Fast restoration scheme for MPLS-TP enabled optical multicast

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To improve the restoration performance of a multicast service of multi-protocol label switching transport profile (MPLS-TP) enabled optical network, this letter proposes a local-node initiated fast restoration (LNIFR) scheme for MPLS-TP optical multicast service. The proposed scheme allows the local node to establish a segment of fast loopback label switch path by the local node along the upstream of the failed node or link to the nearest downstream node. The fast restoration of optical multicast trees is realized through this part restoration, which focuses on failed node or link. Simulation analysis and results demonstrate that the new scheme outperforms the other schemes in terms of restoration time and success rate.

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Based on the mature multi-protocol label switching (MPLS) packet technology, the MPLS transport profile (MPLS-TP) has seen rapid development and gained wide support from manufacturers under the joint efforts of Internet Engineering Task Force (IETF) and the Telecommunication Standardization Sector (ITU-T). The MPLS-TP is aimed at following the trend of the packet switch-oriented optical transport network services and combining the advantage of MPLS with the operational experience of the traditional synchronous optical networking/synchronous digital hierarchy (SONET/SDH) network[1,2]. Among packet-based services, broadcast service, which is the dissemination of information from one or more source nodes to multiple destinations, is especially emphasized in MPLS-TP to support newly emerging applications, such as Internet Protocol television (IPTV)[3].

However, considering the high demand for multicast services, MPLS-TP-based optical multicast still faces various challenges, including those regarding performance, reliability, and survivability. Various novel optics technologies have been developed to improve the performance of optical networks[4,5]. However, restoration performance has remained as an important issue in the multicast circumstance. The classic restoration mechanisms are source initiated and have failed to satisfy the high requirement of multicast service due to their comparatively long restoration time resulting in serious data loss during the period of restoration operation. Several studies have been conducted to improve the restoration performance of multicast in a wavelength-division multiplexing (WDM) network[6,7]. A dynamic core-based selection (DCS) algorithm has been presented in these studies. In one study, the DCS focused on the restoration of one-to-multipoint multicast traffic in the WDM mesh networks[7].

Despite these developments, multicast service still poses great challenges to the current version of the MPLS-TP optical network. A multiple ring-based local restoration (MRLR) has been proposed in Ref. [8]; however, due to the complexity, it is too costly for the algorithm to calculate and set up multiple protection rings in each segment.

Therefore, a faster and more efficient restoration mechanism for optical multicast is required in supporting the MPLS-TP network using resource reservation protocol-traffic engineering (RSVP-TE)[9] as the signaling protocol and open shortest path first (OSPF) TE as routing protocol. In this letter, a local node-initiated fast restoration (LNIFR) mechanism for MPLS-TP optical multicast service is proposed. This allows the local node, which is the upstream node of a broken node or link, to establish a segment of the loopback label switch path (LSP) to the nearest downstream node of the failure link in the event of a link failure and merge this segment of loopback LSP into the original LSP of a multicast tree. This new restoration scheme is more direct and efficient. Analyses and simulation results have shown that the new restoration scheme outperformed other restoration mechanisms in terms of restoration time and rate.

The basic idea of the new mechanism is that each node in the network already maintains an overview of the network topology and a database of link state advertisement (LSA) to other nodes; it also has detailed state information of its outgoing links. Each intermediate node of a multicast tree maintains a record of information on the multicast tree, including the connection identifier, source and destination addresses, next hop and last hop information, and bandwidth.

One limitation of the MPLS-TP-based optical network is the wavelength continuity constraint imposed by the all-optical cross-connect switches requiring that the same wavelength be used on all the links in a multicast tree. To solve this problem, we assumed that the wavelength converter was implemented in all nodes in such network to ensure that there were sufficient available wavelengths to set up a multicast tree.

Definition 1 (Local node): The nearest available upstream node of the failed node or link; it must be able to calculate a segment of the route from itself to the nearest downstream node of the failed node or link.

Definition 2 (Loopback LSP): The segment of LSP established by local node, which is from the local node to the nearest downstream node of failure.

In the proposed mechanism, when the local node of the failure link detects the fault, it would know immediately that it has been set as the local node and that it has to calculate a segment of alternative route for the loopback LSP. Hence, it conducts this operation directly according to its current view of the network topology, which is stored in its link-state database. The local node simply removes the failed links from the link-state database and calculates a new route toward the downstream node of the failed link or the node to restore the suffered connection. This implies that the other parts of the whole multicast trees, including the upstream and downstream nodes of the related LSP, are not rerouted and do not have to be changed. The explicitly routed setup of the loopback LSP along this calculated alternative path is required, e.g., by means of constraint routed RSVP-TE since other routers may not yet be aware of the failure. The Internet Protocol (IP) routing protocol can continue converging later; meanwhile, it leaves the already restored LSPs alone. In addition, the proposed mechanism can be generalized to the alterable node restoration along the reverse LSP. It can also be used to set this node as new local node if the previous local node fails to complete rerouting or LSP establishment operation.

To illustrate, Fig. 1 depicts both restoration mechanisms for one optical multicast tree. When link h-i fails, the multicast tree has to resort to restoration operation under the condition that there is no protection available. In the classic restoration mechanism, the root node has to reroute the suffered multicast tree. In comparison, the fast restoration mechanism only needs to calculate one segment of the loopback route from the local node h to the downstream node i, which is (h-b-i). In this example, the remaining components of the original multicast tree are not affected and changed.

One issue in the LNIFR mechanism is that the failed node has more than one branch along the downstream of the multicast tree in some cases. To solve this problem, the proposed mechanism has to be extended by allowing the local node to establish several segments of the loopback LSP for each leave that has occurred.

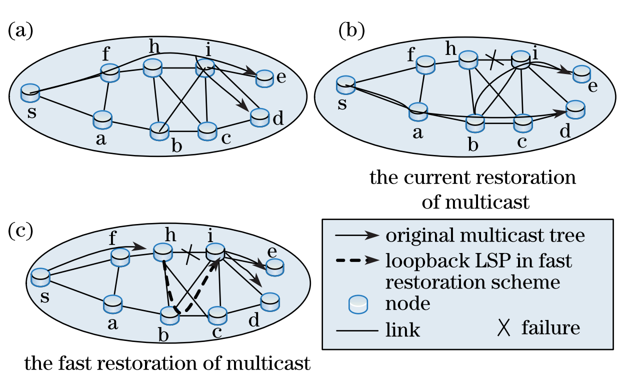

Fig. 1. Fast restoration mechanism of MPLS-TP multicast. (a) Multicast tree when network is normal; (b) current restoration of multicast; (c) fast restoration of multicast.

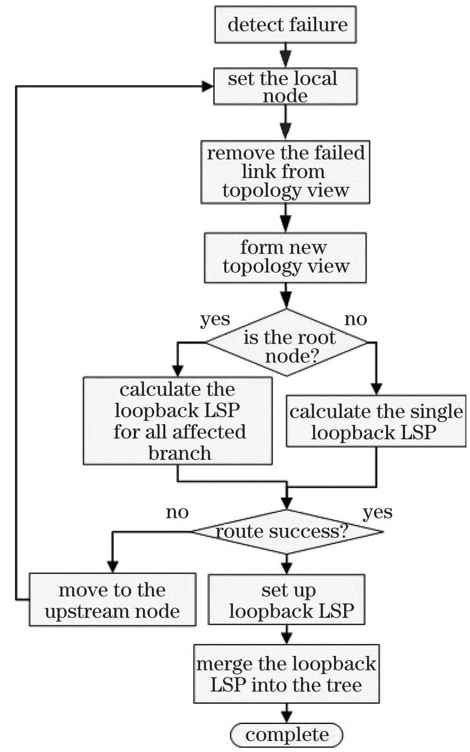

Fig. 2. Flowchart of the fast restoration mechanism for multicast.

The procedure for the new mechanism is given in detail in Fig. 2 and in the section below.

Step 1: A link or node failure is detected by the nearest upstream node. This node is set to be the local node.

Step 2: The local node removes the failed link or node from its database of topology and forms a new view of topology.

Step 3: The local node calculates the loopback route to the downstream node of failure link or node according to the new topology.

Step 4: If the calculation is successive, turn to step 5; otherwise, turn to step 7.

Step 5: With the extension of RSVP-TE, the new loopback LSP is set up.

Step 6: The local node sends the "notify information" alert to the downstream and upstream to notify each node to merge the new LSP into the multicast tree.

Step 7: Move to the next node along the reverse of the the LSP and set it as the new local node, and then turn into step 2.

To support the proposed multicast protection function, the supporting node structure is also given in Fig. 3. The node consists of the MPLS-TP transport plan module, the extended RSVP-TE, the OSPF-TE module, link resources management (LRM) module, and database. The database maintains the overview of the network topology; it is also responsible for keeping a record of information on the multicast tree, including the connection identifier, source and leaves nodes addresses, next hop and last hop information, and bandwidth.

To analyze the performance of the new restoration mechanism, a theoretical comparison was conducted between the source-initiated classic restoration and proposed LNIFR.

The restoration time T_R is defined as follows:

$$T_R = T_d + T_n + T_{rt} + T_{st}, \quad (1)$$

where T_d is the average failure-detection time, T_n is the average notification time, T_{rt} is the average reroute time, and T_{st} is the average time to set up a newly restored LSP, including processing and transmitting time for path/resv.

It takes the same amount of time to detect and reroute in the two mechanisms; hence, T_d and T_{rt} are ignored during the analysis.

First, we compared T_n in the two schemes. The fast restoration mechanism does not need to send a notification to the root node, and the analytic result can be obtained as:

$$T_{n1} > T_{n2}, \quad (2)$$

where T_{n1} is for the source-initiated restoration mechanism, and T_{n2} is the LNIFR mechanism.

Then, we compared T_{st} of the two schemes. T_{st1} is of the source initiation mechanism, whereas T_{st2} is source of the new mechanism. They are defined as:

$$T_{st1} = \frac{\sum_{i=0}^{i=M} \left(T_{path(i)} + T_{resv(i)} + T_{a(i)} + 2T_{p(i)} \right) \times N_i}{M}, \quad (3)$$

$$T_{st2} = \frac{\sum_{i=0}^{i=M} \left(T_{path(i)} + T_{resv(i)} + T_{a(i)} + 2T_{p(i)} \right) \times N_i'}{M}, \quad (4)$$

where T_{path} and T_{resv} are the process time of path/resv message of connection i, T_p is the propagation time of messages through each link, and T_a is the resource allocation time for connection i. In addition, N_i is the distance between the root node and leaf node for connection i, which is represented by the number of hops; N_i' is the length of loopback LSP for connection i; M is the total number of suffered connections.

N_i is the biggest number of hop between root node and terminal leaf nodes through the main branch, whereas N_i' is that between local node and the downstream node, hence, $N_i > N_i'$. We then arrive at:

$$T_{st1} > T_{st2}. \quad (5)$$

According to Eqs. (2) and (5), we can obtain the conclusion expressed by

$$T_{R1} > T_{R2}. \quad (6)$$

Therefore, the new mechanism can diminish the restoration time considerably in comparison with the source-initiated classic restoration mechanism.

Second, we studied the algorithm complexity. For simplicity, we assumed the presence of m leaf nodes in a multicast tree. In the source-initiation restoration mechanism, the root node has to recalculate the shortest paths to each leaf node using Dijkstra algorithm, hence, the complexity is $O(mn^2)$. In the new restoration scheme, if there are no leaves suffered by the link failure, the complexity is $O(n^2)$, otherwise if there are k ($k < m$) leaves suffered by the link failure, the complexity is $O(kn^2)$.

To evaluate the performance of the proposed mechanisms, an experimental hardware platform test-bed was constructed, consisting of 14 interconnected nodes and 21 bi-direction fiber-links. In this experiment, each link included only a single fiber containing 32 wavelengths. The experiment was conducted using a widely accepted National Science Foundation Network (NSFNET) topology. The simulation was triggered through custom-built C++ event-driver software. Multicast connection requests were set to be Poisson distribution with $\lambda = \{1, 2, \cdots, 10\}$ per minute, and their holding-time followed the exponentially distribution with the average value of one minute. Root nodes and leaf nodes of multicast trees were selected randomly.

Four kinds of restoration mechanism of multicast were compared in this experiment: the proposed LNIFR mechanism, MRLR, DCS, and the classic source initiated restoration mechanism. Additionally, the comparison was made by observing and studying three major performances in terms of restoration time, restoration rate, and signaling protocol load. The experimental results are illustrated in Figs. 4 – 6.

Figure 4 provides the comparison between restoration time and the number of request rates of multicast connections for the four mechanisms. Two distinct observations have been observed. First, the restoration time increases as the number of request rates of multicast connections increases; second, the proposed fast restoration mechanism displays a shorter restoration time than the classic

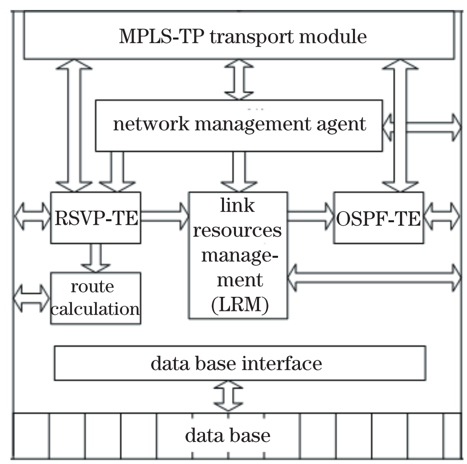

Fig. 3. Supporting node structure for the fast restoration mechanism of the MPLS-TP multicast.

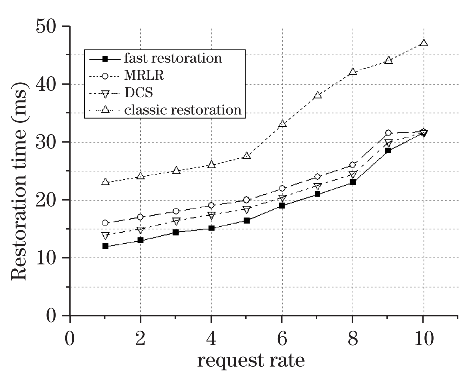

Fig. 4. Comparison of restoration time.

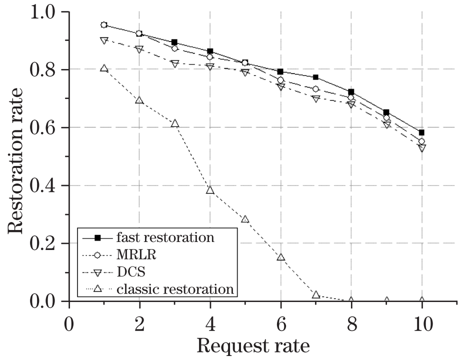

Fig. 5. Comparison of restoration rate.

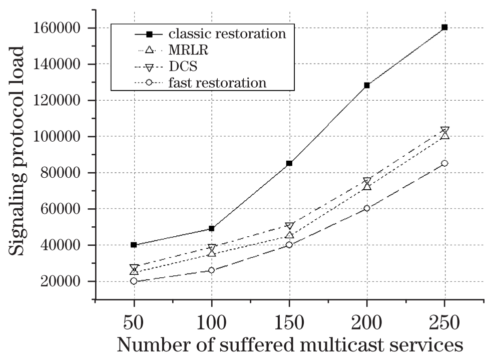

Fig. 6. Comparison of signaling protocol load.

restoration mechanism, DCS, and MRLR. One reason for these results is that the notification time is saved in the fast restoration mechanism. Considering the time taken to reroute calculation, the fast restoration mechanism just needs to calculate the route of part of the whole multicast tree, which is from the local node to the downstream node for the failed LSP. In comparison, the classic mechanism is source-initiated and has to evoke the routing calculation and establishment of restored multicast tree, which is a relatively complex and long procedure. Therefore, the LNIFR mechanism outperformed the others in terms of restoration time.

The proposed mechanism showed good performance as the MRLR and had a much higher restoration rate than the rest (Fig. 5). The reason for this is that the fast restoration mechanism suffered from fewer constraints than the classic mechanisms in calculating the loopback route. Moreover, the fast restoration scheme can adjust itself by selecting another upstream node as local node to repeat the routing calculation if the previous rerouting operation failed.

A comparison between the signaling protocol load and the number of suffered multicast connections, which is calculated by the number of the signalling messages generated, is presented (Fig. 6). In addition, the fast restoration mechanism showed a much lower signaling protocol load than the other three mechanisms (Fig. 5). This advantage is more obvious given that the number of suffyered multicast connections increased. The fast restoration mechanism simplified the procedure of the multicast tree recovery; hence, the generated signaling messages are obviously fewer than those of the other restoration mechanisms.

In conclusion, the MPLS-TP has been developed by the IETF and the ITU-T to follow the trend of packet-oriented optical transport network. As multicast becomes increasingly important, the MPLS-TP still faces great challenges in providing support to this network. This letter has presented a LNIFR scheme for MPLS-TP optical multicast service. This scheme allows the establishment of a segment of fast loopback LSP by the local node along the upstream of the failed node or link. Based on the simulation analysis and results, the proposed scheme has better performance in terms of restoration time and restoration rate when compared with traditional MPLS-TP restoration schemes.

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