Adaptive Routing Algorithms for All-Optical Networks

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Abstract

This paper proposes two new heuristic algorithms based on link-state for the dynamic routing problem in optical networks deprived of wavelength converters. In those networks, dynamic routing consists of transmitting data over unique wavelengths along dynamically established paths, while trying to minimize blocking probabilities of call requests. Both new algorithms were implemented and tested within ring topology and achieved satisfactory performance when compared to former algorithms such as FPLC and LLR algorithms.

Sommaire

Cet article propose deux algorithmes heuristiques basés sur le "link-state" pour le problème de routage dynamique dans les réseaux optiques sans convertisseurs de longueurs d'ondes. Dans ces réseaux, le routage dynamique consiste à transmettre des données sur des longueurs d'ondes uniques selon des chemins établis dynamiquement, tout en tentant de minimiser les probabilités de blocage des requêtes d'appel. Ces deux nouveaux algorithmes ont été implantés et testés sur une topologie en anneau et ont atteint une performance satisfaisante comparés aux algorithmes précédents tels que FPLC et LLR.

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Link-state routing, optical routing, routing and wavelength assignment (RWA), wavelength division multiplexing (WDM).

1.0 Introduction

In the last decades, many applications have been limited by the bandwidth allowed by carrier networks. Nowadays, optical networks based on *wavelength division multiplexing* (WDM) technology offer high-speed rate of data transfer combined with high reliability of the transmission channels. They convey data on light wavelengths through optical fibers. Physically, two requests cannot be transmitted simultaneously on the same wavelength, so it is mandatory to find the best way to allocate network resources in order to support heavy traffic. Since optical routers have high switching frequencies and no waiting queues for data transmitted, it is critical to find routing path for each request sent to these networks. In all-optical networks, each routing path is called *lightpath* and used a unique wavelength during its lifetime. This constraint is the *wavelength continuity constraint* (WCC).

Optical routing algorithms that predetermine a unique path for any connection requested between two nodes, are called *static,* whereas those that respond to each request by taking into account the links' state before choosing a path among a set of candidate paths are known as *dynamic*. In dynamic routing problem, for a set of requests between source-destination pairs (s-d) coming dynamically to the nodes, we have to determine the best routing paths among *K* candidate paths, by considering links' state, related costs and WCC. For the whole network, we must find the best strategy to route payload data and satisfy the greatest number of requests. Processing time of requests and paths selection are primordial to avoid network congestion and, consequently, minimize blocking probabilities of entering connections.

This paper presents two new algorithms for dynamic optical routing. Section 2.0 states the mathematical model considered. Section 3.0 describes the proposed algorithms. Section 4.0 presents and analyzes experimental results. A conclusion is presented in Section 5.0.

2.0 The Mathematical Model

Let us consider an optical network with *N* nodes and *M* links, one fiber per link and *W* wavelengths per fiber. The node and link locations are fixed and known. Each link has its own bandwidth, latency and cost. Connection requests arrive at each node following a Poisson process of mean value λ. The following model is a classical optical routing model we present in order to describe our objective function.

Let F_{ij}^{sdw} be the request arrived at the node *s* for the node *d* and which will be transmitted on link (*i,j*) by using wavelength *w*. Note that *i* and *j* belong to the set of nodes *N*.

The total number of requested calls accepted through the network after the simulation, using the wavelength *w* between *s* and *d*, will be γ_w^{sd}.

In this problem, we wish to maximize the utilization rate of each link (*i,j*) in the network:

$$\max_{ij} \sum_{sdw} F_{ij}^{sdw} \qquad (1)$$

subject to following constraints:

- $F_{ij}^{sdw} \in \{0,\ 1\}$; which means either the lightpath established for each request uses the wavelength *w* or not;
- $\sum_{s \in N} \sum_{d \in N - \{s\}} \sum_{w \in W} F_{ij}^{sdw} \le W$; which represents the capacity constraint on each link;
- $\sum_i F_{ij}^{sdw} - \sum_k F_{jk}^{sdw} = \begin{cases} -\gamma_{sdw} & \text{if } s = j \\ \gamma_{sdw} & \text{if } d = j \\ 0 & \text{otherwise} \end{cases}$;

which is the WCC for each lightpath chosen.

The problem is solved by choosing the F_{ij}^{sdw}, depending on links' state. Then, our dynamic model uses this method applied step-by-step. By trying to resolve our objective function, we also help minimizing the number of blocked requests.

As formulated, this problem has been demonstrated NP-hard and is not solvable with standard mathematical approaches.

3.0 The Two Heuristic Algorithms Proposed

In order to simulate our algorithms, *K* candidate paths must be precomputed for each source-destination pair and we modify Yen's Algorithm [4], [6] to achieve suitable results over shorter time. Dijkstra's Algorithm is used to obtain the shortest path between two nodes.

Our two algorithms used the criteria of former algorithms such as LLR [5] and FPLC [1] to define new strategies. The first one, called Estimated Congestion Routing (ECR), is based on an estimate function of the congestion over links. The second algorithm, Hybrid Fixed-Paths Least Congested (HFPLC-k), is more rigorous with an exhaustive analysis of the resources available on the network.

A. Estimated Congestion Routing Algorithm

This algorithm uses two important helpful criteria to define congestion in an optical link: its cost that represents its liability and its relative importance in the network, and the current traffic on the link. The computation of the congestion degree for a link, at the arrival time of one request, uses the cost of this link over a whole path and the number of its free idle wavelength. It is expressed by:

$$DC_{(i,j)} = \frac{\sum_{(k,l)\in P} C_{(k,l)}}{C_{(i,j)}} * \frac{1}{\lambda^{free}_{(i,j)}} \qquad (2)$$

where $\lambda^{free}_{(i,j)}$ is the number of free wavelengths available on link (i,j), $C_{(k,l)}$ and $C_{(i,j)}$ represent the costs of links (k,l) and (i,j) respectively. So, the congestion degree of a path *P* with *l* hops is given by the mean value of congestion degrees computed on the links along P. The candidate path with the smallest degree of congestion will be selected to route the request's payload. After the route's selection, WCC is applied and if no wavelength is actually available, the request is blocked.

In a network of diameter *H*, the mean computational time complexity of ECR algorithm is ***O(NKH²W)***. Indeed, each path cost is computed in linear time and, for each link on a mean length *H*-hops path, we calculate the degree of congestion by examining the *W* wavelengths of each link in the worst case scenario.

B. Hybrid Fixed-Paths Least Congested Routing Algorithm

This algorithm is inspired of FPLC-k routing algorithm. It adds a new criterion to the former algorithm by using the *k* most *congested links* of each path for evaluation, instead of the first *k* links of each path in FPLC-*k*. The additional criterion brings precious tuning to the routing algorithm that tends to avoid current and future congested paths. In this case, the more congested a link is, the less idle wavelengths it has. Continuous wavelengths available on the *k* most congested links of each path are counted and the path with the greatest number of continuous wavelengths is selected. After path selection, the WCC is verified and the request is blocked if ever no wavelength is common to all links of the selected path. The performance of the algorithm depends on the chosen number *k*, with *k* inferior to the mean diameter of the network.

Our routing algorithm is more balanced and its computational time complexity is ***O(NKkH²W)***. Although HFPLC-*k* is more complex than the ECR algorithm, it considers the WCC during the selection path process by using only continuous wavelengths for the *k* links analyzed.

4.0 Experiments and Results

In this section, we introduce a few details regarding the implementation and the numerical results obtained with our algorithms. Node positions and characteristics are retrieved from a text file. Each pair of nodes is interconnected by unidirectional links. To simulate real networks in which link failure can occur sometimes, we choose to implement random link failures. In case of failure, path restoration is used, which means that new paths are found to retransmit former requests from paths affected by broken links. Call requests are generated dynamically in a text file and subsequently read as discrete events.

The initial number of *W* wavelengths per fiber for each link varies from 1 to 6. For each experiment cycle, we made 25 iterations, taking the mean value to represent final results. For each experiment, blocking rate and mean response time for each accepted call are measured.

Simulations are conducted on a ring network with 8 nodes interconnected by 16 links of single cost. Initial rate of arriving requests at each node is three per minute and link failure rate is set at 0.2% and the mean time of each simulation is fixed to 10 minutes. Parameter *k* is equal to 2 for FPLC-*k* and HFPLC-*k*. Blocking rate represents the number of blocked calls compared to the total number of call requests.

Table I shows the results obtained for each routing algorithm with *least used* or *spread* wavelength assignment [2], [3] and 3 wavelengths per fiber. ECR and HFPLC-2 generally yield the same results as well as LLR. In addition, we notice that the FPLC-2 algorithm has the worst results, regardless of the wavelength assignment method used. The particular network ring form implies that path length between two nodes can reach 7 hops. Thus, analyzing two links to select routes in this situation remains insufficient for FPLC-*2*. It requires greater value of *k* to give better results in this case. However, ECR gives the best overall results since it uses simple criteria to estimate the paths' congestion and it does not consider the WCC during the path selection process. Thus, the constraint relaxation during this process improves the set of feasible solutions and the estimation of congestion degree is more useful than an estimation based only on the number of free wavelengths available.

Number of requests per minute	Shortest Path	LLR	FPLC	ECR	HFPLC-2	FPLC-2
3	0.0598	0.0418	0.0371	0.0400	0.0413	0.0438
6	0.0832	0.0686	0.0684	0.0662	0.0695	0.0779
9	0.0969	0.0845	0.0802	0.0801	0.0834	0.0949
12	0.1311	0.1297	0.1248	0.1162	0.1302	0.1462
15	0.1410	0.1384	0.1363	0.1284	0.1398	0.1617
18	0.1549	0.1574	0.1541	0.1447	0.1558	0.1789
21	0.1817	0.1905	0.1851	0.1697	0.1928	0.2167
24	0.2091	0.2291	0.2241	0.2057	0.2294	0.2591
27	0.2164	0.2406	0.2367	0.2145	0.2399	0.2712
30	0.2272	0.2507	0.2439	0.2261	0.2501	0.2798
33	0.2378	0.2632	0.2592	0.2359	0.2633	0.2940
36	0.2563	0.2843	0.2826	0.2614	0.2862	0.3169

Table 1: Blocking Rates of Various Algorithms vs. Traffic Load

Also, measurement of the network mean response time presented in Table II shows that in fact, our algorithms require a little more time compared to others. For example, ECR had the highest response time due to amount of floating operations before path selection. Moreover, HFPLC-*2* consumes 10 to 50 milliseconds more than FPLC-*2*. However, FPLC appears to be the most efficient algorithm as it has low blocking rate with low response time. Thus, network operators could choose the most appropriate algorithm depending on which parameter is most important to them.

Number of requests per minute	Shortest Path	LLR	FPLC	ECR	HFPLC-2	FPLC-2
3	84.12	96.24	96.44	102.48	92.24	99.32
6	110.88	133.36	128.96	163.12	153.40	135.44
9	139.00	181.48	178.32	195.08	181.88	173.44
12	161.00	220.44	217.80	253.60	236.68	222.76
15	187.76	265.24	267.28	302.04	290.08	262.32
18	220.04	300.64	303.76	356.84	323.28	305.60
21	248.64	353.80	354.52	401.80	363.68	351.24
24	263.20	385.00	384.12	455.64	410.60	398.04
27	299.20	433.48	425.80	512.16	457.48	443.04
30	317.56	492.76	468.28	573.56	501.20	472.40
33	359.00	514.52	519.92	622.04	547.12	514.40
36	376.24	575.28	553.28	660.96	595.60	546.68

**Table II:
Mean Response Time of Various Algorithms vs. Traffic Load**

5.0 Conclusion

This paper presented two new routing algorithms proposed to solve the dynamic routing problem in all-optical networks. These algorithms are partially based on previous studies of former algorithms. Experimental results for ring topology show that we can improve former algorithms such as LLR routing. ECR algorithm produced the best results in ring topologies, whereas HFPLC-*k* remained stable versus FPLC-*k* for smallest values of k. Our two algorithms have higher response times due to floating operations costs for ECR and additional sorting of congested links in HFPLC-*k*.

6.0 References

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