Flexible MPLS Signaling (FMS) for Mobile Networks

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Abstract— **Multiprotocol Label Switching (MPLS) has gained momentum in recent years as an effective tool to provide Quality of Service (QoS) in a variety of networks. This has in turn created active interest in the area of recovery in MPLS based networks. A number of recovery schemes for MPLS domains have been proposed in recent years. However, the current schemes lack support for recovery in dynamic network topologies. In this paper, a new flexible signaling protocol for LSP rerouting in dynamic network environments is introduced. The signaling protocol recovers from node and link failures reactively, eliminating the need for end-to-end LSP reestablishment. The performance of the signaling protocol is presented through simulations.**

I. INTRODUCTION

Next generation communication networks are migrating towards a unified network architecture where both wired and wireless network segments will co-exist. This is accompanied with the growing demand on networks to provide QoS, due to the rise in popularity of real time and multimedia applications. MPLS [1], with its Traffic Engineering (TE) capabilities [2] has emerged as a powerful tool to provide QoS support in MPLS enabled networks. MPLS uses the label-swapping paradigm to provide high speed packet switching over various types of networks, including IP. Within an MPLS domain, traffic flows from the source or ingress, to the destination or egress, in an MPLS path known as a Label Switched Path (LSP). LSPs created using MPLS can also be used to deliver packets across multiple network segments, each with potentially different underlying technologies, making them suitable for next generation network architectures. Hence, the implementation of future network architectures would be associated with the need of MPLS to support mobile wireless networks with dynamic topologies.

MPLS signaling protocols provide control mechanisms for setup, tear down, and maintenance/recovery of LSPs. Recent research in MPLS signalling has focussed on improving techniques for recovery in MPLS domains. However, the proposed solutions, mainly based on the CR-LDP [3] and RSVP-TE [4] signaling framework or extensions thereof, are geared toward wired networks. In wired networks, paths once established, hardly change. On the other hand in mobile networks, calculated routes have limited lifespan since the network connection structure changes due to nodal mobility. Hence, MPLS recovery techniques assume even greater significance in dynamic networks, and form the focus of our research.

The Internet Engineering Task Force (IETF) has developed a framework for MPLS recovery[5], which defines two basic models for MPLS path recovery: *Protection Switching* and *Rerouting*. In the former, the recovery Label Switched Path (LSP) is pre-established while the latter employs an on demand approach to recovery LSP establishment. Hence, there is a recovery time versus resource utilization tradeoff between the two approaches in handling failures.

One such protection switching scheme based on CR-LDP is presented in Fast Reroute extensions of CR-LDP (FR) [6]. FR maintains pre-computed backup LSP tunnels for LSPs established by CR-LDP. Several backup segments may be maintained for a single LSP and they provide link and node failure protection along various segments of the LSP. In the possible implementation of FR in mobile networks, along with the original paths, the backup paths would also require maintenance. Furthermore, in mobile environments, all segments of an LSP are subject to mobility. Hence, protection of multiple segments of an LSP increases the vulnerability of the LSPs since the starting point of the backup segments may lose communications with the main LSP.

A second rerouting technique is LSP Modification using CR-LDP [7]. This scheme can be used to modify the parameters of an existing LSP (like bandwidth, route etc.) without service disruption. Rerouting by this procedure is implemented using a differential bandwidth reservation approach in order to prevent double booking of network resources. This scheme relies on the ingress node to initiate the LSP modification signaling, hence this scheme is also referred to as Ingress Based Rerouting (IBR). When considering mobile networks, a local recovery scheme as opposed to an ingress based recovery scheme like the one discussed above, may be more suitable from a recovery time perspective.

To the best of our knowledge, no LSP rerouting technique for mobile networks has been proposed in literature. In this paper, we propose a novel Flexible MPLS Signaling (FMS) protocol for mobile networks. FMS recovers from a link or node failure by linking the upstream and downstream nodes around the point of failure without the intervention of the ingress or egress routers. The alternate path is established hop-by-hop using the underlying routing mechanism. The label distribution to establish the recovery path uses downstream unsolicited mode [8]. Our proposed FMS protocol is reactive in nature, i.e., it does not rely on any pre-computation or pre-reservation of resources. Being a local recovery technique, FMS also provides fast recovery from failures.

The remainder of the paper is organized as follows: In Section II, we introduce the FMS protocol. The performance evaluation of FMS and two possible alternate recovery tech-

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niques is presented in Section III. In Section IV, we conclude the paper.

II. DESCRIPTION OF FMS

We propose to employ FMS in a multi-hop wireless network environment. Each of the individual mobile nodes are MPLS enabled Label Switched Routers (LSRs). The mobile nodes communicate with neighboring nodes that lie within their transmission radii. Additionally, we assume the existence of an underlying routing protocol. This higher layer routing protocol is responsible for recomputing routing tables whenever there is a topology change in the network. The topology change can be caused by node mobility or node and link failures. Only bandwidth constraint parameters are considered in FMS. FMS is composed of the following phases:

LSP Setup Phase: Consider a connection to be established from source *S* to destination *D* with a bandwidth requirement of B_w. Let there be a shortest path between *S* and *D* passing through the LSRs $\{\mathrm{N}_1, \mathrm{N}_2, \mathrm{N}_3, \mathrm{N}_4, \mathrm{N}_5\}$, which satisfies the bandwidth requirement B_w of the connection. An LSP is explicitly established from *S* to *D* passing through the nodes $\{S, \mathrm{N}_1, \mathrm{N}_2, \mathrm{N}_3, \mathrm{N}_4, \mathrm{N}_5, D\}$ as shown in Figure 1. This LSP is uniquely identified in the MPLS domain by an LSP identifier LSP_i. LSP_i setup follows the basic CR-LDP setup procedure. Additionally, information pertaining to the LSP required for local recovery is stored in the LSRs along the LSP. Traces of the explicit route record $\{S, \mathrm{N}_1, \mathrm{N}_2, \mathrm{N}_3, \mathrm{N}_4, \mathrm{N}_5, D\}$ along with the constraint parameter B_w and LSP identifier LSP_i are stored in each LSR on LSP_i.

Failure Detection Phase: Failures are detected at the node downstream to the failure. The failures can be detected through a timeout mechanism or based on feedback from the lower layers. FMS does not differentiate between node and link failures. This reduces the protocol overhead required to distinguish between these two possibilities. Link failures are also treated as the failure of the upstream node. Let there be a node failure in LSR N_f or a link failure between N_f and N_{f+1}. In both these cases, N_{f+1} detects the failure and initiates the recovery signaling. Hence, N_{f+1} assumes the role of the Initiator of Recovery (IOR).

Failure Recovery Phase: The IOR N_{f+1} attempts to establish a link with the upstream router N_{f-1} around the failure. At LSR N_{f-1}, the recovery path joins the original LSP. Hence, LSR N_{f-1} is called the Merge Point of Recovery (MP). In the special case where the link between *S* and N_1 goes down, the ingress itself becomes the MP. IOR sends a Recovery LSP Setup message (RLS) directed towards the MP. The RLS message contains a recovery flag indicating whether the recovery mode is active, the IP address of the MP, LSP ID of the recovery LSP, and the route record of the original LSP. Further, a label-mapping message containing the label bindings for the recovery path is also embedded in the RLS.

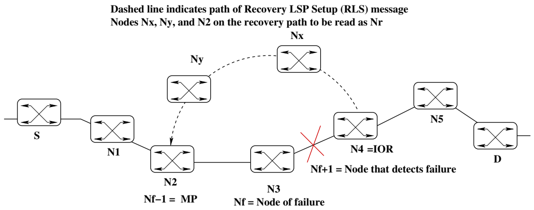

Fig. 1. Failure Recovery Phase

The RLS message travels hop by hop towards MP, aided by the underlying routing mechanism. During this phase, there is an interaction between the network and MPLS layers at every hop. The network layer is responsible for obtaining the forwarding address of the next hop towards MP. The MPLS layer is responsible for the constraint-based establishment of the next hop. We assume that the original explicit LSP is also created using a shortest path routing algorithm. When a node along the recovery path N_r, receives the RLS message, it becomes aware that it is to accept labels in unsolicited mode. Consequently N_r performs the following set of functions:

1) N_r accepts the label contained in RLS message, stores the value of the label and binds it with LSP_i
2) N_r updates the route record by inserting itself into the appropriate location in the route record if $\mathrm{N}_r \notin \mathrm{LSP}_i$
3) If $\mathrm{N}_r \notin \mathrm{LSP}_i$
    a) Try to establish an equal resource path to the next hop satisfying bandwidth constraint parameter B_w
    b) If B_w is not available, renegotiate another parameter $B'_w < B_w$
    c) If B_w is allocated, send updated RLS message to next hop, the new N_r
    d) Otherwise, send failure notification to IOR to abort recovery.
4) If $\mathrm{N}_r \in \mathrm{LSP}_i$, & r > f+1, i.e., if N_r lies downstream of the IOR, there is a potential for double bandwidth allocation after recovery phase. In this case, N_r releases the bandwidth between itself and N_{r-1}
5) If $\mathrm{N}_r \in \mathrm{LSP}_i$, & r < f-1, i.e. N_r lies upstream of MP
    a) If recovery flag is set, i.e., if N_r is the first node on the original LSP_i upstream of the failure receiving the RLS message
        i) Replace binding with new LSP binding
        ii) Reset recovery flag
        iii) Send the RLS message to N_{r+1}
        iv) Release the Bandwidth allocation between N_r and N_{r+1}
    b) If recovery flag is not set, i.e., N_r is on the unused part of the LSP_i upstream to the failure.
        i) Remove label bindings with LSP_i
        ii) Send the RLS message to N_{r+1}
        iii) Release the Bandwidth allocation between N_r and N_{r+1}
6) If N_r = MP, Recovery flag is set
    a) Replace binding with new LSP binding
    b) If N_f is down, terminate
    c) If N_f is up, release the bandwidth allocation between MP and N_f, send RLS to N_f. At N_f remove bindings and terminate.

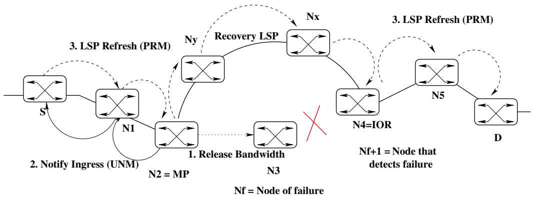

Fig. 2. LSP Refresh Phase

7) If N$_r$ = MP, Recovery flag was reset
   a) If N$_f$ is down, remove bindings and terminate
   b) If N$_f$ is up, release the bandwidth allocation between MP and N$_f$, remove bindings from cross-connect tables and send RLS to N$_f$. At N$_f$ remove bindings and terminate.

In Figure 1, a sample scenario is depicted. Upon failure of the link between N$_3$ and N$_4$, N$_4$ assumes the role of the IOR and sends an RLS message to N_x on the shortest path to MP = N$_2$. The message traverses N$_x$ and N$_y$ and is finally received by N$_2$. Hence, in this example N$_r$ is first N$_x$, then N$_y$ and finally N$_2$, the merge point. As soon as the label binding in N$_2$ is done, the traffic can be diverted to the new path. After that, N$_2$ proceeds with the release of the bandwidth between N$_2$ and N$_3$.

Ingress Coordination and LSP Refresh Phase: The MP creates a Update Notification Message (UNM) with the updated route record and constraint parameter values. MP sends UNM to the ingress node *S*. Upon receiving UNM, the ingress node *S* sends an LSP Parameter Refresh Message (PRM) across the new path. LSRs receiving PRM update their route record trace and B'_w value. An example ingress coordination and LSP refresh phase is depicted in Figure 2. The UNM is sent by N$_2$ to *S*. After that, *S* triggers LSP refresh process sending PRM to N$_1$. This message is forwarded to N$_2$, N$_y$, N$_x$, N$_4$, N$_5$ and *D*. These nodes refresh the LSP traces of LSP$_i$ and adjust the new bandwidth allocations.

Recovery Abort Phase: If a suitable path to the merge point can not be found, a failure notification message is sent to the IOR. The IOR will then send a release message to release up any bandwidth that may have been reserved in the attempt to establish a recovery path to the MP. In the example Figure 2, assume that bandwidth negotiations have failed between N_y and N_2. Considering that the recovery path setup was unsuccessful and aborts at LSR N_y, the IOR releases bandwidth in links between N_y and N_x and between N_x and IOR. IOR then sends a failure notification for LSP$_i$ to ingress *S* through another path in the network. *S* then makes an attempt to modify the entire LSP using CR-LDP LSP modification [7].

III. PERFORMANCE ANALYSIS

In this section, the performance of the FMS algorithm has been evaluated, and compared with the performance of existing Ingress Based LSP Rerouting (IBR) [7] and Fast Reroute (FR) [6] algorithms, via simulations.

Three main experiments were conducted for the purpose of this evaluation:

TABLE I
SIMULATION PARAMETERS

Type	Number of Nodes	Node Density (Nodes/m^2)	Area (m^2)	Transmission Radius (m)
Denser	150	.00060	500x500	90
Dense	150	.00042	600x600	90
Coarse	150	.00031	700x700	90

- **Experiment I:** We compare the difference between the shortest paths after failure compared to the paths set up by each rerouting technique.
- **Experiment II:** We measure the time between occurrence of failure and instance of traffic resumption and observe the response time for each technique.
- **Experiment III:** We measure and compare the total rerouting overhead for each technique.

Experiments were performed on random network topologies with specific size, area and node density parameters as presented in Table I. For each topology generated, we randomly distribute 150 mobile nodes over three different areas creating three different node densities.

We assume that communication between a mobile node and its neighbor nodes takes place within a fixed transmission range, which is chosen as 90m. LSPs are established between randomly selected source-destination pairs in the network. Initial LSP path setup follows minimum hop paths calculated using Bellman Ford shortest path algorithm [9].

A random walk mobility model is used to simulate node mobility. Mobility events are injected randomly within the simulation interval. The mobility of a node may cause it to move out of the communication range of its neighbors, causing link failures. All LSPs that pass through a failing link must be rerouted. Readings pertaining to the original LSP and the modified LSP after rerouting are noted for each rerouting event. All data points presented in this section reflect the average of 1000 independent simulation runs.

A. Path Optimality

We define an optimal path as a path that has the minimum number of hops between a given source-destination pair. Based on this definition, the recovery LSP created after rerouting by various algorithms may be sub-optimal. In this experiment, we measure the length of the recovery LSPs after rerouting for each technique. For this purpose, data pertaining to the length of the LSP was collected before and after a rerouting event for each of the schemes under three node densities. While the IBR scheme selects the minimum hop path in the network at the time of rerouting, recovery paths produced by FMS and FR are potentially suboptimal.

Figure 3 depicts the length of LSPs after rerouting for each rerouting technique. The recovery LSP established by IBR is the same as the shortest path in the network. The FR recovery LSPs are longest and farthest away from optimal paths. This is because, there is a higher probability that the shortest link-disjoint LSP, which is used by FR, is much longer than the original LSP. The length of the recovery LSP in the case

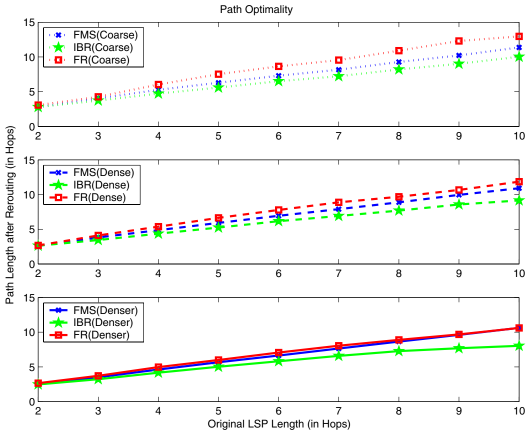

Fig. 3. Path Optimality under Different Node Densities

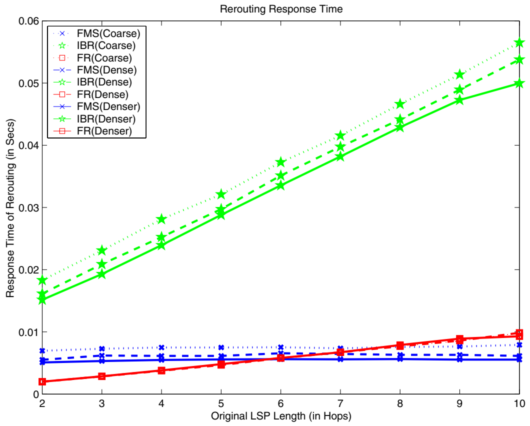

Fig. 4. Rerouting Response Time under Different Node Densities

of FMS lies between these two techniques. The decrease in network density has the effect of increasing the length of the rerouted LSP for all three schemes. This increase is caused by the lack of short alternative paths in sparsely populated networks.

B. Response Time

The response time is measured between the instant of failure and the instant when traffic can resume on the rerouted LSP. The total response time (T_r) until traffic can resume is calculated as T_r= T_d+T_n+T_s, where

- T_d (Detection time): The time taken to detect failure.
- T_n (Notification time): The time to notify the failure processing node about the failure
- T_s (Switch over time): The time taken to switch to the new LSP.

In the following simulations, failure detection time T_d is not considered as it adds the same offset to the total response time for all three algorithms.

Figure 4 depicts measured response time for varying LSP lengths. For FMS, the processing node (IOR) and the node detecting the failure are the same, resulting in short notification time T_n independent of the LSP length. Also, since FMS uses unsolicited label distribution mode to setup the recovery LSP between the IOR and MP, the switch over time T_s is also greatly reduced. For all original LSP lengths considered, response time of FMS is significantly shorter than IBR. This can be attributed to FMS employing intermediate node recovery approach as opposed to IBR, which relies on the ingress to initiate and coordinate LSP modification signaling. Furthermore, IBR scheme uses conventional CR-LDP signaling to reestablish the recovery path starting over from the ingress, which increases the response time. Response time of FR is shorter than FMS for shorter LSP lengths because it employs pre-established recovery LSPs, enabling negligible switch-over time T_s. However, the fast response time of FR comes at the cost of valuable bandwidth resources needed to establish and maintain a backup LSP for each LSP in the network, as will be presented in Section III-C. As the original LSP length increases, the position of the node of failure in the LSP can potentially be further away from the ingress, increasing the average notification time for FR. Hence, overall response time of FR increases with the increase in original LSP length. On the other hand, for a given density, response time of FMS is fairly constant. The switch-over under FMS happens when the notification packet is received by MP. This time period is independent of the original LSP length. Hence, the increasing FR response time curve catches up and surpasses the FMS response time curve for longer original LSP lengths. As the node density increases, the point where FMS starts having shorter response times than FR shifts towards the left. Also, response times of FMS and IBR decrease with increasing node density. On the other hand, FR response time is fairly constant for different node densities because the response time under FR is mainly made up of the notification component T_n and is independent of the node density.

C. Protocol Overhead

The total protocol overhead for the signaling is measured in this experiment for each rerouting technique for the three node densities. The overhead is expressed as the number of control packets exchanged during the entire signaling process. The total signaling overhead (O_s) is expressed as O_s= O_n+O_{rs}+O_{rm}+O_{rl}+O_{rf}, where

- O_n (Notification overhead): The overhead required to notify a particular node in the network regarding the failure.
- O_{rs} (Recovery LSP setup overhead): The overhead required to setup the new LSP.
- O_{rm} (Recovery LSP maintenance overhead): The overhead required to maintain the new LSP, if required.
- O_{rl} (Original LSP release overhead): The overhead required to release unused bandwidth on the old LSP.
- O_{rf} (Recovery LSP refresh overhead): The overhead required to refresh the new LSP.

The signaling overhead of all three schemes is depicted in Figure 5. Signaling overhead of FMS is found to be extremely competitive of all three rerouting techniques. FMS has a very

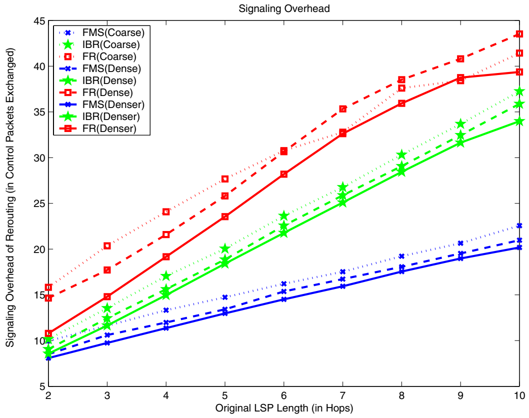

Fig. 5. Signaling Overhead of Rerouting

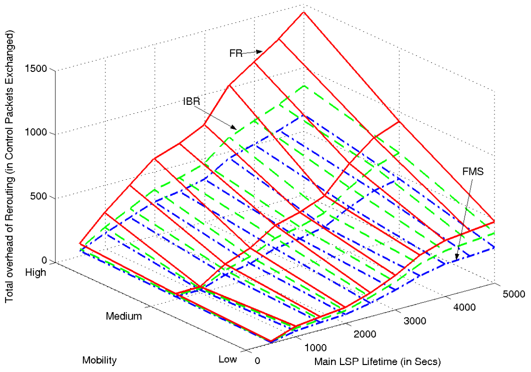

Fig. 6. Cumulative Signaling Overhead

small notification overhead since the recovery is started by the immediate neighbor of the point of failure. The notification in FR and IBR is sent to the ingress node. Hence, the notification overhead is comparable between the two, but always larger than FMS. The IBR and FR LSP setup overhead is higher than FMS since the entire recovery LSP is signaled from source to destination and back. In FMS, the recovery LSP setup overhead is restricted to a portion of the LSP between IOR and MP. This explains the steeper rise in the IBR and FR overhead when compared to FMS. The path maintenance overhead O_{rm} is present only in the FR scheme and is mobility dependent. O_{rm} can be prohibitively high under high mobility conditions since the backup LSP is subject to multiple refreshes due to mobility before the main LSP warrants rerouting. The release overhead O_{rl} under FMS is limited to releasing bandwidth on portions common with the original LSP. O_{rl} for IBR consists of releasing the old LSP after setup of the new LSP. O_{rl} is again very large for FR due to multiple reroutes on the backup LSP, each associated with the requirement of bandwidth release. The refresh overhead O_{rf} for FMS is required to update parameters in the new LSP regarding the new route and bandwidth parameter. In the case of FR and IBR, the refresh takes place in the LSP setup phase itself. Hence, there is no additional refresh overhead component. When all overhead components are taken into consideration FR has the highest overhead, followed by IBR. Our proposed FMS technique has the lowest overhead as shown in Figure 5. Figure 6 shows the cumulative signaling overhead taken over the lifetime of an LSP of length 5 for different mobility rates (low-0.12m/s, medium 0.23m/s, high-1.04m/s). The cumulative protocol overhead increases over the lifetime of the LSP because the number of rerouting events for the LSP increases over time. An increase in mobility rate increases the frequency of rerouting events. Hence, as the mobility rate increases, so does the total protocol overhead for all three schemes. Note that, in the case of FR, the average overhead of a single reroute event increases faster with the mobility since higher mobility rates increase refresh requirements on the backup LSPs. FMS has the lowest overhead performance along both mobility and LSP lifetime axes because of its low average overhead performance per reroute event.

IV. CONCLUSION

In this paper a novel rerouting technique (FMS) for MPLS based mobile networks is introduced. The proposed algorithm takes a reactive approach to LSP recovery and combines intermediate node rerouting with unsolicited label distribution to establish the recovery LSP. The performance of the proposed scheme has been evaluated and compared with two existing rerouting schemes, FR and IBR, via simulations. FMS has been found to be very effective in mobile environments with a low protocol overhead compared to the existing rerouting schemes. The response time is low as traffic can be diverted onto recovery LSPs as soon as the signaling message reaches an intermediate node MP, rather than the ingress node. Additionally, LSPs rerouted via FMS were found to be close to the shortest paths available. The FMS rerouting scheme is geared towards effectively and efficiently addressing the problem of rerouting in dynamic network environments.

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