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Traffic Grooming in VS-Based Multicast Mesh Optical Networks with GA*

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[A bstract] In this paper, we propose genetic algorithm (GA) to solve the problem of traffic grooming in multicast mesh wavelength-division multiplexing (WDM) bidirectional network. We give out both the theoretical upper and lower limits of Add/Drop Multiplexers (ADMs) and wavelength of our network model. And the blocking of our algorithm is described in our paper. Before we begin our solution, we route the multicast messages with the approach: spawn from virtual source (VS) and assign wavelengths. While utilizing GA with our problem, we encode the problem with natural number and get a near optimal result.

[Keywords] virtual source(VS), multicast, mesh network, GA, traffic grooming.

1. Introduction

With the technologies: communication, WDM and fibre optics development, the capacities of fiber and wavelength have been exploited and come to utilization. By using WDM, a fiber can support a great number of wavelengths to propagate simultaneously. But in the era of information blast, the traffic in the Internet is greatly vast, when each communication between nodes is established with one wavelength respectively, then it need a vast mass of resources. For the case that the SONET is the domain technology of today networks, on every node in the network it needs SONET Add Drop Multiplexers (S-ADMs). By the utilization of wavelength add drop multiplexer (WADM), the node has the capacity to select the proper wavelengths to drop or add, and bypass the others optically, lest additional devices needed. When one node has information from multi-sources to dropped, then it must equipped with several ADMs, this will bring up the waste of resource. In most case, the information call from node to node is low, i.e. OC-3, when the wavelengths dropped can be compressed to less number wavelengths, that is to say, e.g. those several OC-3s are multiplexed to OC-48, then it can save up resource greatly. That is traffic grooming [1].

The network today is mostly looked as building upon rings; SONET ring is its infrastructure. But the network in practice is of a mesh network. For mesh network, there are many styles of physical topology, which can be classed into two kinds: irregular and regular. We focus on the irregular topology (e.g. NSFNET) in our study. The mesh should not be look as making from rings, but routing and wavelength assignment (RWA) in mesh network is proved to be NP-complete. In this paper, we propose a heuristic algorithm for RWA in mesh network.

In the network, communications between nodes are multicast, several to several, that is one source has several destinations, and several sources would send information simultaneously to the common destination. As we know, multicast can save up a great deal of resource contrast with uni-cast and broadcast [2]. In this article, we only consider the scenario that the multicast data copies would be produced optically mainly via light splitting [3]. The device that support light splitting is a switch which is also called multicast capable (MC) switch, that can't support is called multicast incapable (MI) switch. The node equipped with MC switch is called MC node, and the node only with MI switch is called MI node. Because the MC switch is more expensive than the MI one, we can't equip with MC node all in the network, in fact, the network is equipped only with several MC nodes, which is called sparse MC network. When the MC node also has the capacity of wavelength conversion, then it becomes a virtual source (VS) node [4]. When a session comes to this node, it can produce copies by splitting the light wavelength income, or convert some of its branches to wavelengths different. We then concentrate on the network with sparse VS.

Most of the previous works focuses on traffic grooming are based on SONET ring[5-7], and several, almost we can say, few cracks down on mesh network,

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and fewer on traffic grooming [8-10]. In our study, we mainly devote our energy to traffic grooming in multicast mesh network, we consider traffic grooming in combination with routing and wavelength assignment (RWA). Our objective is to minimize the total number of ADM and the total number of wavelengths required in the network. But constructing light tree in mesh network is a classical Steiner tree problem and is NP-complete, in our paper, we propose the algorithm for RWA, for routing, we bring up that the light tree using spawn from VS algorithm, and for wavelength assignment, one wavelength is assigned to the tree that has the least hop lengths and the least wavelengths on its fiber links. As such an algorithm, it makes the tree which the session propagating along with the least congestion and the shortest route length (least length and least congestion based on virtual source, L^3CVS) [10].

To allocate the virtual sources in the mesh network, we utilize exhaustive search algorithm to make the best allocation. And in order to minimize the number of ADM and the number of wavelengths in mesh network, for the merit of power in solving complicated problems and get the optimal results, we select genetic algorithm as the approach for optimization. In our approach, we neither constrain the traffic form, nor constrain the source number or number of destinations of every source.

In our article, it is organized as following. In section 2, we provide the problem statement and mathematical formulation of traffic grooming; in section 3, we describe the genetic algorithm and its theoretics; in section 4, we present the routing and wavelength assignment in mesh network, worthwhile we introduce the approach of virtual sources allocation; in section 5, it presence the computer simulation; in section 6, we analyze the computer simulation result; and finally, we draw a conclusion and give the prospect with the remain un-finished problems.

2. Problem Statement and Mathematical Formulation of Traffic Grooming

2.1. Problem Statement

The physical topology with high-bandwidth wavelength channels which the low-speed traffic grooming required is stated below.

1) A physical topology $G=(V,E)$ consists of a weighted bidirectional graph, where V is the set of nodes in the network, and E is the set of links in this network system. In the optical network, nodes correspond to the network nodes and links correspond to the fibers between nodes. And the nodes of the network would not have the same degree (number of fibers link to the nodes); links are weighted, whose weight is corresponding to the physical distance of two nodes. The devices needed in the nodes are not constrained before grooming.

2) The wavelengths on every fiber are also not constrained before grooming. The capacity of wavelength channels is C, and granularity g pretences that the number of low-speed traffic can be multiplexed and carried in one wavelength channel, e.g. OC-48 can contain 16 OC-3s, so g=16.

Our goal is to build light trees based on VS, and the trees are all the minimum tree. Then we bed the virtual topologies-these light trees on the physical topology.

2.2. Mathematical Formulation of Traffic Grooming

The traffic grooming in multicast mesh network with static non-uniform traffic can be turned to an integer linear program. Here we give out our assumptions:

1) In the network, only one fiber links two nodes.
2) The number of transceiver needed in every node is not limit before grooming while we only consider that they are fixed but rather tunable.
3) The number of wavelengths on the fiber link is not limit. And its capacity which replaced by granularity g is the maximum 16; a wavelength can carry at most 16 OC-3s.
4) The number of ADM equipped in one node is also not being limited.
5) We need not to consider other devices such as router, multiplexer and demultiplexer, cross-connector, etc. needed in the network but for ADM and wavelength.

While start to groom the traffics in the mesh network, we formulate the problem as an optimization problem, and following we use the notations in the mathematical formulation:

m and $n$node in the network.

- *Optimization:*

our goal is to minimize the number of ADM needed in network with the less number of wavelengths;

N number of node in the network.
V number of source node in the network.
i number of source node, $i \in \{1,2,\cdots,V\}$.
j number of destination node, $j \in \{1,2,\cdots,N\}$.
D_j degree of node j.
H_{mn} hop distance of nodes in the physical topology.
t_i traffic from source i. The granularity of these traffics is variable from 1 to 16.
L_{mn} (L) the direct physical link of node m and node n.
R_{mn} route from node m to node n.
C capacity of wavelength channel.
A_j the number of ADM needed in node j.
W_L wavelength on link L_{mn}.
W^N wavelength in the network.
s_i and d_j^i the i^{th} source and j^{th} destination of the session
χ_{mn} index of congestion of link L_{mn}.
VS_i virtual source presenced in light tree i.
s_i^d the source that is only a source and not served as a destination of anyone of source.
$t_{ij}^{w,L}$ traffic from s_i to its destination j carried by wavelength w goes through link L_{mn}.

meanwhile we try to construct minimum trees.

$$Hop = \min \sum_{m,n} H_{mn} \quad n \in \{1,2,\cdots,N\} \tag{1}$$

$$\chi_{mn} = \min \sum_{m,n} \left(H_{mn} + W_L\right) \ |m-n| = 1 \ \forall m,n \tag{2}$$

$$A_T = \min \sum_{j=1}^{N} A_j \tag{3}$$

- *constrain:*

$$R_{mn} \geq 1 \quad \forall m,n \tag{4}$$

$$2 \leq D_n \leq 6 \quad \forall n \tag{5}$$

$$VS_i \geq 1 \quad \forall i \tag{6}$$

$$\chi_{mn} = H_{mn} + \sum_k W_L^k \quad k \in \{1,2,\cdots,V\} \tag{7}$$

$$\sum_i^V t_{ij}^{w,L} \leq g \tag{8}$$

$$A_{\max} = \sum_{i=1}^{V} \sum_{j=1}^{N} d_j^i + \sum_i s_i \tag{9}$$

$$A_{\min} = \sum_{j=1}^{N} \left\lceil \sum_{i=1}^{V} t_{ij} \Big/ g \right\rceil + \sum_{i=1}^{V} s_i^d \tag{10}$$

$$W_{\max}^N = \sum_{i=1}^{V} s_i \tag{11}$$

$$W_{\max}^L = \max \sum W_L \quad \forall m,n \tag{12}$$

$$W_{\min} = \max \left\lceil \sum_i t_i^L \Big/ g \right\rceil \quad \forall m,n \tag{13}$$

- *explain:*
  - ✧ In Equation 1, with the optimal location of virtual sources in the mesh network, the network is divided into several districts by several VS' and each district one virtual source. In one district, H_{mn} means the summation of hop length of every node to its virtual source m. And *Hop* means the minimum of summation of hop length of districts after optimal VS location.
  - ✧ Equation 2 shows that when assign sessions (one session one wavelength) on physical topology, we assign a new wavelength to the least congestion link when there are some candidates.
  - ✧ In equation 3, A_j means the number of ADM the equipped on node j, and A_T means the minimum total number of ADM needed in the network.
  - ✧ Equation 4 means that there is at least one route from one node to the other node in the network.
  - ✧ Equation 5 means the node in the network at least links to 2 nodes, and has 6 neighbors mostly.
  - ✧ Equation 6 shows that there is one VS at least in any one light tree.
  - ✧ And equation 7 indicates that the index of congestion in link <m, n> is considered as its hop length and the number of wavelength in this link.
  - ✧ Equation 8 gives the meaning that the traffics carried by wavelength w on an ingressive link will not out of the channel's capacity.
  - ✧ Equation 9 implies that the maximum number of ADM equipped in the network equalizes to the number of aggregation of source nodes and its destinations on every tree.
  - ✧ And equation 10 shows that the minimum number of ADM needed in the network, for one node, is the number of wavelength on every one ingressive link to it is that the summation of traffics of varied sources on the link can be groomed to, then for one wavelength it needs one ADM.
  - ✧ Equation 11 means that the maximum number of wavelength needed in the network is that each session is assigned one wavelength respectively.
  - ✧ Equation 12 means that the optimal maximum number of wavelength without traffic grooming but with wavelength conversion is the maximum number of non-overlapped wavelength on a link.
  - ✧ Equation 13 shows that the minimum number of wavelength in the network is the maximum of all the numbers of non-overlapped wavelength on

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anyone link after traffic grooming.

3. Mesh Network Construction

The optimal physical topology can be formulated as an optimization problem. But we don't focus on the design of physical topology; we only concentrate on the optimization of the existent topology. For the sake that our Algorithm can be utilized in all of the mesh networks, we construct a mesh network randomly upon a connected tree produced from Prufer numbers. The detail is showed in subsection 3.1

And we know that RWA in multicast mesh network is NP-complete problem, while there are many approaches for RWA in this network, we select the method: virtual source-based multicast tree construction. So before construct trees, we must locate the virtual sources optimally. Then the source nodes are randomly generated and located in the network after VS location, it is detailed in the following section. At the same time, the traffic of different source node is also randomly provided, so do their destinations. With the source nodes and their destinations respectively, based on the minimum tree construction and the idea of the least congestion, these virtual topologies are bedded on the physical topology-the mesh network given previously, that will be showed in subsection 3.2.

3.1. Mesh Construct and VS locate

We construct the mesh networks with Prufer numbers. With Prufer numbers, we first construct a connected tree, it guarantees that $R_{mn}=1$, in other words, the tree makes the node pairs on it has connected route to each other; and then we construct a mesh upon it based on (5). The approach we used guarantees us that the networks is arbitrary and the node pair in the system has no less than one route to connect each other, showed in (4). And the network we construct is a bidirectional network and it is only one fiber link between neighboring nodes. With the method above we construct a mesh network showed in fig. 1.

After the mesh networks constructed, then we begin to locate virtual sources (VS), here we assign this network 4 VSs, for we initially consider the network with sparse virtual sources. While locating VSs, we make use of exhaustive search to achieve the optimal result, with constrain showed in (3). Before VS allocating, we count the total hop length to the VSs, with the location of the VS's varied, the total hop length varied, and on the property locations, we can get the optimally located VS's. We get the optimal VS location based on the previous method. We can see that the node 3, 10, 17, 18 are equipped and serve as virtual sources, which are the grey nodes showed in fig. 1.

3.2. RWA

With the best distribution of virtual sources, we first produce some source nodes and their respective destinations, thereupon the traffics from the sources are all decided respectively at the same time, and the traffics from these sources are varied from 1 to 16 (accordingly from OC-3 to OC-48), given in our article, e.g. the traffic from source node 1 is 15, which in optical carrier is 15×OC-3, or 3×OC-12+3×OC-3. But the upper limit can be to OC-768 or even higher when it needs, so does the lower limit, it can be low to STS-1, while the upper limit and the lower limit are both according to their multiplexing/demultiplexing mechanism.

When the source nodes and their destinations respective are all determined, the construction of light tree for each session begins. For one session node, it first find the nearest virtual source node and builds a virtual link to this VS node, on the way, the virtual link may select the physical route that goes through one of its destinations; and then from this VS node (primary VS, p-VS) the tree sprawl its branches to the destinations

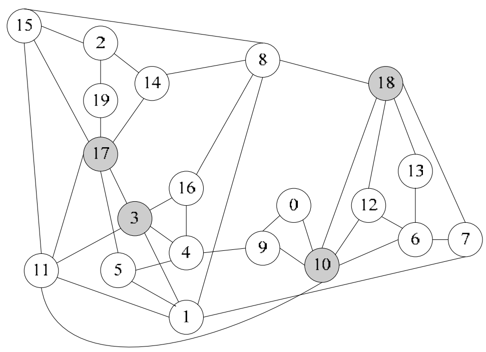

Figure. 1. The mesh network and its VS distribution

linking directly to p-VS; if there are some destinations untouched then a new branch bring out to the nearest VS (this branch may prefer to the stretch of existing branch when the VS has no direct link to p-VS), then from this VS node it links all the destination nodes that have direct link to this VS; when there are destinations have not linked, select one of the linked VSs that nearest to the VS node who has direct link to the remain destinations and link them; when there are still some destinations have not linked and have no direct link to VS nodes, then find way shortest to VSs; when there are candidates, the preferable way is the way which goes through the destination node.

When considering constrain of the least congestion as listed in (2), the number of wavelengths on the physical link will be counted at the same time. Given that the light trees are firstly assigned a different wavelength respectively-one session one wavelength. With the constructed light trees, then the sessions will propagate along the decided physical routes during their lifetime without any variations.

4. Genetic Algorithm (GA)

4.1. Algorithm description

As we know, all the life-forms in the earth evolve by chromosome crossover and mutation. And genetic algorithm is the simulation of life evolution which is powerful for solving problems and getting an optimal result. When there are two chromosomes originally decoded like A and B in fig. 2, and these two chromosomes exchange their some fractions of genes each other, in fig. 2, the gray fractions of A and B denote the sections that will be exchanged each other. After crossover, the new chromosomes are coded like A and B in fig. 3. As we know that the crossover among chromosomes may not be two fractions, it can be only one section or more than two according to the facts: the length of chromosome, the degree you need them crossover and the activity of chromosomes, etc. You know the longer of the chromosome, the more possibility of crossover and the more number of fractions of chromosome will occur crossover.

A	1	2	3	4	5	6	7	8	9	0
B	6	7	8	9	0	1	2	3	4	5

Fig. 2. the original chromosomes

A	1	7	8	9	5	6	2	3	9	0
B	6	2	3	4	0	1	7	8	4	5

Figure 3. the new chromosomes after crossover

At the time of occurrence of crossover among chromosomes, some fractions of gene-string or some genes on some chromosomes will mutate on occasion. Then the mutated individuals become new members to the population as showed in figure 4. And here we think that the repeating pretence of fraction is also legal, e.g. in fig. 3, the 4th section is 9 and the 9th section also is 9 in chromosome A, and in B, the 4th and 9th are both 4; and so do in figure 4.

After crossover and mutation, there are more members in the group with the original individuals. According to the natural law of evolution, the better ones are selected to remain and bring up new children, and the bad ones are eliminated through selection or contest. In our algorithm, the one that needs the least ADMs and the least wavelengths is the best, so we count the number of ADM and number of wavelength needed by every individual, that is fitness account, when there are individuals that need the same number of ADM, then the one that needs the less wavelengths is the victor. The genetic algorithm is the simulation of natural evolution.

4.2. GA for traffic grooming

After the light trees decided, we begin to groom the multicast traffics in the mesh network with GA. When utilization of GA, the populations of chromosome will be produced firstly, meanwhile we design an algorithm to encode the scene of RWA of sessions to a chromosome and ensure that the chromosome would not be an illegal one. From this original chromosome, we produce a certain number (p_0) of population of chromosome who are all legal according to the original one. The population evolves ($p_0+\lambda$) with genetic approaches such as crossover and mutation. And each individual is decided to survival with its fitness under certain constraint.

4.3. Encode of problem

As there are several sources send message simultaneously in the mesh network, and the wavelengths for these source nodes may not be the same for the constrain of the capacity of wavelength. The routing and wavelength assignment in the network will be encoded by

A	1	1	3	4	5	6	7	8	9	0
B	6	7	8	9	0	1	2	4	4	5

Figure 4. new chromosomes after mutation

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natural number based on two considerations: one is the difference of wavelengths, the other is that problem decoded with rational number (including natural number) will make the Algorithm more efficiency.

4.4. Framework of genetic algorith m for grooming problems with traffic

Here we use (μ+λ) strategy for genetic algorithm: form the model chromosome we generate p_0 population and select μ as parents to generate λ offspring, all the solutions compete to survive and the best μ is chosen to be parents of next generation. The program is outlined as following:

a. set all the parameters in the program;

b. generate initial p_0 population of μ individuals randomly;

c. repeat

  a) from the p_0 population, select the best μ as parents of next generation;

  b) with the function of crossover and mutation, they will generate λ new individuals;

  c) count the fitness of new individuals and sort them with their parents on fitness;

d. end the program when the termination scenario is violated.

The detail of program will be described in the following subsections.

4.4.1. C hromosome representation

When a source sends its multicast message in the mesh network, its routing matrix becomes a sparse matrix. If we decode all the wavelength appearance in the link matrix then there are mostly the genes of chromosome is zero which present that the wavelength is not assigned in the link or the link is not exist. With multiple sources in the network, the encoded chromosome will be long with most of the genes which carry the same message (zero) and have no more benefit to our algorithm. So we abstract these sparse matrixes that the worth in the sparse matrix is not zero will be encoded into gene of the chromosome, thus the gene on the chromosome carries only with helpful message and the length of chromosome will be shortened obviously.

4.4.2. Cr ossover

In this paper, we select some pairs of chromosomes randomly to crossover, for there are some sessions utilize same wavelength in the same fiber link, so there are some genes in chromosome that are same, and it does not make the chromosome illegal.

4.4.3. Mutation

Just like the natural gene operation, there may be the scenario that there are some mutant gene exist in some of the offspring chromosomes. While there are many kinds of mutation operations, we select the easy one: replace the gene string with a new gene string encoded with natural number between two random points of the chromosome.

4.4.4. Fitness count

As for our purpose is to minimize the number of ADMs needed in the multicast network, we count mainly the ADMs equipped in the network, and meanwhile we also count the number of wavelengths required by the network. The one with the minimum of ADMs is the best one, while the number of wavelength is considered secondly.

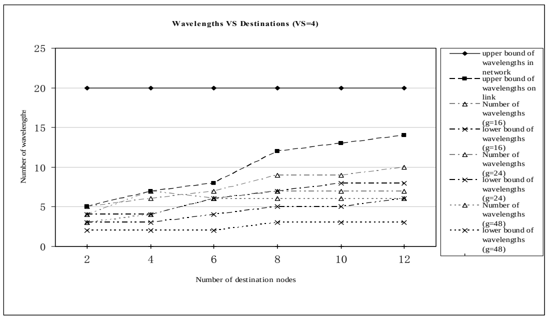
5. Computer Simulation

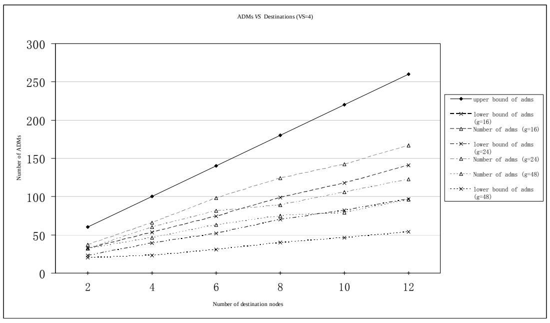
We use GA proposed in this paper to solve the problem of non-uniform traffic grooming in the bidirectional multicast mesh network. The traffic granularity varies among 16, 24 and 48 in our test. And the network model has 20 nodes with all of them are sending message to groups of users, while their destinations vary from 2 to 12 every 2 at the same time, 4 VSs distribut in the network. The traffic requirements from these source nodes are set randomly at the integers in the interval [1, 16] even the granularity varies. The population is set to 500 and so does the size of offspring. The generation is set to 200. The run times is 10, and each time with the same source nodes, the same traffic requirements and the same user groups, the chromosomes are encoded randomly on every run cycle. The rates of crossover and mutation are set to 0.4 and 0.6 respectively. The operation of crossover operates before mutation; and if the size of offspring reaches then stops the operation of mutation arbitrarily. The optimal result of traffic grooming is showed in table 1.

6. Conclusion

From table 1, we can see that the maximum number of wavelengths present in the network - 20 is the maximum different wavelengths appearing in this network before grooming – here we assign every one of the session one different wavelength; with the reuse of wavelength, the

Table 1 result of grooming





upper bounds of wavelengths in the fiber change before grooming when the sets of destinations belonging to every source differ. And the theoretical lower bounds of wavelengths of this model network is changed with variations of granularity and sets of destinations, the numbers of wavelengths after grooming are all close to the low-bounds and getting a much greater ratio of saving of wavelengths contrast with the upper bound of wavelengths when granularity grows, a near optimal results of number of wavelengths needed in this model network is got. We can also see that the upper bounds of ADMs vary accordingly to the sessions' variation; with different granularity, the upper bounds of ADMs are same when the sets of destinations are same. The low bounds of ADMs deduce with the granularity grows and the same sets of destinations, and the grooming results - number of ADMs needed in the network also along with the low-bounds deduce contrarily to the granularity's change, the greater of granularity, the more of saving of ADMs, the greater of set of destinations, the greater of ratio of number of ADMs of pre-grooming vs of post-grooming, and we can see that the results are mostly near optimal - they are near to the low-bounds, as showed in table 1. With our method, as showed in table 1, we can save up resources greatly in the mesh network.

In this paper, we propose traffic grooming with GA in multicast mesh network and get a result. And this algorithm can also be cast on the network existing or to be designed, it can give us a cost evaluation of network.

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