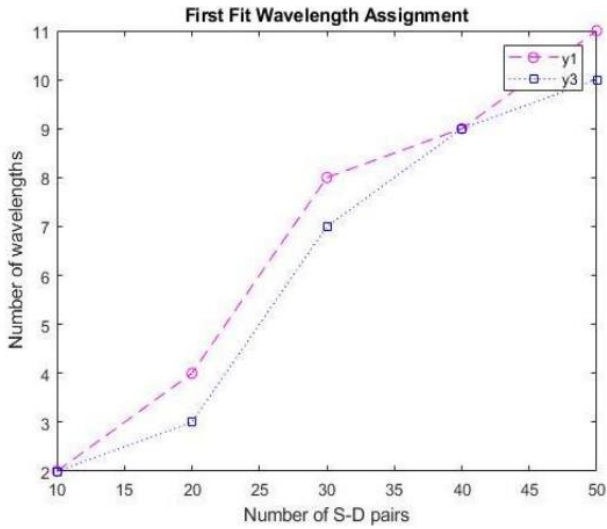


Figure 8 Frequency of Wavelengths vs S-D Pairs

The number of wavelengths required to honour the traffic request, i.e., traffic between S-D pairs by using GA approach with different fitness functions for Most Used wavelength assignment is given in the Figure 9.

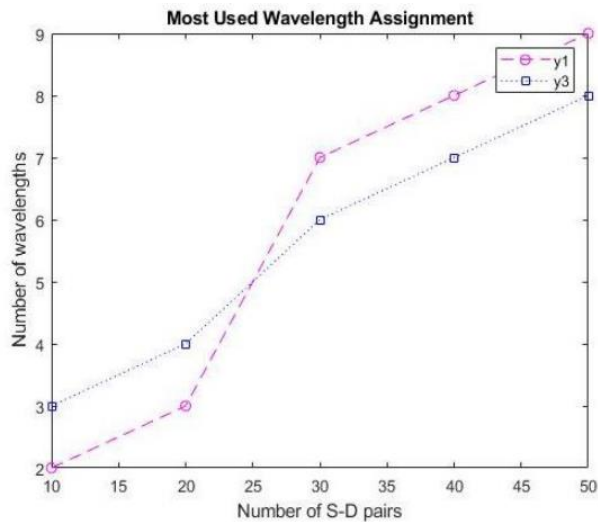


Figure 9 Quantity of wavelengths vs S-D pairs

The performance comparison in terms of blocking probability against number of grooming and conversion devices with different fitness functions of the GA is presented as graph in Figure 10 for the First Fit wavelength assignment is adopted.

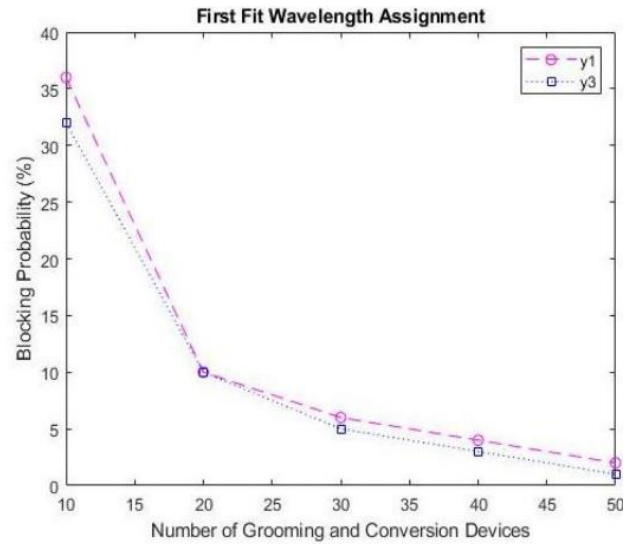


Figure 10 Estimating the Blocking Probability Using Available Grooming & Conversion Tools

The performance comparison in terms of blocking probability against number of grooming and conversion devices with different fitness functions of the GA is presented as graph in Figure 11 for the Most Used wavelength assignments adopted.

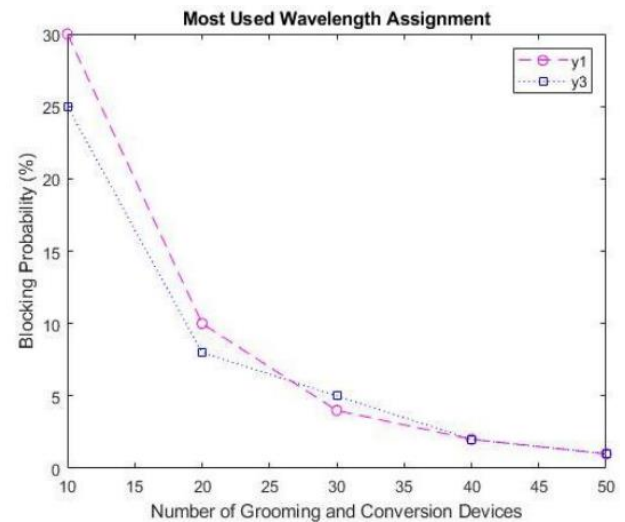


Figure 11 Probability of Blocking vs. Quantity of Grooming and Conversion Tools

The performance comparison in terms of blocking probability is given as a graphical representation in Figure 10 and Figure 11. The horizontal axis represents number of source and destination pairs and the vertical axis represents the number of wavelengths in Figure 8 and Figure 9. The wavelength assignment schemes adopted, present a difference in the performance of the network as depicted in the graph.

Y1 - represents single objective function.

Y3 - represents multi objective function

In both the analyses made, the multi objective Genetic Algorithms has the requirement of lesser

number of resources and comparatively lesser blocking probability.

CONCLUSION

This paper concluded a multi-objective integer linear programming approach of the routing & wavelength assignment problem, with the goal of minimizing the number of wavelengths, quantity of wavelength converters, & grooming devices. As the ILP formulation of the RWA problem is NP-hard, the evolutionary GA heuristics were utilized to achieve near optimal solution. The provisioning of wavelength resources, wavelength converters at sparse nodes and grooming devices at some of the nodes were performed by GA approaches. The fitness functions were utilized to evaluate the performance of the GA heuristics under the two different wavelength assignment schemes. The minimization of wavelength resources, wavelength converters and grooming devices by the multi objective GA heuristics is found to have better results in terms of blocking probability and number of resources utilized than the other approaches analysed in this work.

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