Wavelength Assignment Algorithms for a Multihop Lightwave Network

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ABSTRACT

GENMET(GEneralized Multihop Network) which is based on Wavelength-Division Multiplexing(WDM) and can be used in order to construct the next generation lightwave network is a logical(virtual), packet-switched and multihop topology network. GENMET is a regular multihop network which is a generalization of Shuffle network and de Bruijn network. As such, it has the advantage of simple routing which is critical in a high speed network. Given a physical topology, different logical topologies can be derived for assigning wavelengths to the UserNodes. By appropriately assigning wavelengths, performance of the network, such as mean hop count, maximum throughput and mean packet delay can be improved. In this paper, we propose heuristic algorithms for effectively assigning a limited number of wavelengths to the given UserNodes. The performance of proposed algorithm is compared with the random assignment and the lower bounds.

key Words : Optical networks, WDM, Regular topology, GEMNET, Wavelength assignment

I .Introduction

There has been an increasing demand for high speed data transmission including voice, video, high-resolution graphics, medical imaging and distributed databases. As a means of satisfying such wideband transmission needs, lightwave network using optical-fibers has been studied[1]. Diverse topologies such as bus, star, ring and mesh can be used in a lightwave network. Although increased throughput can be obtained by merely replacing coaxial cables or twisted pairs in traditional shared medium networks, the opto-electronics conversion bottleneck limits maximum throughput of a network as in a FDDI (Fiber Distributed Data Interface) network. A promising architecture for future LANs uses a passive star coupler. This creates a broadcast-and-select network where multiple parallel channels derived by Wavelength-Division-Multiplexing(WDM) can be accessed by users transmitting and receiving on different wavelengths. Since many concurrent transmissions are possible, the aggregated network throughput can be made much greater than that of the conventional LANs using shared medium approach. There are basically two approaches of designing a LAN using a optical passive star coupler: single hop approach and multihop approach[2][3].

Single-hop network delivers informations

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from source to destination directly without passing through intermediate nodes. But, it requires a multiple access protocol that can perform dynamic pretransmission coordination and arbitration among all nodes connected to network. Performance of single-hop network basically depends on fast tunable optical-transceivers(e.g.laser) which have not commercially appeared[4][5][6][7].

To the contrary, **multihop network** requires a limited number of fixed(or slowly tunable) opticaltransceivers. However, this simple hardware structure may require intermediate nodes to route informations from a source node to a destination node. A logical topology of a multihop network is relatively independent of a physical topology and exhibits different performances according to various wavelength assignment schemes. The desirable properties of optical multihop network which can support hundreds of thousands of users' traffic and provide high-speed, packet-switched network are the followings.

1) Small nodal degree(for low network cost)
2) Simple routing(to allow fast packet processing)
3) Small diameter(for short message delays)
4) Growth capability(for future scalability)

In this paper, we focus on GEMNET-topology which offers the above properties[8].

The GEMNET is a regular multihop network which generalizes Shuffle networks and *de Bruijn*networks. It allows a simple routing in gerent to a regular topology network. The number of nodes in a Shuffle network or in a *de Bruijn* is rather tightly constrained. This causes scalability problems. On the contrary, it is relatively easy to increase the size of a GEMNET by a small increment by reassigning wavelengths to the nodes.

The regular topology network is known to suffer from performance degradations in terms of increased mean hop count and/or decreased maximum throughput, when traffic load is not balanced. In order to avoid these problems, one may assign wavelengths so that disered performance is optimized. There have been papers dealing with wavelength assignment problem in a Shuffle network or in a general mesh topology network[9][10][11][12]. However, no previous study of the wavelength assignment algorithm for the GEMNET have appeared in the literature. In this paper, we propose heuristic wavelength assignment algorithms and the performance of the proposed algorithm are investigated through computer simulatives.

The paper is organized as follows : We first describe in section 2 the GEMNET as introduced in [8]. We then present the wavelength assignment problem as a node placement problem in section 3. In section 4, we describe two greedy algorithms for assigning wavelengths. Performance in terms of mean hop count, mean, maximum and minimum link traffic is given in section 6. In section 7, a concluding remark is given.

II. GEMNET

2-1. Logical topology

A GEMNET is a generalization of the shuffle-exchange network to create a flexible virtual topology. It consists of wavelength-routing switches and a passive star coupler[8]. It can be represented by three parameters:K, M and P. K is the number of columns, M is the number of nodes in each column and P is the number of wavelengths from each node. In a (K,M,P) GEMNET, KM nodes each with degree of connectivity P are arranged in a cylinder of K columns and M nodes per column as shown in Fig.1.

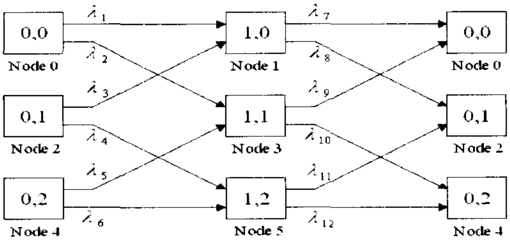

Fig. 1(a) Logical topology of a GEMNET

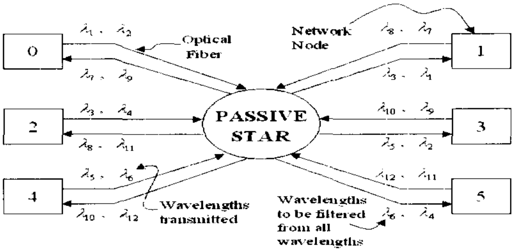

Fig. 1(b) Physical topology of a GEMNET

The logical topology of Fig.1(a) can be realized by assigning wavelengths as shown in Fig.1(b) in a broadcast-and-select network using a passive star coupler. When M =PK, the GEMNET reduces to a Shuffle network. On the other hand, if K=1and M= PD where D=1,2,3, and P=2,3,4, , the GEMNET reduces to a *de Bruijn* network. The flexibility of choosing K and M for any integer in a GEMNET allows one to have a network with any number of nodes as opposed to the strict restriction imposed on a Shuffle network or on a *de Bruijn* network. This flexibility is particularly useful for scaling up the GEMNET provided that each node has tunable transmitters and/or tunable receivers.

Define diameter of the networks are the longest distance between a pair of nodes. Then, D is given by

$$D = \lceil \log_P M \rceil + K - 1$$

where ⌈ ⌉ is the ceiling function.

2-2 Routing [8]

Every node-address in GEMNET can be represented by column-address and row-address. Let (CS , RS) and (CD , RD) be the source-node address and destination-node address, respectively. The minimum hop distance in which the sources touches(covers) a node(not necessarily the destination) in destination node's column is δ = $[(K+C_D)-C_S]\bmod K$. Therefore, the hop distance from source node (CS ,RS) and destination node (CD , RD) is given by the smallest integer h of the form $(\delta + jK), j = 0,1,2,\ldots,$ satisfying the following expression:

$$h = (\delta + jK), \; j = 0,1,2\ldots$$

$$R = [M + R_D - (R_S \cdot P^h) \bmod M] \bmod M < P^h$$

R on the route code, which specifies a shortest route from the source node to the destination node when it is expressed as a sequence of *h* base-*P* digits.

In general, if R=[$\alpha_1,\alpha_2,\ldots,\alpha_h$]*base P*, the node about to send the packet on its jth hop will route the packet to its α_j^{th} outgoing link. The maximum number of iterations needed to solve for R is just D/K , where D is the diameter of the network.

Define an all-0-link pathe to be the path traced, from a particular source node, by taking the 0-link out of every intermediate node(including the source-node) for an arbitrary number of hops. Now, note that $[R_S \times P^h]_{\bmod M}$ is the row index of the node in column CDreachable from the source node in *h* hops, by following the all-0-link path. Then, (*h-1*) 0-links followed by a 1-link leads to the node with row index $[R_S \times P^H + 1]_{\bmod} M$ in column CD , and so on. However, on the h^{th} hop, a maximum of Ph nodes can be covered. The node reached on the hth hop from the source node by following the all-(*P-1*)-link path(defined similar to the all-0-link path) will be $[R_S \times P^h + (P^h - 1)]_{\bmod} M$. Thus, if R is less than Phwhich means that destination node is falls somewhere between the all-0-link path, then the destination node reachable in *h* hops and its route code is given be R.(The addition of M and *mod* operations are required to accommodate the wraparound of row indices). On the other hand, the Ph nodes covered on the hth hop could be greater than the number of nodes in that column. This means that multiple shortest paths may exist to some nodes in that column. Having calculated R, if (R+jM) <Ph for j=1,2,3,, then (R+jM) is also a routing code with path-length h for any j that satisfies this inequality. Thus, if the shortest path from node *a* to node *b* is *h* hops, the number of shortest paths is given by $Y = (P^h - R)/M$. Hence, for a given alternate shortest paths increases as M decreases. The larger the number of shortest paths, the more opportunity there is to route a packet along a less-congested path and the greater is the network ability to route a packet along a minimum-length path when a link or node failure occurs. The trade-off is that decreasing M will increase K, which, in general, will cause the average hop distance to increase.

In our research, to minimize the nodal processing-time and complexities, we only consider a unique shortest-path between node-to-node.

Ⅲ. Wavelength Assignment Problem

On the assumption that GEMNET employs a fixed-shortest path routing algorithm which simplifies nodal processing, it is important to aquire optimal performance in terms of minimizing mean hop count, mean link traffic or maximum link traffic.

Given a traffic matrix, T ={tij} where tijis the traffic from UserNode i to UserNode j, one can assign wavelengths to the nodes in such a way that we optimize a particular performance measure. In this paper, we will use the mean hop count as the measure of network performance.

The wavelength assignment problem is then finding an index vector I = [i1, i2,,iN], where N=KM is the number of nodes and I(k) = iK is the index of the UserNode attached to the NetworkNode. Then the mean hop count of the network using assign-ment I is given by

$$\bar{h} = \sum_{m=1}^{N}\sum_{n=1}^{N} d_{mn} t_{I(m)I(n)}$$

where d_{mn} is the minimum distance in number of hops from source NetworkNode *m* to destination NetworkNode *n*. Optimal assignment can be determined by enumerating all the *N!*assignments and comparing the resulting mean hop counts. However, the number of enumerations becomes prohibitly large as N increases. Therefore we need to consider heuristic algorithms for an appropriate compromize between the complexity and the performance.

Ⅳ. Greedy Algorithm

Optimal wavelength assignment algorithm requires comparisons of N! permutations. For a reasonably large network, it is prohibitly time consuming to perform such a search for an optimal assignment. Therefore, we considered a number of greedy algorithms.

We describe two greedy algorithms: Greedy1 and Greedy2.

Input : T = { t_{ij} }, t_{ij} is the traffic from i to j

K = number of columns of the network

M = number of nodes in a column.

P = number of wavelength for each node

Output : UserNode = a vector of user node corresponding to the network nodes.

Greedy1 :

The element traffic matrix tij are sorted in descending order. Attempt to place the nodes(User-Node) corresponding to the largest element(say tij) so that a one-hop path from I to j is available.

Until all nodes are placed, perform the following steps 1 and 2.

1. Let L be sorted list of element of traffic matrix T.
2. Choose the highest element in L corresponding to traffic from i to j. Let tij = 0.
   1) *If both i and j have not been placed*, find a pair of NetworkNode a and b which are directly connected and which are not occupied by UserNodes. If successful, the UserNodes i and j are placed at the NetworkNode a and b. Otherwise, i and j are not placed.
   2) *Else if i has been placed and j has not been placed,* let the NetworkNodes corresponding to i be a.
   Identify NetworkNodes b1,b2,,bP which are a single hop away from a. If there is an unoccupied node among b1,b2,,bP, place j to one of them. Otherwise j is not placed.
   3) *Else if i has not been placed and j has been placed,* Let the NetworkNode corresponding to j be b.
   Identify NetworkNodes a1,a2,,ap from which b is a single hop away. If there is an unoccupied

node among a1,a2,,ap, place i to one of them. Otherwise, i is not placed.

4) *If both i and j have been already placed,* no additional placement is needed.

Greedy2

In Greedy1, we first try to place i and j corresponding to the largest element of T without regard to tji. In Greedy2, we form a matrix sum S = T + TT where TTis the transpose of T. We attempt to place the node pairs corresponding to the largest element of S in Greedy2.

Until all nodes are placed, perform the following steps

1. Let L be sorted list of elements of traffic matrix S.
2. Choose the highest element in L corresponding to traffic between i and j. Let S_{ij} =0.
    1) *If both i and j have not been placed,* find a pair of NetworkNodes a and b, such that when i is placed to a and j is placed to b, the weighted hop count is minimized. This can be done by first calculating the weighted hop count between NetworkNodes which are not yet occupied by any UserNode and then choosing the one having the minimum hop count.
    2) *If only one of the UserNodes i or j has been placed,* choose a NetworkNode corresponding to the unplaced nodeusing the same method as in 1).
    3) *If both i and j have been placed,* no additional placement is needed.

V. Lower Bounds

Since it is impossible to obtain the optimal assignment for most realistic network, we derive a tight lower bound on the mean hop count . For row i of traffic matrix { t_{ij} , j=1,2,,N}, we define H_{iR} as the minimum of total hop count for traffic from i to all other nodes j={1,2,,N} (j≠i) where destination node can be arranged in an arbitrary manner. Similarly, for column j of traffic matrix { t_{ij}, i=1,2,,N}, we define H_{jC} as the minimum of total hop count for traffic from i (i=1,2,N) to j where source node can be arranged in an arbitrary manner. Then the lower bound of the mean hop count is given by

$$h_L = \frac{\min(\sum_i H_{iR}, \sum_j H_{jC})}{\sum_i \sum_j t_{ij}}$$

VI. Performance Evaluation

In this section, we evaluate the performance of the Greedy algorithms and compare it to the lower bound for uniformly and nonuniformly distributed internodal traffics. For uniformly distributed random traffic, the traffic-rate from any node to any other nodes is a uniformly distributed random number between 0 and 1. For nonuniformly distributed random traffic, k nodes are configured as database servers-each serves a disjoint set of PK1 nodes. Traffic rate from a nonserver node to any other nodes is a uniformly distributed random number between 0 and 1. The traffic rate from a server node to any other nodes it serves is a uniformly distributed random number between 0 and , where is a given traffic skew factor.

Experiment1:

Each value in the table is obtained by averaging over 500 experiments.

Table1: (2,12,2) GEMNET

Uniform	Random	Greedy 1	Greedy 2	Avg. hop. Bound
Mean hop count	3.3467	3.3478	2.8122	2.6283
Min-link traffic	6.0761	6.0319	7.4773	(7%)
Mean-link traffic	19.236	19.235	16.166	·
Max-link traffics	35.242	35.348	26.392	·

ϒ = 10	Random	Greedy 1	Greedy 2	·
Mean hop count	3.353	3.3473	2.5217	2.4024
Min-link traffic	6.4723	6.5276	8.5154	(4.97%)
Mean-link traffic	30.032	29.938	22.25	·
Max-link traffics	75.839	75.58	46.503	·

ϒ = 50	Random	Greedy 1	Greedy 2	·
Mean hop count	3.3535	3.3397	2.0929	1.9861
Min-link traffic	6.4752	6.5951	8.1554	(5.38%)
Mean-link traffic	74.303	74.093	45.544	·
Max-link traffics	261.95	267.1	135.05	·

ϒ = 100	Random	Greedy 1	Greedy 2	·
Mean hop count	3.3601	3.3447	1.9076	1.8105
Min-link traffic	6.4682	6.3664	8.5723	(5.36%)
Mean-link traffic	116.43	115.77	66.343	·
Max-link traffics	454.37	451.6	224.01	·

In Table1, assuming (2,12,2) GEMNET, we compare the performance of the proposed algorithms(Greedy1 and Greedy2) with that of the random assignment. We also show the lower bound on the mean hop count for comparison. It is shown that the performance of the Greedy1algorithm is not significantly better than that of random assignment except for the network with a large skewness factor. The Greedy2 algorithm, on the other hand, performs significantly better than both random and Greedy1 algorithms. The comparison of the Greedy2 algorithm with the lower bound on hop count indicates that the Greedy2 algorithm does not have more than 7 % of the mean hop count of the lower bound.

Experiment2:

In Table2 we consider various logical topologies having 64 nodes. The results reported are the average of 500 computer simulations. For a ShuffleNet, the mean hop count found utilizing Greedy2 algorithm is only 8.78% above the average lower hop bound among other virtual topologies. This result in smaller hop distances variances between node-pairs in ShuffleNet compared to other virtual topologies. Instead of having small variance of hop-distance between node-pairs, Shuffle-Net cannot be conveniently expanded and scalable by arbitrary size.

Table2 :Various 64 node networks

ϒ =		Random	Greedy 1	Greedy 2
De Bruijn K=1 M=64 P=2	Mean hop count	4.5272	4.8279	4.1732
	Avg.hop bounds	·	·	3.645 (14.48%)
	Min-link	29.35	29.243	29.356

	traffic			
	Mean-link traffic	180.95	192.96	166.82
	Max-link traffics	2208.9	3128	1948.5

ShuffleNet K=4 M=16 P=2	Mean hop count	4.6335	4.556	4.1119
	Avg.hop bounds	·	·	3.78 (8.78%)
	Min-link traffic	20.996	20.515	20.566
	Mean-link traffic	185.21	182.11	164.41
	Max-link traffics	2462.1	2499	2195.3

GEMNET K=2 M=32 P=2	Mean hop count	4.4465	4.4573	4.1375
	Avg.hop bounds	·	·	3.675 (12.59%)
	Min-link traffic	15.046	14.361	14.688
	Mean-link traffic	178.17	178.62	165.83
	Max-link traffics	1993.7	1691.6	1895

GEMNET K=8 M=8 P=2	Mean hop count	5.718	5.6086	4.8643
	Avg.hop bounds	·	·	4.329 (12.36%)
	Min-link traffic	6.8415	6.9687	6.9335
	Mean-link traffic	228.91	224.56	194.83
	Max-link traffics	2887.4	3233.9	3021.8

VI. Conclusion

In this paper we proposed heuristic algorithms for assigning wavelengths in a multihop lightwave network using optical passive star coupler and WDM. GEMNET, which is a generalization of the Shuffle network and De Bruijn network, enjoys the advantage of a regular topology. While maintaining scalability which is not possible the original Shuffle network or *de Bruijn* network, GEMNET, by appropriately placing the UserNodes at the NetworkNodes can improve the performance such as mean hop count and mean link traffic.

Two greedy algorithms are proposed. Greedy1 assigns nodes in order of decreasing traffic elements in { t_{ij} } while Greedy2 uses { t_{ij} + t_{ji} }. It is observed that Greedy2 performs significantly better than random or Greedy1 algorithms.

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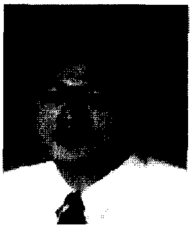

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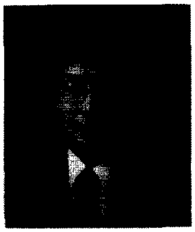

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