# Parallel signaling-based fast restoration scheme in distributed optical networks

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The fast parallel restoration (FPR) scheme is proposed to achieve the fast setup of restoration label switched path (LSP) in the distributed optical networks. The scheme is derived by dividing the whole restoration LSP into several segments of sub-LSP and triggering each sub-LSP along the new route to finish the signaling procedure concurrently, and subsequently merging all sub-LSPs into a whole LSP. The theoretical analysis and simulation results show that the FPR scheme outperforms the other two typical restoration schemes in terms of connection setup time.

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The distributed optical network, which employs generalized multi-protocol label switching (GMPLS)[1] as the control plane protocol, is a network technology that has been used recently to build networks that can support newly emerging services. In spite of this, the demand for strong survivability is expected to increase rapidly. Under this network circumstance, the traditional survivability mechanism needs to be improved to obtain better restorability. Restoration, as one of the main methods of survivability, is widely studied because it has better resource utilization ratio compared with protection. However, restoration time requires corresponding cost. Therefore, research on the fast restoration scheme is very important to improve the performance of restoration time. Furthermore, a considerable challenge for researchers is to develop faster restoration schemes in relation to the conduct of restoration operation. Researchers must take a significant number of constraints into consideration, such as bandwidth availability, wavelength continuity, and lightpath establishment efficiency.

Generally, restoration time is one of the important performance parameters of network survivability. Thus, in this letter, carrier restoration time of 50 ms is regarded as the optimization objective. With the aim of realizing the fast lightpath restoration, numerous studies have focused on the fast routing algorithms[2−4]. However, the schemes used in these studies only considered the routing computation. Another type of approach is the local restoration, wherein the backup route is found only around the failed arc, and the origin node of the failed arc is responsible for rerouting[5]. The restoration of lightpath includes two procedures, namely, rerouting computation and signaling procedure. Therefore, the signaling procedure is also an important issue which should be addressed to achieve the fast setup of restoration label switched path (LSP).

In the original signaling procedure of lightpath setup in restoration operation, e.g., in the resource reservation protocol-traffic engineering (RSVP-TE), the Path message is transported along the route from source node to destination node. Subsequently, the Resv message is reversely returned along the LSP. This would take a period of time to finish the signaling procedure, especially in the case of long-range lightpath, the setup time would be a little longer. To decrease the setup time, several schemes have been proposed, such as those utilized by Bai *et al.*[6,7]. Bai *et al.*[6] employed a local node-initiated fast restoration scheme for multi-protocol label switching transport profile (MPLS-TP) optical multicast service, which decreases the time of signaling procedure through the mechanism of local restoration, thereby achieving fast restoration. Hou *et al.*[7] used a reserved deflection routing scheme, wherein GMPLS/path computation element (PCE) extensions are applied to achieve fast restoration.

This letter proposes a fast parallel restoration (FPR) scheme, which is different from the abovementioned schemes, to achieve the fast setup of restoration LSP. By triggering each segment of sub-LSP along the new route to finish the signaling procedure concurrently, the FPR scheme guarantees that the restoration LSP can be set up with high speed. The simulation results show that the FPR scheme achieves better performance in terms of the lightpath setup time.

We focus on the fast signaling procedure of the LSP establishment during the restoration procedure. One of the key performance metrics in the LSP restoration is the connection restoration time.

For convenience, the following definitions are made:

Definition1 (sub-LSP): a segment of the restoration LSP along the new route;

Definition2 (sub-source node and sub-destination node): the first node of each segment of the sub-LSP is called a "sub-source node" and the last one is called a "sub-destination node."

Moreover, it is assumed that each node has a full wavelength conversion capacity.

In the GMPLS/ASON architecture, the Path message of every connection request includes the unique connection ID, source ID and destination ID, and IDs of upstream node and next node. Therefore, the management plane could directly trigger all sub-source nodes to produce and send a Path message all the way to its corresponding sub-destination node. This will return the Resv message to reserve resource for the connection, and thus the segments of sub-LSPs are built. After all sub-LSPs are set up successively, the entire LSP is also set up because all intermediate nodes have the common unique connection ID and information of its upstream node and next node, as well as the port IDs. Moreover, all sub-LSPs can be naturally merged individually to form a complete LSP.

A problem, which lies in the scheme is the division of segment. To solve this problem, a LSP segmentation algorithm is included. The main idea of LSP segmentation algorithm is that the segment is divided according to its total delay after the new route is calculated, and the total delay of all links and nodes in each segment should be no more than the threshold value of 50 ms. To meet the demand better, each link is considered as a segment.

The procedure of the FPR scheme is described in detail as follows:

Step 1: The source node receives the notification message of a failure.

Step 2: The source node calculates a new route for the failed connection.

Step 3: The LSP segmentation is conducted by the management plane according to the number of links along the route.

Step 4: All sub-source nodes and sub-destination nodes are set by the management plane for each segment of sub-LSP.

Step 5: Through the following three processes, namely, the interaction between the source node and the management plane, the message processing in the management plane, and the interaction between the management plane and each of the sub-source nodes, the control plane of all sub-sources is concurrently triggered to produce and send a Path message to its corresponding sub-destination node through the soft permanent connection.

Step 6: The sub-source node receives the Resv message, and the lightpath resource is reserved.

Step 7: Sub-LSPs are set up concurrently along the new route.

Step 8: The LSP of whole lightpath is also set up by organizing all sub-LSPs together using the common connection ID and the source and destination node IDs.

As Fig. 1 shows, the signaling procedure of FPR scheme is given, where the route is assumed to be (S-a-b-c-d-D) in the distributed optical network, and that it contains five sub-LSPs, (S-a), (a-b), (b-c), (c-d), and (d-D).

In addition to the aspect of parallel signaling, determining when is it safe to start sending data[8] in the restoration LSP is also important. Data can only be transmitted once all of the sub-LSPs have been established and stitched together, which includes programming an optical switch. In this process, the source node needs to know when the restoration LSP is complete so that it can understand when the alarm condition has eased and data are flowing again. Simultaneously, it needs to know when the LSP is correctly set up end-to-end, and when it is safe to turn on its laser. Each node is assumed to have a full wavelength conversion capacity. Thus, the safety aspects must be examined after each sub-LSP is established.

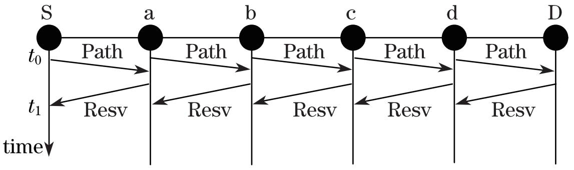

Fig. 1. Signaling procedure of FPR scheme.

The first key metric is the setup time of restoration lightpath, the value of which is compared among the three schemes. In terms of the same network load, the comparisons are as follows.

For the FPR scheme, the setup time $T_1$ is defined as

$$T_1 = T_{\text{notify}} + T_{\text{m}} + \text{Max}\left[\sum_{i=1}^{M_j}(2T_{\text{D}_i} + T_{\text{Path}_i} + T_{\text{Resv}_i})\right]. \quad (1)$$

For the traditional RSVP-TE signaling scheme, the setup time $T_2$ is defined as

$$T_2 = T_{\text{notify}} + \sum_{i=1}^{N}(2T_{\text{D}_i} + T_{\text{Path}_i} + T_{\text{Resv}_i}). \quad (2)$$

For the local restoration approach, the restoration time $T_3$ is given as

$$T_3 = \sum_{i=1}^{N'}\left(2T_{\text{D}_i} + T_{\text{Path}_i} + T_{\text{Resv}_i}\right), \quad (3)$$

where $T_{\text{notify}}$ is the time required to transport the failure notification to the source node; $T_{\text{D}_i}$ is the link delay; $T_{\text{Path}_i}$ is the processing time of Path message; $T_{\text{Resv}_i}$ is the processing time of Resv message. $T_{\text{m}}$ consists of four parts: the message propagation time from the source node to the management plane, processing time at the management plane, congestion time around the management plane (because it has to send out a bunch of messages to all of the sub-sources), and the message propagation time from the management plane to a sub-source. $M_j$ is the number of hops of the different sub-LSPs which is equal to 1 in the present letter. $N$ is the number of hops of the whole restoration LSP and $N'$ is the number of hops of the local restoration LSP. According to Eqs. (1), (2), and (3), the following relationship is easily obtained

$$T_2 > T_3. \quad (4)$$

Interestingly, this comparison is obvious when the number of hops of the new route is large in the large-scale distributed optical network.

With regard to the different network load, the setup time of restoration lightpath is different, owing to the queuing delay of signaling messages. The delay is compared as follows.

The model can be considered as an $M/M/n$ queuing system. The mean waiting time $E(w)$ can be obtained from the Erlang $C$ formula and Little formula:

$$E(w) = \frac{C(n,a)}{n\mu(1-\rho)}, \quad (5)$$

where $a$ represents the network load, $n$ represents the maximum number of wavelengths, and $\mu$ represents the average departure rate. $C(n,a)$ and $\rho$ are obtained by

$$C(n,a)=\frac{a^n}{n!}\times\frac{p_0}{1-a/n}, \tag{6}$$

$$\rho=\frac{a}{n}, \tag{7}$$

$$p_0=\frac{1}{\sum\limits_{k=0}^{n-1}\frac{a^k}{k!}+\frac{a^n}{n!}\times\frac{1}{1-a/n}}. \tag{8}$$

As the network load $a$ increases, the value of $C(n,a)$ increases as well. At the same time, the value of $1-\rho$ decreases and thus, the value of $E(w)$ increases.

Another key metric is the blocking probability. Although we have assumed that all nodes in the network have full wavelength conversion capacity, a certain blocking probability exists. In this letter, blocking occurs when all channels are occupied.

The model can be considered as an $M/M/n(n)$ queuing system. Therefore, the probability (occupied $m$ channels) can be obtained from the Erlang B formula:

$$P_i(m)=\frac{(\lambda/\mu)^m/m!}{\sum\limits_{i=0}^{n}\left[(\lambda/\mu)^i\Big/i!\right]}, m=0,\cdots,n, \tag{9}$$

where $\lambda$ represents the average arrival rate of the newly launched requests, which meets the Poisson process; $1/\mu$ represents the average holding time of wavelength resource for requests, which is exponentially distributed. Equation (9) represents the blocking probability of one link, while the blocking probability of restoration lightpath is

$$P(m)=1-\prod_{i=1}^{L}[1-P_i(m)], \tag{10}$$

where $1-P_i(m)$ represents the reliability of one link and $L$ represents the number of links, which the restoration lightpath incorporates. Based on Eq. (9), the blocking probability of each link in the three schemes under the same network load is the same. Thus, the value of $P(m)$ is dependent on the value of $L$. In the three schemes, the value of $L$ in the FPR scheme and traditional RSVP-TE signaling scheme is greater than the value of $L$ in the local restoration approach, and the trend of $P(m)$ is the same as that of $L$. However, due to the very small value of $P_i(m)$, the value of $P(m)$ in the three schemes under the same network load is nearly the same. In the different network load, the value of $P_i(m)$ increases as the network load increases, and subsequently, the value of $P(m)$ increases.

To evaluate the performances of the proposed mechanisms and demonstrate the validity of the analytical conclusion, several simulations are conducted in NSF Net topology[9], which consists of 14 interconnected nodes and 21 bi-directional fiber links wherein each direction contains 20 available wavelengths.

To simplify our calculation, the transmission time in each link for the RSVP message is assumed to be $T_{\mathrm{Di}}=$ 3–5 ms. The processing time of RSVP message $T_{\mathrm{Path}_i}$ and $T_{\mathrm{Resv}_i}$ is assumed to be 8–15 ms (which includes switch programming time) and $T_{\mathrm{m}}$ is assumed to be 4–6 ms. In the link failures, the failures are generated randomly in each link of NSF Net topology, and the background traffic of 100 Erlang is considered to obtain more accurate simulation results.

The various schemes mentioned above are compared in these simulations. The comparisons are made by observing and studying two major performances: restoration time and blocking probability.

Figure 2 shows the comparative results of the average restoration time among the traditional RSVP-TE approach, local restoration approach, and FPR scheme. As the network load increases, the restoration time of all approaches gradually increases. Generally, FPR and the local restoration schemes show good performance because the limitation of the maximum time of request and the failed requests are not taken into account. A distinct observation that can be drawn from Fig. 2 is that the FPR scheme can achieve very quick restoration time of connection within 50 ms, which is considerably faster than the other two. In comparison, the traditional RSVP-TE approach is much slower, although its values are as smooth as those of the FPR mechanism. This highlights the advantage of the FPR scheme with regard to restoration time for failed connections.

The blocking probabilities of the three approaches are compared in Fig. 3, which shows that all blocking

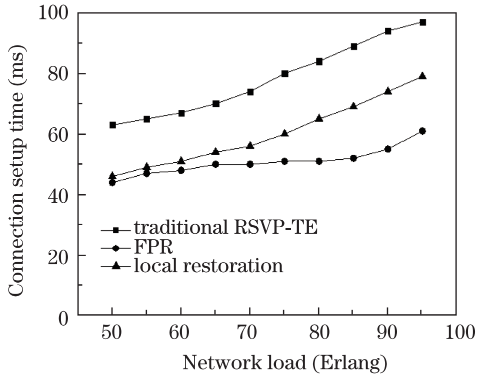

Fig. 2. Connection setup time of restoration lightpath.

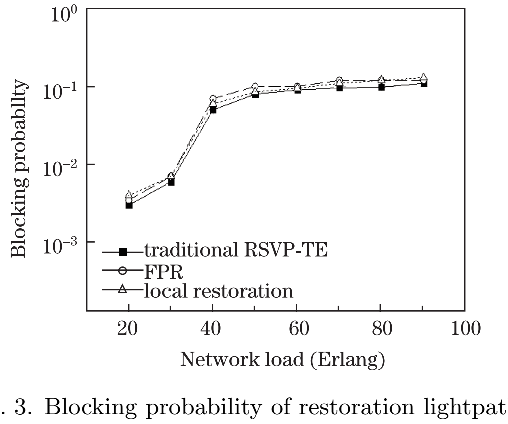

Fig. 3. Blocking probability of restoration lightpath.

probabilities have similar trends. As the network load increases to some degree (greater than 40), the blocking probabilities of three approaches begin to soar to near 0.1. This suggests that the FPR scheme is able to keep a similar performance in blocking probability and manages to improve significantly the restoration time of failed connections compared with the other two schemes.

In conclsuion, a FPR scheme is proposed to achieve the fast setup of restoration lightpath in the distributed optical network. By dividing the restoration LSP into several segments of sub-LSP, the FPR scheme triggers each sub-LSP to finish the signaling procedure concurrently. Simulation results show that the FPR scheme has better performance than the local restoration scheme and the traditional RSVP-TE scheme, especially in terms of the signaling time of the lightpath setup.

Although the FPR scheme has been proven to show better performance, several imperative problems need to be addressed, such as the details of the protocol extensions, which is the crux of the application of the FPR scheme. In particular, more work should be done on the FPR scheme for signaling LSP segments, and on identifying them as part of the end-to-end restoration LSP to make the scheme functional.

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