Weight Based Edge Disjoint Path Routing and Wavelength Assignment (WEDP-RWA) Algorithm for WDM Networks

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Abstract—*In this paper the problem of Routing and Wavelength Assignment (RWA) in optical Wavelength Division Multiplexing (WDM) networks has been addressed and a new weight based Edge Disjoint Path (EDP) algorithm for RWA has been proposed to optimize the wavelength resources in a wavelength routed WDM networks. The simulation results reveal that the network topology characteristics and link utilization factor have a significant impact on light path selection for traffic routing to minimize the required number of wavelengths. The weight based RWA solution reports significant improvement in wavelength utilization in particular for large network with increase in the call request for a source destination pair.*

Keywords-Routing and Wavelength Assignment; Edge Disjoint Paths (EDPs); Wavelength Continuity Constraint; Wavelength Converter

I. INTRODUCTION

WDM in optical fiber networks has been rapidly gaining acceptance as a means to handle the ever-increasing bandwidth demands of network users. In a wavelength-routed WDM network, end users communicate via all-optical WDM channels, known as light paths. The light-path provides a circuit-switched interconnection between two nodes which are located far from each other. So the number of wavelengths available on fiber links limits the number of end-to-end connections, further physical constraints such as wavelength channel spacing in a fiber, capability of optical transceivers, and bandwidth granularity limit the utilization of available bandwidth [1-3]. In this respect, WDM optical network imposes additional constraints on the available wavelength. In WDM optical networks light path establishment and wavelength assignment in combined known as RWA. A light path must operate on same wavelength across all the links that it traverses for an end to end communication if wavelength continuity constraint exists. This constraint leads to inefficient utilization of wavelength channels and results in higher blocking probability [4-5]. For example, a request may have to be rejected even though a route is available because of the non availability of the same wavelength on all the links along the route. This constraint can be overruled by providing wavelength converter facility at a node. This makes routing problem as similar to normal circuit switched network and the only limiting factor is the total available channels on the link. Amount of conversion and placement of the converter node are the two important factors. Further converter nodes increase the cost of the network along with poor signal to noise ratio and signal strength. Therefore, the problem of RWA becomes complex in WDM routing networks where the goal is to maximize throughput by optimally assign the routes and wavelengths [6-7].

The RWA problem is partitioned into two sub-problems; routing and wavelength assignment. We can further divide each routing and wavelength assignment problem into two components i.e. search and selection criteria. In routing problems, the search criteria are usually performed by well-known techniques such as shortest-path algorithm and its variations. Alternate routing, deflection routing and k-shortest path methods (i.e., more than one route is available), are few of them addressed frequently. However, the k-shortest path algorithm has a better performance than others even if the computational complexity is extremely high. In the k-shortest path routing, the optimal selection modeled by multi-commodity flow problem always finds the best solution, but it does not promise that the algorithm can handle considerably large networks. The selection function is performed by either sequential or combinatorial optimization algorithms. The combinatorial methods are divided into two approaches; optimal and heuristic mechanisms. The optimal approaches use all possible combinations of the inter-dependency. Heuristic methods reduce the combination space. The optimal selection achieves the best result, but the cost of computational complexity becomes critical. In wavelength assignment, the search function is trivial since any wavelengths can be assigned for the route determined. First fit is the simplest among them. However, selection is a hard combinatorial problem when the objective is to minimize the number of wavelengths used. The sequential approach is faster than the heuristic algorithms [8-13].

Traffic pattern assumption also affects the performance of a RWA algorithm. The traffic assumptions generally fall into one of the two categories. In static traffic a set of connections for source and destination pairs are given where as in dynamic traffic connection requests arrive to and depart from the network one by one in a random manner. The common performance metrics investigated generally fall under one of the following four categories number of wavelengths required, blocking probability, throughput and number of fiber resources at the routing nodes. For the class of algorithms with static traffic assumptions, the objective is to minimize the required number of wavelengths in order to accommodate a given set of connection requests or to maximize the number of connections accommodated if the numbers of wavelengths are limited. On the other hand, for the class of algorithms with dynamic traffic assumptions, the objective is to minimize the blocking probability [14-15].

Numerous methods have been proposed to solve RWA problem for a given network topology and traffic matrix. The basic objective is to reduce the computation complexity of each sub-problem. Mathematical programming solutions are most popular among them. However, large number of variables and constraints increases problem size and complexity. Heuristic methods are used to reduce the complexity of the problem formulation. RWA problem can be formulate such that for a given set of light-paths that need to be established on the network, and given a constraint on the number of wavelengths, we need to determine the routes and the wavelengths that should be assigned to the light-paths so that the maximum number of light-paths may be established or the minimum number of required wavelengths used or the minimum light-path blocking probability is achieved. The routing problem is solved by techniques based on the shortest path algorithm. The wavelength assignment problem can be solved by graph based techniques such as finding EDPs for the selected routes. It can be easily observed that taking the advantage of edge disjoint paths for wavelength allocation gives better results in terms of required number of wavelengths. Algorithms developed to solve RWA problem using EDP approach gives better results for establishing light-paths with minimum number of wavelengths [16-20]. These algorithms differ in the way of finding EDPs and choosing path among these EDPs to fulfill the next demand from the demand set. EDPs can be find offline for all possible source destination pair or online as per arrival of demand. Offline method gives better run time complexity over online method. Wavelength utilization differs on traffic assumption category i.e. static or dynamic. Hence, the RWA problem can be defined as an optimization problem in a number of ways using various cost functions. For example, (i) establish all light-paths using a minimum number of wavelengths (ii) establish all light-paths using a minimum of path length, (iii) maximize the number of light-paths established subject to a constraint on the number of wavelengths and/or path lengths. The algorithm MEDP (Maximum Edge Disjoint Path) for solving RWA problem presented in [18] is calculating maximum set of EDPs for all possible pairs, in advance, prior to investigation of the demand set. The entire edge disjoint paths and their maximum quantity between source and target can be found from the solution of maximal unit flow in graph, from source to target. This algorithm treats all disjoint paths between a source-destination pair as same and path allocation is done on first come first serve basis. Further selection criteria can be applied to choose a path among available disjoint paths between s-d pair. Authors observed that the incorporation of the current wavelength load on each link and the topological characteristics (i.e. in degree and out degree) of the link in the EDP based wavelength allocation technique through some weight function can further improves the wavelength utilization. In other words it can do some kind of load balancing among the available wavelengths. The rest of the paper explores and formulate the problem as an modification to the EDP based wavelength allocation scheme for the solution of RWA. Section 2 describes the problem formulation and proposed algorithm for weight calculation with a case study. Simulation has been carried out in section 3 to show the performance improvement of the proposed scheme over the normal EDP algorithm without weight consideration.

II. PROBLEM FORMULATIONS

Let G (V,E) denote a graph that models the network, where V is the vertex set and E is the edge set. The request set R is a set of pairs $\{(s_1,d_1), (s_2,d_2), \ldots\ldots.(s_k,d_k)\}$, where s_i, d_i Є V, i =1,….m. Here m is the total number of requests for connections, s_i and d_i denotes source and destination respectively. When a request is arrives at source node s_i for a destination node d_i, a wavelength (W) and light path has to be assign. A different wavelength is needed to assign light paths using same physical link simultaneously. The above constraint can be relaxed for edge disjoint paths that minimize the number of wavelengths. The optimal number of wavelengths is given by m divided by the cardinality of the edge cut set between s and d. In the proposed work we are using pre computed maximum quantity of edge disjoint paths at each node to find all possible EDPs in a given network and assigns weights to each link as per algorithm explained in next section.

A. *Proposed Algorithm*

Two important observations have been investigated for assigning a weight factor to each edge to find path between given source and destination pair. Static weight is assigned on the base of network topology and each edge is assigned a weight as the summation of in-degree and out-degree of the two vertices forming the edge. More the static weight for an edge implies the link participates in more number of EDPs. A link having more static weight should have less priority to be included in the path to fulfill the next source destination pair request. Dynamic weight is assigned on the base of the number of wavelengths which are currently being used on the edge. More the number of wavelengths are used in an edge at a time; more the weight will be assigned to it and it is less likely to be used that edge for light path establishment for a new request. Now a path is searched by first choosing with minimum dynamic weight and then with minimum static weight from the available EDPs for a given pair of source and destination node. That gives us a different method named as WEDP (Weight based Routing and Wavelength Assignment) algorithm to assign wavelengths for the randomly generated request set.

B. *Weight Calculation and Wavelength Allocation Algorithm*

The static weight for an i^{th} edge given as follows.

$$Staticweight\_Edge_i = Indegree\_Edge_i + Outdegree\_Edge_i.$$

Static weight of the path is given by summing the static weight of each edge included in the path as given below.

$$Staticweight\_Path = \sum (Staticweight\_Edge_i).$$

Dynamic weight of each edge is given by number of wavelengths currently used on that edge. The weight of each edge is summed for all EDPs between given set of source and destination node pair to find dynamic weight of the path as given below.

$$Dynamicweight\_path = \sum (Dynamicweight\_Edge_i).$$

The function FindBestPath(s,d) searches the available free EDPs (pre-computed in the table) first with minimum dynamic weight and then on the result it searches minimum static weight. Algorithm to find best path is as follows.

```
FindBestPath(s,d)
{PathSet = getEDP(s,d) and dyn, st = 9999 /* Some large
value that represents as infinity*/
/*EDPs are pre-computed using EDP_Table(G) and fetched
from the table */
path = PathSet.getfirstpath()
While (Path != NULL){
If(path.Dynamic_weight < dyn){
Add path to Dynresult
dyn = path.Dynamic_weight
}
path = PathSet.getnextpath()
}
path = Dynresult.getfirstpath()
While (path!= NULL){
if(path.Static_weight < st){
Add path to result
st = path.St_weight}
path = PathSet.getnextpath()
}
Return result.getfirstpath()
}
```

The wavelength allocation algorithm is given as follows.

```
Begin
EDP_Table(G)
while (the same G)
do
Retrieve a new R   /* Find a route from EDPs */
W = 0              /* Wavelength   */
while (R != NULL) do
W = W + 1
if (FindBestPath(s,d) != NULL)
Assign P(sj, dj, i) and W to (sj, dj)
R = R − (sj, dj)
end if
end while
end
End
```

C. *Case Study*

A random network topology is given in Fig. 1. The request set is assumed as { (1,8), (1,7), (4,6), (3,7), (1,7), (3,7) }. First, the maximum number of EDPs is calculated each request pair from the pre calculated table. The request pair (1,8) has 1→3→9→8 and 1→2→4→6→8. Next pair (1,7) has 1→3→9→8→7 and 1→2→4→5→7. Similarly the pair (4,6) has 4→6, 4→5→6 and the pair (3,7) has 3→9→8→7, 3→4→6→7, 3→2→4→5→7. Table 1 gives the static weight for each calculated path. Initially we assume that all the wavelengths are free so dynamic weight for all the edges is zero and it will change as per wavelength allocation is done for each node pair from the request set. For node pair (1,8) path-1 is selected as its static weight is minimum as shown in Table 1. The dynamic weight for each of the edges included in path-1 becomes one. For next request i.e. (1,7) the path 4 is selected because its dynamic weight is minimum among two available paths. For the node pair (4,6) path-5 is used. For the node pair (3,7) path-8 is used due to minimum dynamic weight among three possible path. Similarly for next two requests for node pair (1,7) and (3,7) the path-1 and path-9 is used. So the given request set can be completed by using only two different wavelengths. If the wavelength allocation is done on the same request set according to the MEDP algorithm it requires at least three wavelengths.

III. SIMULATION AND RESULTS

Simulation of the proposed work has been done using C language program that generates a random network topology for a given number of nodes N. The randomness of the topology is controlled by varying the Pe (probability of edge existence between any node pairs) and Pl (probability of request) as in [18]. Random request set for getting various source destination node pairs is generated by incorporating Mc (multiplicity of the single request) through simulation program. Simulation has been run for one thousand iterations for each combination of N, Pe, Pl and Mc. The number of wavelengths needed for the request set for proposed algorithm along with MEDP algorithm is shown in Table 2. It has been observed in most of the cases that the proposed scheme outperforms the existing one. In particular new scheme performs better for higher values of Mc and for N. Particularly for N = 20, we can see a significant and consistent improvement in terms of number of wavelengths needed to setup light-path over the MEDP algorithm. However, MEDP performs almost in equality with the proposed one i.e. WEDP algorithm for small network.

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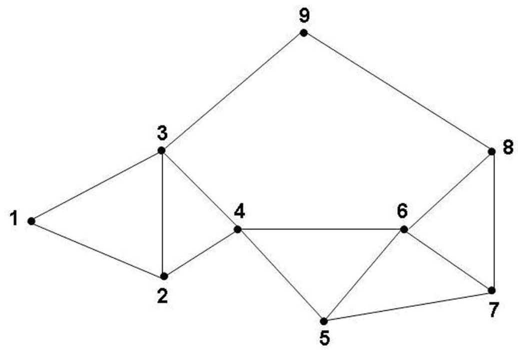

Figure 1. *Random network topology*.

TABLE I. STATIC WEIGHT ALLOCATION FOR EDPS

Path No.	Path	Node pair	Static Weight
1	1→3→9→8	1,8	11
2	1→2→4→6→8	1,8	19
3	1→3→9→8→7	1,7	15
4	1→2→4→5→7	1,7	17
5	4→6	4,6	6
6	4→5→6	4,6	10
7	3→9→8→7	3,7	11
8	3→4→6→7	3,7	17

IV. CONCLUSIONS

In this paper, RWA problem in WDM optical networks has been studied and a new weight based scheme is proposed for EDP based RWA. The objective is to minimize the number of wavelengths for a given set of request. In particular result reveals that as number of node increases in the network with increasing value of multiplicity i.e. request repeat factor for a particular set of node pair in a given request set, the required number of wavelengths to establish the light-paths are decreases as compared to the algorithm proposed in MEDP algorithm. The comprehensive simulation supports the proposed technique for better utilization of available wavelengths especially when more requests are coming for same set of node pairs within a given network. Further this approach can be extended for dynamic traffic assumption to calculate the blocking probability. There is no significant contribution in the run time complexity of the algorithm as static weight of links is fixed for a given topology while dynamic weight calculation contributes O(const) to run time complexity.

TABLE II. COMPARISON FOR NUMBER OF WAVELENGTHS

N	Pe	Pl	Mc=1		Mc=4		Mc=7		Mc=10		Mc=13	
			MEDP	WEDP (New)	MEDP	WEDP (New)	MEDP	WEDP (New)	MEDP	WEDP (New)	MEDP	WEDP (New)
5	0.2	0.6	4.018	4.018	9.159	9.159	21.627	22.354	33.545	33.545	47.369	47.969
	0.2	0.8	6.411	6.411	16.958	16.958	29.03	28.792	42.626	42.815	61.123	60.773
	0.2	1.0	4.806	5.001	20.358	20.969	30.96	32.319	58.614	57.03	67.25	65.001
	0.4	0.6	2.208	2.208	6.813	7	20.215	20.398	23.119	22.762	26.034	27.097
	0.4	0.8	3.191	3.395	13.502	13.43	24.735	25.101	30.525	31.193	50.852	52.655
	0.4	1.0	4.77	4.77	19.108	19.66	24.148	24.144	44.75	45.275	61.184	59.108
10	0.2	0.6	10.392	10.433	42.09	42.076	65.688	64.984	99.921	98.75	108.174	110.01
	0.2	0.8	11.383	11.504	55.9	56.956	77.117	78.286	153.439	151.096	155.355	155.25
	0.2	1.0	17.607	17.677	64.538	64.64	112.62	115.51	178.192	179.59	228.375	230.55
	0.4	0.6	4.903	4.88	17.717	17.717	33.141	34.248	45.32	45.551	60.521	61.741
	0.4	0.8	8.125	8.43	28.448	29.487	46.302	46.731	57.781	57.967	90.996	93.174
	0.4	1.0	11.499	10.868	36.07	36.759	67.503	68.902	86.672	83.201	134.284	135.91
15	0.2	0.6	16.296	16.328	60.912	60.432	94.521	94.004	166.716	165.767	192.293	192.64
	0.2	0.8	20.909	20.825	91.846	90.86	140.31	139.14	201.506	200.837	298.288	295.81
	0.2	1.0	26.186	25.605	118.27	117.63	195.64	194.58	248.575	243.006	357.276	355.17
	0.4	0.6	7.765	7.988	27.05	27.021	44.817	44.781	65.356	65.95	90.068	90.001
	0.4	0.8	10.342	10.553	39.781	39.916	70.344	70.501	104.813	105.04	122.755	123.97
	0.4	1.0	13.969	14.245	55.4	54.863	93.285	93.935	126.928	129.285	166.342	166.35
20	0.2	0.6	22.056	21.991	85.194	83.893	144.22	143.22	207.231	205.789	254.483	251.72
	0.2	0.8	28.992	28.735	114.88	113.41	207.51	204.82	283.94	281.29	370.495	364.44
	0.2	1.0	36.117	35.485	140.90	138.22	256.82	254.13	365.944	359.942	474.539	464.67
	0.4	0.6	8.883	8.787	33.434	33.202	56.438	56.06	79.379	79.067	106.618	106.04
	0.4	0.8	13.248	13.267	51.594	51.261	86.498	86.263	126.725	126.699	158.691	157.89
	0.4	1.0	17.397	17.364	66.916	65.984	116.52	115.58	167.165	164.593	217.617	214.52

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