Load Balancing Routing Policies in Wavelength-routed WDM Networks

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Abstract: - In order to use WDM networks efficiently and effectively, a lightpath is dynamically established upon the arrival of a connection request. The dynamic routing algorithms are usually classified into adaptive and alternative schemes based on whether the chosen routes are predetermined or not. In this work, we propose a new weighted function for link cost assignments. The purpose of the cost function is to differentiate network in different traffic load. Based on the link cost assignments, one adaptive routing algorithm referred to as EWSCP and one alternative routing named LAPA are presented in the paper. Simulation results reveal that EWSCP can achieve lowest call blocking probability than conventional adaptive routing schemes. On the other hand, the low overhead LAPA can obtain performance approaching to adaptive routing.

Key-Words: - WDM Network, Adaptive Routing, Alternative Routing, and Exponential Link-cost Function.

1 Introduction

The success and rapid growth of the Internet has contributed exploding traffic demand into the network. Thanks to the advances in wavelength division multiplexing (WDM) technology, optical networks are now capable to provide tremendous bandwidth economically. In WDM, the bandwidth of an optical fiber is divided into many individual wavelength channels. By concatenating the wavelength channels in a WDM network, a lightpath can be set up to provide a circuit-switched connection between two nodes. In the absence of wavelength converters [1][2], a lightpath must occupy the same wavelength on each link in its route. This is known as the wavelength-continuity constraint.

It is believed that the on demanded lightpath establishment is much more efficient in using WDM networks. To provide such function, it is essential for a network to be able to dynamically find out a route and assign wavelengths upon the arrival of a connection request. Therefore, there have been many researches focusing on dynamic routing and wavelength assignment (RWA) problems with targets to utilize network resources efficiently and maximize the number of establishment lightpaths [4][6][7][8][9].

The dynamic routing in wavelength-routed WDM networks can be classified into adaptive routing and alternative routing based on the chosen routes are predefined or not. In the adaptive routing, based on the current network status, an optimal route is selected upon the connection request arrives. For alternative routing, there is a list of candidate routes which is prepared in advance for each communication node pair. As a connection request arrives, one route is selected from the predetermined list. If the network cannot setup the lightpath along the chosen route, it will try another candidate. The process is continued until the lightpath is successfully established or the call is rejected after trying all of the candidate routes. Generally speaking, alternative routing has less network overhead and computation cost than adaptive routing. However, based on the prompt of network state information, adaptive routing can provide better performance than alternative routing.

To maximize the probability of successful connection establishment, we propose an adaptive routing strategy named Exponential Weighted Shortest Cost Path (EWSCP) for load balancing purpose. We compare the performance of different adaptive routing schemes in wavelength-routed networks and demonstrate that the EWSCP has the best performance in different traffic loading distribution and various network topologies. To reduce the overhead of adaptive routing for collecting global network information and finding optimal routes, we apply the same concept to alternative routing and propose a Load-balanced Alternative Path Algorithm (LAPA). LAPA is used to pre-compute multiple fixed ordered routes for each communication pair and stores the results as candidate paths at the source node's routing table. The simulation results show that the blocking performance of LAPA can approach to the adaptive routing scheme.

The rest of this paper is organized as follows. Section 2 presents conventional adaptive routing and the proposed EWSCP routing. Section 3 discusses the alternative routing and presents the load balancing LAPA algorithm. The simulation results for those schemes are shown in Section 4, and finally we make a concluding remark in Section 5.

2 Adaptive Lightpath Routing: EWSCP Scheme

In adaptive routing, a lightpath is dynamically constructed upon the arrival of a connection request. The routing computation is based on global network state information which could be derived from communication protocols such as link state or distance vector approaches [10][13]. The routing is usually based on shortest path algorithm [14]. However, with different link cost assignment, different routing effects can be achieved.

In this section, we compare different cost assignments for adaptive routing schemes in a wavelength routed WDM network. The objective is to minimize the call blocking probability of connection requests. Routing policies including traditional equal-weighted link cost assignment [1], linear-weighted link cost assignment [6], and the proposed exponential-weighted cost assignment are considered. Herein, we assume optical switches with the capability of performing full-range wavelength conversion. The signaling protocols for setting up lightpaths are beyond the scope of this paper and not addressed here.

For the traditional shortest-cost-path routing denoted as SCP, an equal-weighted link cost assignment is applied to obtain a least-cost routing path. The selection of a route is to minimize the number of hop count for the purpose of consuming as least network resources as possible. The associated cost function from source node *s* to destination node *d* is represented as:

$$C(P_{sd}) = \sum_{i=1}^{n} C_{e_i} \ ,$$

where P_{sd} represents a path consisting of link e_1, link e_2, …, and link e_n, and C_{e_i} is the cost of the link e_i which value is usually assigned to one.

In the SCP scheme, only paths with minimum number of hop count are considered. It doesn't regard the loading on each link along the path. Therefore, some particular links may have heavy traffic while the others remain light load. By equally distributing traffic load, better network utilization in accordance with lower call blocking probability can be obtained. To achieve load balancing, Hsu el al. proposes a Weighted Shortest-Cost Path routing (WSCP) by assigning the link cost proportional to the number of wavelengths in use on the link [6]. The cost function of a path in WSCP is defined as:

$$C(P_{sd}) = \sum_{i=1}^{n} (1 + \frac{b(i)}{W} \times v \ ) \ ,$$

where v is balance factor and $b(i)$ is the number of occupied wavelengths on link i, and W is the total wavelengths on each fiber link.

In WSCP, the usage of link resources is reflected on the term $\frac{b(i)}{W}$. Since it is equally changed with the proportion of $1/W$ to the wavelength usage on the link, it does not distinguish the difference of network status between heavy and light load. It means no matter how congested the network is, the WSCP performs route selection with same strategy.

Different from the WSCP, we propose a new load balancing routing scheme named Exponential Weighted Shortest Cost Path (EWSCP). By applying nonlinear link cost function, the EWSCP algorithm is able to adopt different routing strategies for different network load. For network with light load, it is reasonable to select shortest path for consuming minimum network resources. While the network loading is gradually shifting from light load to heavy load, the traffic should be distributed equally into the network. Finally, once the network load is very heavy, the routing strategy should avoid exhaust all wavelengths on a link so as to reduce the blocking probability of future calls.

To achieve the objective, the link cost function C_{e_i} of EWSCP for link e_i is chosen as:

$$C_{e_i} = ab^4(e_i) + 1,$$

where $b(e_i)$ is the number of occupied wavelengths on link e_i, and a is a constant value for limiting the maximum link cost.

Figure 1 depicts the variation of weighted link cost among SCP, WSCP, and EWSCP. According to the Fig. 1, the behavior of the EWSCP is similar to the SCP in light load. In the middle load, the cost function is approximately linear that makes EWSCP act like WSCP. When load is heavy, the link cost of EWSCP is growing up very quickly which avoids the routing algorithm to use up all of wavelengths in congested links.

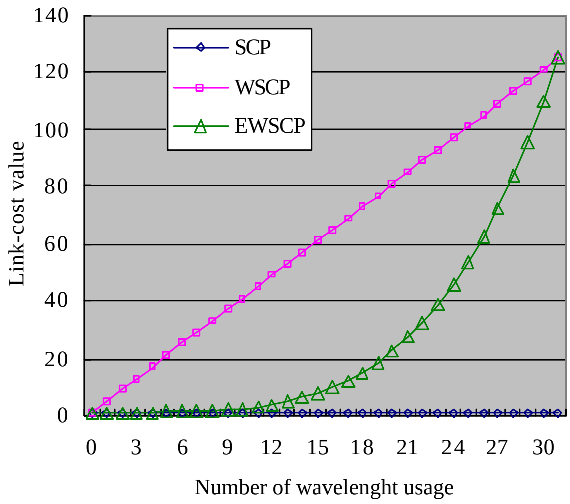


Figure 1 The comparison of the link cost in different routing schemes

3 Alternative Path Routing: LAPA Algorithm

In addition to the adaptive routing, alternate routing is one of the major routing strategies in a wavelength routed network. Different from the adaptive routing, alternative routing does not require monitoring the global network resources and selecting an optimal route for the arriving call. Instead it pre-computes multiple candidate routes for each s-d pair and stored them as an ordered list in source node for path selection. Upon the arrival of a connection setup request, the source node just selects a route from the routing list. A connection is blocked only when there is no available precomputed route from the source node to the destination node. Comparing adaptive routing to alternative routing, the former has higher control overheads for collecting network state and longer route selection delays while the latter is not optimal for path selection. There are many related works targeting on alternative routing. In [11], a shortest hop-count algorithm is proposed to compute a set of Fixed-Alternative Routes (FAR) for each s-d pair. In [12] a Least-Congested-Path (LCP) routing scheme is present to select a least congested path among the precomputed routes when the call arrives. Another LCP based routing algorithm is in [7]. In order to reduce the overhead, the algorithm only examines the congestion condition of the first k links of each precomputed routes. An approximate analytical model for the alternative path routing can be found in [5].

Most of the previous works focus on connection setup signaling and wavelength assignment. To our best knowledge, there is not any work to investigate how to intelligently derive the alternative route for each s-d pair. The candidate routes for each s-d pair are usually determined manually by the network administrator or precomputed by shortest hop count path. Thus, these alternative paths do not relate to possible network states.

Different from the above discussion, we propose a Load-balancing Alternative Path Algorithm (LAPA) which considers the load-balance in precomputing the required alternative paths. The LAPA algorithm is shown in Fig. 2. First, in Step 1, we set the first route based on shortest hop count path for each s-d pair. In this phase, the cost of each link is simply assigned to one. After Step 1, the initial weight matrix *Init[n:n]* of the link represents the *link congestion factor* (it is defined to represent how many shortest paths going through the link). Then we transfer the link congestion factor *Init[n:n]* by using exponential function *F(x)* and save the result to exponential weight matrix *W[n:n]*. The exponential function F(x) is

$$F(x) = ax^4 + 1,$$

where the variable a is a constant value for limiting the maximum link cost. The value of *Init[n:n]* is also assigned to primary weight matrix *L[n:n]*.

In Step 2, we first sort the network nodes according to the link congestion factor *I[n:n]* and save the sorting results into *P[n]* in descending order. By using the exponential weight matrix *W[n:n]* to be the link costs, we find the alternative route for each node sequentially based on the order of *P[n]*. The purpose is to let the nodes with higher congestion factors have higher priorities to select their alternative routes. Once an alternative route is selected, the primary weight matrix *L[x:y]* is added by one and the exponential weight matrix *W[x:y]* is updated by F(*L[x, y]*)× *Init[x, y]*, where (x, y) represents a link which is on the selected alternative route. In addition to the exponential transformation in computation *W[x:y]*, the link congestion factor

Init[n:n] is also applied to further enlarge the weighting.

Step one: find the first route and decide the initial weight for each link

```
for i = 1 to n do
   for j = 1 to n do
      if(i ≠ j)
         Find the shortest hop-count path for each
            s-d pair (i, j);
         Store the selected route to the first entry of
            routing table in source node i;
         for all link (x,y) on the selected path
            Init[x,y]=Init[x,y]+1;
      end if
   end for
end for
let L[n:n] = Init[n:n];
let W[n:n] = F (Init[n:n]);
```

Step two: compute the alternative paths

```
Sort the node priority L[n:n] on decreasing order and store
the results in array P[n];
for k = 2 to the amount of alternative paths do
   for i = 1 to n do
      for j = 1 to n do
         if (P[i] ≠ P[j])
            Using the exponential link-cost W[n:n] to
              find the alternative route for node pair
              (P[i], P[j]) and store the path
              information in the kth entry of the
              routing table of source node P[i];
              for all link (x,y) on the selected path
                  L[x,y]=L[x,y]+1;
                  W[x,y]=F(L[x,y])×Init[x,y];
            end for
         end if
      end for
   end for
end for
```

Fig. 2 LAPA Algorithm

4 Simulation Results

4.1 Simulation Model

Extensive computers simulation is performed to assess the performance of different routing schemes including the SCP, WSCP, EWSCP, FAR, and LAPA. Three different network topologies are used in our simulation. The NSFNET network, the Grid network, and the Random network are shown in Fig. 3, Fig. 4, and Fig. 5. In the networks, each link consists of bidirectional fibers and the number of wavelengths on each link is 32 for each direction. In addition, we assume that each node has enough wavelength converters for changing wavelengths (i.e., the wavelength continuity constraint is not considered in the simulation). The connection requests follow Poisson arrival and with exponential holding time. We consider networks with uniform distributed traffic and with a hot communication pair (HCP). The uniform distribution traffic means the destination of a connection is randomly determined by uniform distribution. The network with a hot communication pair refers to a situation in which *p*% of arriving calls are dedicated to one specified s-d pair and *(1-p)*% of traffic demands are randomly assigned among the other nodes. The rate of connection request will be denoted in units of Erlangs, which can be calculated by multiplying the connection arrival rate with the average connection holding time. In order to compare the performance of LAPA, traditional fixed-alternative routing, FAR, is evaluated. The number of candidate paths for each communication pair is two in both FAR and LAPA schemes.

Three metrics, the call blocking probability, average connection hop count, and link congestion index, are used to evaluate the performance. Herein the link congestion index is defined to

$$link\_congetion\_index = \frac{average\_wavelength\_usage}{wavelength\_capacity\_of\_link}.$$

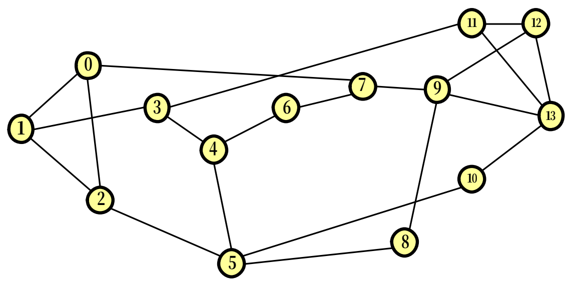


Fig. 3 NSFNET Network

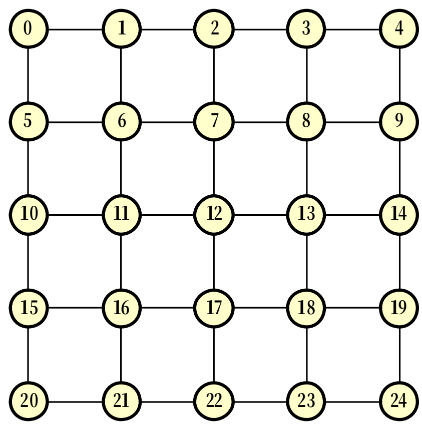


Fig. 4 25 Nodes Grid Network

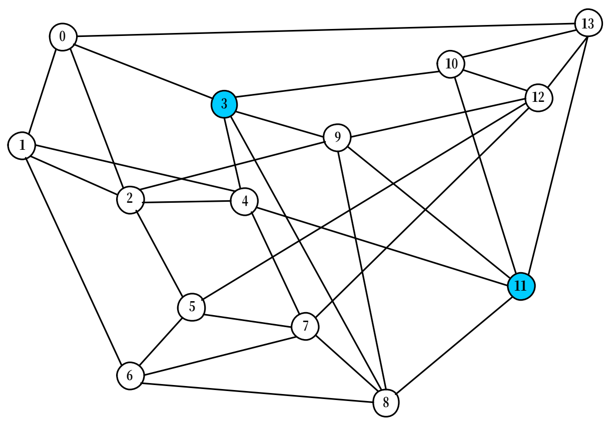


Fig. 5 14 Node Random Network [6]

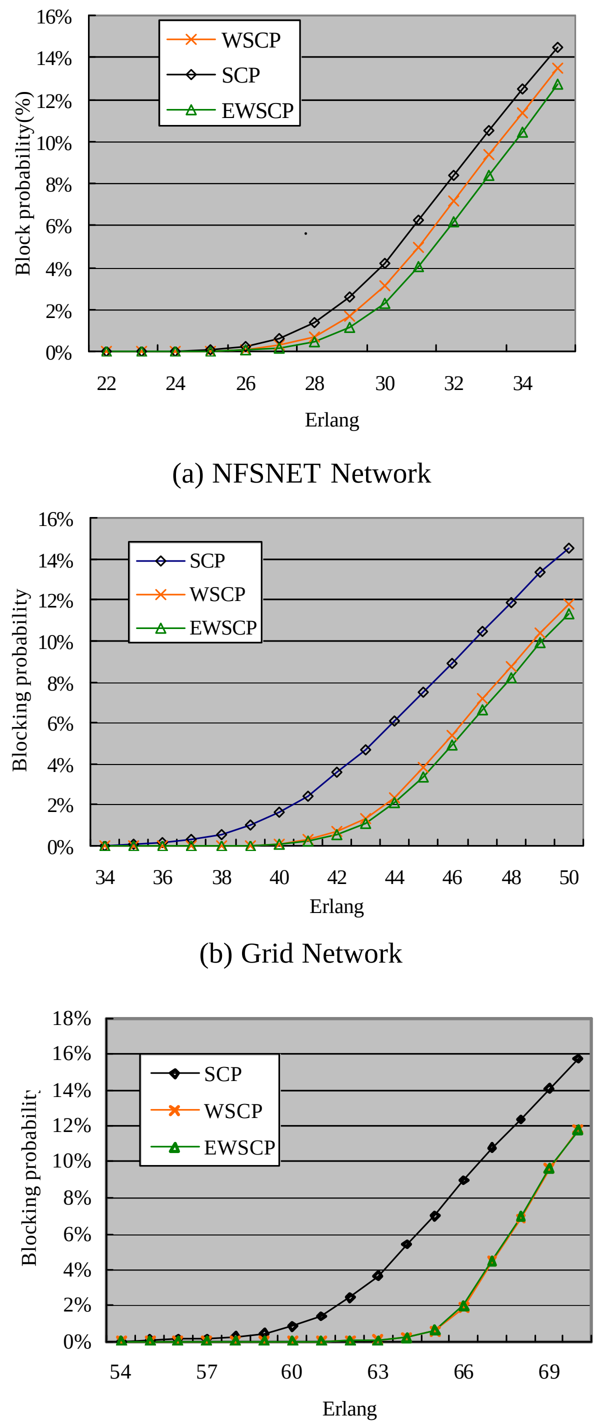
4.2 Simulation Results

The results of the simulations are as follows.

(A) Blocking probability

As the connection request arrives, there may be insufficient network resources to set up a lightpath, in such case the connection request is blocked. First we compare the blocking probability of the three different adaptive routing schemes (SCP, WSCP, and EWSCP) and two alternative routing schemes (FAR, and LAPA) in different traffic loads and in different network topologies. The results for call blocking probability are summarized in Fig. 6, Fig. 7 and Fig. 8. The results of uniform distribution are shown in Fig. 6 and Fig.8 for adaptive routing and alternative routing respectively. While the traffic demand in Fig. 7 is an example of hot communication pair. In this case, we dedicate 30% of the network traffic load to the bidirectional hot communication pair between node 11 and node 3.

As expected, it has higher blocking probability for all schemes when increasing traffic load. Apparently both WSCP and EWSCP are superior to SCP scheme. As Fig. 6 illustrates, the EWSCP has best blocking performance comparing to SCP and WSCP at light load and heavy load. Because WSCP considers both hop-count and residual bandwidth into the link-cost function, it results in 37% and 52% less blocking probability than SCP in both NSFNET and Grid network. Since EWSCP applies nonlinear link cost function to avoid one link to exhaust its wavelength it can reserve much more resources for future route request. The simulation results show that EWSCP has 32% and 11% performance improvement than WSCP in both NFSNET and Grid network. In the random topology network, both WSCP and EWSCP are notably 60% lower than SCP. It is noticed that WSCP and EWSCP have similar blocking performance in random network with randomly distributed traffic. This is because for high connectivity networks and under uniform traffic demands, each s-d pair has more routes to be selected. Thus, it induces both EWSCP and WSCP have similar routing results. Furthermore, for HCP case shown in Fig. 7, the performance gap between EWSCP and WSCP is even larger. The improvement can up to 38%.



(a) NFSNET Network

(b) Grid Network

(c) 14 Node Random Network

Fig. 6 Blocking probabilities for adaptive routing schemes under different traffic load

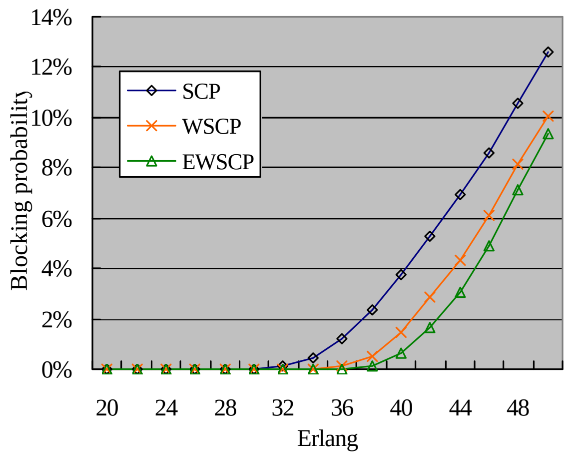


Fig. 7 Blocking probabilities for having hot communication pair in random network topology

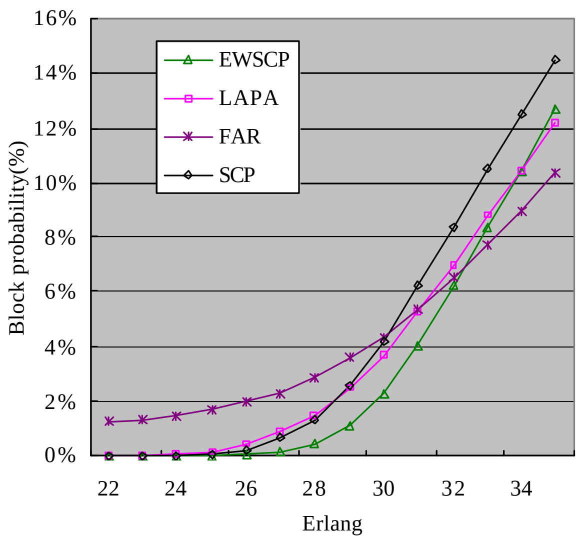


Fig. 8 Blocking probabilities between EWSCP adaptive routing and alternative routing schemes

Generally, adaptive routing is superior to alternative routing. Fig. 8 indicates that the blocking probability of the LAPA is lower than the SCP and close to the EWSCP. It shows that if the set of alternative routes can be properly selected, the good blocking performance can be derived.

(B) Average Hop Count

Figure 9 plots the average hop distance per connection under different traffic loads. Obviously, SCP has the shortest hop distance before traffic load reaches 26 Erlang. According to Fig. 6(a), the blocking probability is almost zero before 26 Erlang traffic. This means that the network has enough capacity to serve the arriving calls. Once the traffic load is beyond 26 Erlang (we define the traffic in heavy load), both blocking probability and average hop counts increase fast in SCP scheme. In such condition, some particular links may incur heavy traffic load and may exhaust their wavelengths. It prevents further lightpath setup on those congested links. Thus, it forces SCP to select longer hop-distance route resulting in consuming much more network resources and increasing the call blocking probability.

In contrast to the SCP, EWSCP uses nonlinear weight function for different network traffic states. Under light load (before 6 Erlang), the shortest-hop count is the dominative criteria for EWSCP to select a route, which behaves just like SCP to setup shortest hop count path. Once the traffic load increases over 6 Erlang (it is called medium load here), not only the path hop-count but also the link wavelength usage (link congestion index) are considered in EWSCP. In such load, EWSCP distributes the traffic load more equally to the network. Although the average path hop-count is larger than the SCP, EWSCP leaves more network resources on congested links for future routing. When the network load continues to be heavy, the average hop-count increases rapidly in three adaptive routing schemes. However, EWSCP still maintains the lowest blocking probability in the three schemes. It reveals that assigning exponential link-weight endeavors to avoid exhausting link wavelengths. As Fig. 9 illustrates, the drawback of linear weighted link cost assignment for WSCP has two folds. First, it lengthens the paths in light load. This may cause the waste of network resources and increase blocking rate. Secondly, by applying only one cost increasing strategy, the WSCP cannot greatly distinguish the loading of links between medium and heavy. Therefore, link resources may be exhausted. It induces higher blocking probability in heavy load.

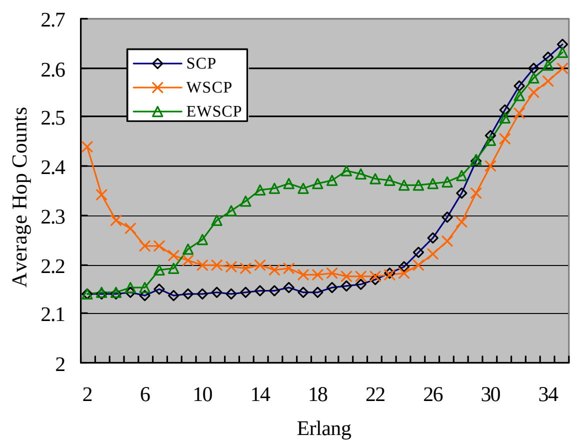


Fig. 9 Average number of hops per connection

(C) Link Congestion Index

We then use link congestion index to evaluate these three adaptive routing schemes. Figure 10 and 11 illustrate the link congestion index for each link in different traffic loads. Figure 12 depicts the variance of link congestion index in different traffic loads. We observe that the variance of link congestion index will affect the blocking probability. If the routing scheme induces larger variance of link congestion index, the traffic distribution is more unbalanced and the associated blocking probability is higher. As Fig. 12 plots, the EWSCP has a lowest variance for link congestion index in all traffic loads. It is because that the EWSCP can distribute traffic load more balancing. Therefore, EWSCP derives much better blocking performance than other schemes shown in Fig. 6.

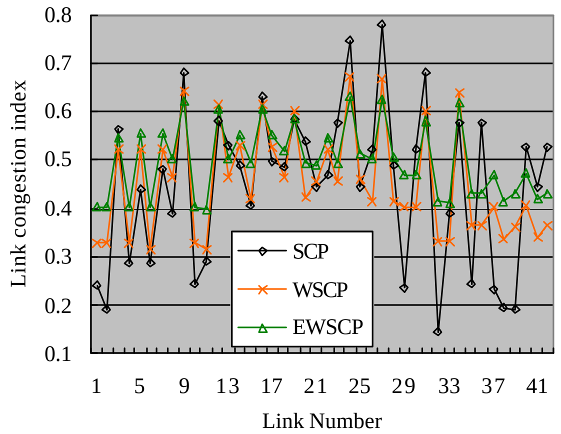


Fig. 10 The comparison of the link congestion index under medium load condition

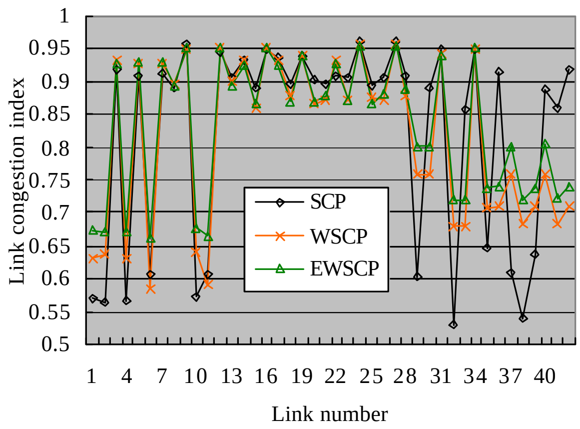


Fig. 11 The comparison of the link congestion index under heavy load condition

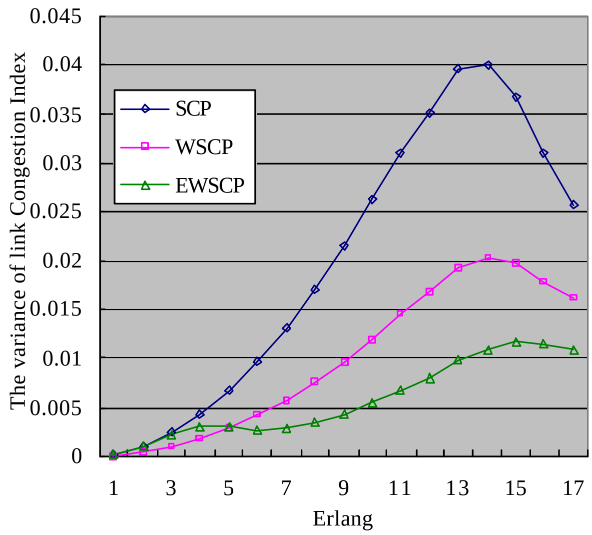


Figure 12 The variance of link congestion index in different traffic loads.

5 Conclusion

In this work we investigate both adaptive routing and alternative routing schemes using traffic-load balancing consideration in wavelength-routed optical networks. An exponential link cost function is presented to distinguish different network load condition. Based on the link cost, we propose an alternative routing algorithm, named EWSCP. By evaluating the metrics, the average hop-count of established paths, the link congestion index, and the variance of link congestion index, the proposed EWSCP scheme has excellent performance. Moreover, we also apply the concept of exponential weighted link cost function to the alternative routing strategy and propose the LAPA algorithm. Different from the previous publications, the list of alternative paths for each communication pair is precomputed under load-balancing consideration. Simulation results demonstrate that the blocking performance of LAPA is over SCP and close to EWSCP.

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