Link Failure Protection in Wavelength-routed Survivable WDM Networks

Wang-Hsai Yang, Wen-Ching Chen

Abstract

PWCE concept provides a new paradigm for fast and simple dynamic lightpath provisioning with survivable capability. Based on PWCE concept, we propose an efficient approach, called Primal Adjust Heuristics (PAH), aim to protecting single link failure in survivable WDM networks. We employ the concept of bifurcation to protect a single link failure. This strategy simultaneously addresses the problems of routing working traffic and determining multi-backup paths for each single link failure. Numerical results demonstrate that PAH outperforms shortest path heuristic by assigning unit cost weight for each link in blocking probability for networks with uniform and non-uniform demand distribution.

Keywords:survivable, bifurcate, WDM.

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在具存活性的WDM網路中之鏈路錯誤保護方法

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摘 要

在具存活性的WDM網路中，當一鏈路發生斷線時，這個鏈路的上游節點啓動保護交換程序，將通過這個鏈路的traffic重新繞路通過備用路徑。在本文我們提出使用備用路徑分流的概念，即使用多個備用路徑來保護當一鏈路繞路失敗，重新將該鏈路之流量繞路至多條備援路徑。在具存活性的WDM網路中，根據PWCE 概念我們提出一個分流演算法，作爲單一鏈路保護。這個策略同時論及繞送traffic的問題，同時爲各鏈路決定多備援路徑。從模擬計算中結果顯示出，我們所提出的bifurcate鏈路保護方法在所有traffic模式中，特別爲網路具有不均勻的需求時有較佳的效能。

關鍵詞：存活性、分流、WDM網路。

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Ⅰ. Introduction

With the rapid advance of wavelength division multiplexing technologies, a WDM-capable fiber transport network which offers almost unlimited bandwidth has become the most promising solution for future wide-area backbone networks. A procedure for designing survivable WDM networks is the subject of this investigation. We address the problems of re-routing working traffic as well as determining multiple backup paths for single link failure simultaneously. We have determined that bifurcating the traffic on a single link failure over multiple backup paths greatly enhances the survivability of data.

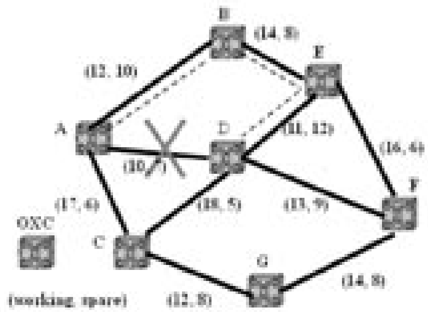
The survivable WDM network is important since the failure of fiber span can lead to the failure of all the lightpaths that traverse the failed link. Since each lightpath is expected to operate at a rate of several gigabytes per second, a failure can lead to a severe data loss; a fiber span cut could cause a data loss disaster to both users and operators [6]. To fact the possible fiber link failure, dynamic provisioning of protected lightpath, is an interesting and challenging issue since survivability and resource utilization need to be considered at the same time.

Survivable network architectures are based either beforehand on dedicated resources protection or afterwards on dynamic restoration. In the former, the network resources may be dedicated for each failure scenario. In the latter, the reservation spare capacity available within the network is utilized for restoring services that need to be adjusted when a failure occurs. Generally, protection schemes have a faster restoration time and provide guarantees of restoration ability, whereas dynamic restoration schemes provide resilience against different kinds of failures and are more efficient in utilizing capacity. There are several approaches to ensure fiber network survivability. In this study, we use a link protection approach to adjust for a single failure scenario based on a protected working capacity envelope (PWCE), which we introduce below.

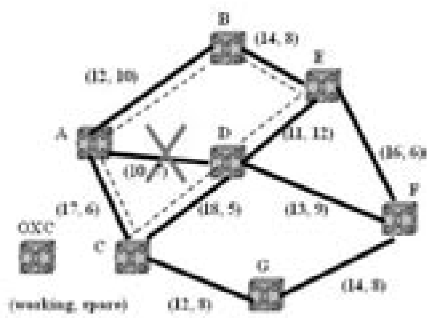
Plenty of research aims at the dynamic provisioning of protected lightpaths with a basic paradigm of shared backup path protection (SBPP). SBPP determines each connection's primary route and disjoints backup route at the provision time. The disadvantage of the SBPP scheme is the complex signaling protocol overhead. Since SBPP uses shared risk link groups (SRLG) to share backup paths. Tremendously large amount of global network capacity and SRLG information have to be disseminated through the whole network for each connection setup and takedown, which makes SBPP not scalable to large network. Besides, SBPP considering SRLG disjoint routing is proven to be an NP-Complete problem [3]. In order to advertise the SRLG information, it needs new OSPF/IS-IS routing protocol instead of traditional OSPF [4]. To overcome the difficulties of SBPP, a new procedure named Protected Working Capacity Envelop (PWCE) concept has been proposed in [2].

Grover [2] introduces the PWCE concept to handle dynamic demand without the necessity of disseminating network state information in real time. In addition, only traditional OSPF routing is required in PWCE schemes. The basic idea of the PWCE concept is to have survivability of provisioning over protected capacity, rather than provisioning protection for each connection. Each link is configured with working capacity and spare capacity, where the working capacity is used to route primary connection demand and the spare capacity is used for restoration. By using the OSPF routing mechanism, each primary connection can be determined.

The remainder of this paper is organized as follows. In Section Ⅱ, the concept of PWCE is introduced. In Section Ⅲ, the solution approach is presented. In Section Ⅳ, computational results are reported. Section Ⅴ finally summarizes and concludes this paper.



(a) single backup path



(b) multi-backup path

Figure 1 Protected Working Capacity Envelop

Ⅱ. Concept of PWCE

A simple example of PWCE is shown in Figure 1(a). Assume the fiber span between OXC node A and OXC node D for some primary route is cut, node A and node D find a backup route (A-B-E-D) to recover any working paths traversing this fiber span by using the spare capacity on this backup route. This requires the spare capacity, for each span on this alternate backup route, which should not be less than the working capacity of the protected span. This backup route could be preplanned offline since the PWCE protects the working capacity of this fiber span instead of individual connection. The major advantages of the PWCE concept are clear: it is more flexible than SBPP and it supports dynamic lightpath provisioning [1].

The problem of operating the PWCE concept in survivable WDM networks is how to determine the working capacity and spare capacity properly on each link under the survivability requirements to get the minimum blocking probability. In addition, how to assign the arc weight on each link would also be important. It would perform OSPF shortest path routing to fully utilize the information of working capacity on each span to determine each online connection's primary path. This system parameter can decrease the blocking probability. On the other hand, if the multi-backup paths can be used instead of one backup path, then the blocking probability can be dramatically decreased.

Figure 1(b) depicts an example of the PWCE-based survivable network with multiple backup paths. When the primary route is cut in the fiber span between OXC node A and OXC node D, node A and node D find multiple backup routes (A-B-E-D) and (A-C-D); they bifurcate the flow in these backup paths to recover any working paths traversing this fiber span by using the spare capacity on these backup paths. In next subsection, we will discuss bifurcation algorithm.

In survivable WDM networks that apply the PWCE concept, when a link failure occurs, the upstream node of this link creates a protection-switching procedure that reroutes traffic through this link by way of multi-backup paths. In order to fully use the network capacity, reducing the spare capacity for each link of demand is a must. Bifurcated rerouting is a processing method that meets this need. Herein, we employ the concept of bifurcation, using multiple backup paths to protect a single link failure. When a link failure is detected, the link-source node then switches the working path to the backup paths. The network capacities are more effectively utilized because the requirement of spare capacity is lower than a single backup path method. These backup paths are not necessarily of equal cost.

The problem is how to determine the traffic proportion at the link-source of a link failure that must be rerouted over the available multiple backup paths. The algorithm bifurcates the traffic on a single link failure over multiple backup paths to achieve load balancing and enhance survivability. If the rerouting doesn't bifurcate, some links bear the extra traffic, which will inevitably reduce the load working of these links traffic. On the other hand, rerouting under our load balancing concept will have good blocking performance.

III. Problem Formulation and Solution

A WDM network can be modeled as a graph where the processors are represented by nodes and the communication channels are represented by links. Let $V = \{1, 2, \ldots, N\}$ be the set of nodes in the graph and let L denote the set of communication links in the network. Given a physical topology and call arrival rates for all source-destination pairs, determine the working and multi-backup routes, so that the maximum call blocking probability on the most congested link is minimized, subject to the single link failure protection and backup hop count constraint. We assume the call setup requests follow the Poisson arrival process with the same exponential holding time. In addition, there are wavelength converters allocated in each node, so that the backup path can use different wavelengths to protect its working channels. We summarize the notation used in the formulation as follows.

Input values:

- L : the set of optical links;
- C_l : the physical capacity (number of channels) of link l;
- S : the set of source-destination (sd) pairs;
- P_S : the candidate path set for sd pair s;
- λ_S : Poisson arrival rate for sd pair s;
- R_l : the upper bound of traffic arrival rate for link l;
- Q_l : the set of candidate backup path for link l;
- δ_{pl} : =1, if path p includes link l; =0, otherwise;
- H : backup path hop count limitation;
- M_l : the number of backup paths of link l;
- $N(\beta, r_l)$: the number of channels required to satisfy the target blocking probability β under arrival rate

r_l;

Decision variables:

a_l : link weight for OSPF routing;

x_p : =1, if path p is used; =0, otherwise;

y_q : =1, if backup path q is used; =0, otherwise;

w_l : the number of working channels allocated on link l;

s_l : the number of spare channels allocated on link l;

A working and spare capacity configuration and weight assignment joint bifurcate problem is solved by the following Primal Adjust heuristic algorithm. It is shown in Figures 2 and 3.

```
Algorithm Primal Adjust;
begin
   feasible blocking probability  β̄ = Upper_bound_blocking_prob;
   infeasible blocking probability  β̲ = Lower_bound_blocking_prob;
   for each link  l ∈ L  do
      begin
            cost_l := 1;
      end;
   Label 1:
   Repeat
      β' = (β̄ + β̲)/2;
   for ( k := 1; k ≤ Iteration_Number ) do
      begin
         for each sd pair s ∈ S  do
            begin
               src=head node of o-d pair s;
               dest=tail node of o-d pair s;
               run Bellman_Ford_shortest_path(cost, src, dest, H);
            end;
         run   Primal_Heuristic_Algorithm( β');
         if   Primal_Heuristic_Algorithm returns feasible
            then
               begin
                  β̄ = β' ;
                  goto Label 1;
               end;
         else
            then
               begin
                  for   link  l that working traffic > the sum of spare capacity of total
backup paths do
```

```
                    cost_l := cost_l + 1;
                end;
            k:=k+1;
        end;
      β_ = β';      /* infeasible over Iteration_Number*/
    while( β̄ − β_ ≥ Δ );
end.
```

Figure2 Primal Adjust heuristic algorithm (PAH).

```
Algorithm Primal_Heuristic_Algorithm( β' )
Begin
    for each link l ∈ L do
    begin
      src=head node of link l;
      dest=tail node of link l;
          run find_candidate_backup_path(src,dest, H);
   end;
    for each link l ∈ L do
    begin
    r_l' = Σ_{s∈S} Σ_{p∈P_s} x_p δ_pl λ_s ;
    # working channels w_l' = N(β', r_l');
    # spare channels s_l' = C_l − w_l';
    if w_l' > C_l return infeasible;
  end;
  for each link l ∈ L do
    begin
      run  Bifurcate_algorithm( l );
      if  the Bifurcate_algorithm return infeasible then return infeasible;
    end;
      return feasible;
end;
```

Figure3 Primal Heuristic Algorithm.

Given a link blocking probability (β), the Primal Adjust algorithm is used to find whether a feasible solution can be obtained. As given in Figure 2, if the new feasible blocking probability β is lower than the current best achievable feasible probability, the new probability is designated as $\overline{\beta}$. If we cannot find a feasible solution over a predetermined number of iteration, the current infeasible probability β is designated as $\underline{\beta}$. The distance between $\overline{\beta}$ and $\underline{\beta}$ reduces by half after every iteration. At the end of the computation, the feasible blocking probabilityand the infeasible blocking probability are close and within a predetermined distance.

As shown in Figure 3, if the given blocking probability and multi-backup paths can be found, a feasible solution is obtained. By inversing ErlangB formula, the required number of working channels on each link can be computed under blocking probability β and the aggregated arrival rates. We further find out a backup path for each link with non-zero working channels on it. Bifurcate algorithm is applied to get the multi-backup paths with hop count constraint. Finally, program feasibility is returned.

IV. Experimental Results

In the experiments, we considered two widely used network topologies, NSFNET with 14 nodes and 42 links and EON with 19 nodes and 76 links. Each link has 64 wavelengths for all networks. We carried out numerical computation of β, the blocking probability on the most congested link, using our Primal Adjust heuristic method (PAH), and the shortest path heuristic algorithm by assigning unit cost weight for each link.

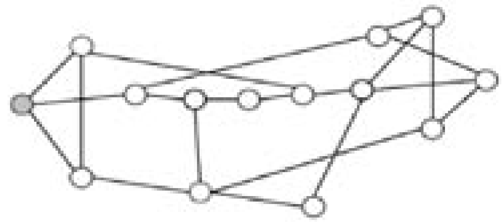
In the PAH algorithm and the shortest path heuristic algorithm method, the simulation was written in C language and terminated at the end of *Iteration_Number=2000*. The initial upper bound blocking probability $\overline{\beta}$ is set to 0.1 and lower bound blocking probability $\underline{\beta}$ is set to 0. The program is terminated when the difference between $\overline{\beta}$ and $\underline{\beta}$ is within Δ =0.000001.

Numerical results for the NSFNET and EON are shown in Figure 4 and 5, respectively. The traffic demands for all *sd* pairs are randomly determined. Two traffic distributions are considered. For the uniform case, the traffic demands for all sd pairs are randomly determined and follow the uniform distribution. For the non-uniform case, we assume there is a hot communication node with high volume of traffic with others. There are 1/10 total network loads going to and coming out from the specific node. The rest of the demands follow uniform distribution. Finally, each plotted point is a mean value over 100 simulation results. The network loads in Erlang is given in the x-axis of all graphs. The blocking probability is shown in the y-axis.

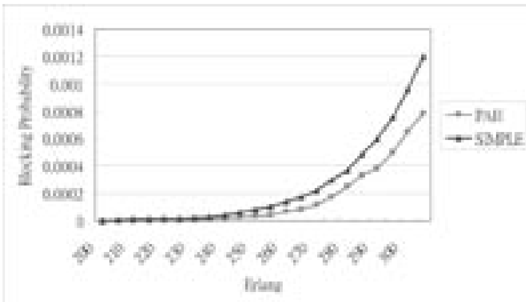
As shown in Figure 4(a) for NSFNET and Figure 5(a) for EON networks, compared to the PAH, the shortest path heuristic algorithm method gives the poorest blocking probability in all traffic demands. We discovered that assigning the same link weight for OSPF routing leads to serious congestion on some links with high blocking probability. The PAH-based heuristic algorithms arrive at much more improved blocking probability due to the use of adjust weight assignment derived upon the solution to working and spare capacity configuration and weight assignment joint bifurcate problem.

V. Conclusions

In this paper, we have presented a simple bifurcation algorithm. When a link failure occurs, the algorithm bifurcates the traffic on the link failure going through multiple backup paths to achieve load balancing and enhances the survivability. The algorithm sets the most important system parameters including link weight, working and backup capacity, and multi-backup paths routing based on PWCE concept with the aim to minimize the dynamic call blocking probability. From the computational experiments, PAH outperform the method of minimum working hop heuristic, in which



unit arc weight is assigned on each link.



(a) 14-node NSFNET network

(b) Uniform Traffic

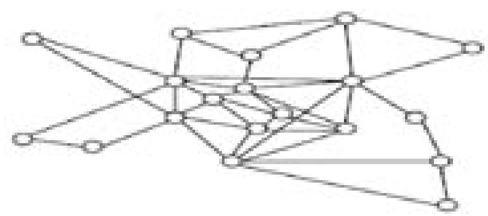
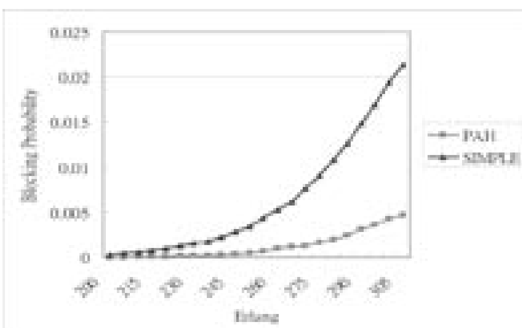
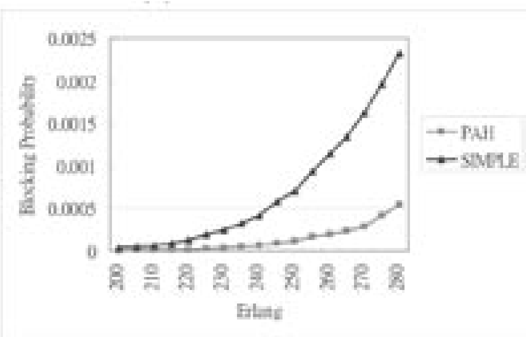


Figure 4 Numerical Results of the



NSFNET network



(a) 19-node EON network

(b) Uniform Traffic

(c) Hot Communication Node

Figure5 Numerical Results of the19-node EON network

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