# Multi-Link Failure Effects on MPLS Resilient Fast-Reroute Network Architectures

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***Abstract*--MPLS has been in the forefront of high-speed *Wide Area Networks* (WANs), for almost two decades [1, 12]. The performance advantages in implementing *Multi-Protocol Label Switching* (MPLS) are mainly its superior speed based on fast label switching and its capability to perform Fast Reroute rapidly when failure(s) occur – in theory under 50 ms [16, 17], which makes MPLS also interesting for real-time applications.**

**We investigate the aforementioned advantages of MPLS by creating two real testbeds using actual routers that commercial *Internet Service Providers* (ISPs) use, one with a ring and one with a partial mesh architecture. In those two testbeds we compare the performance of MPLS channels versus normal routing, both using the *Open Shortest Path First* (OSPF) routing protocol. The speed of the Fast Reroute mechanism for MPLS when failures are occurring is investigated. Firstly, baseline experiments are performed consisting of MPLS versus normal routing. Results are evaluated and compared using both single and dual failure scenarios within the two architectures. Our results confirm recovery times within 50 ms.**

## I. Introduction

MPLS is a layer 3 VPN technology that is used extensively in Wide Area Networks (WAN). The reasons behind its dominance, is due to its high performance and fast-reroute ability [1]. Normal IP routing involves de-encapsulating and inspecting the packet resulting in extra processing [2]. MPLS forwarding decisions are made creating and swapping MPLS labels and consulting MPLS forwarding tables [1, 2]. The MPLS forwarding table entries map labels to next hops. Each entry in the MPLS forwarding table points towards an entry in the MPLS next-hop table that usually is an interface. [7, 19].

Two basic principles are behind the performance of *IP Fast Re-Route* (IP FRR), these are local routing and precomputed detours. When only routers directly adjacent to a failure are notified, this is known as local rerouting. This eliminates one of the most time-consuming steps of *Interior Gateway Protocol* (IGP) - based restoration (global flooding of failure information). As a result of the proactive IP FRR mechanisms detours are computed and installed in routing tables long before any failure occurs. Hence, when a failure occurs, routers are able to select an alternate path instantly.

In order to achieve a reduced failure reaction time to tens of milli-seconds in an intra-domain unicast setting, the *Internet Engineering Task Force* (IETF) defined the framework called *IP Fast Re-Route* (IP FRR) [8]. Existing FRR technology solutions include *Loop-Free Alternates* (LFA), *Remote Loop-Free Alternates* (RLFA) and MPLS-TE (*Traffic Engineering*) FRR. RLFA being an improved version of the LFA mechanism. The LFA and RLFA mechanisms cannot repair all possible failures within networks as they depend heavily on the cost of individual links. The MPLS-TE FRR is developed only for MPLS enabled networks, as a result cannot be implemented without MPLS support [15]. A prerequisite for IPFRR is an IGP such as *Open Shortest Path First* (OSPF) or *Intermediate System to Intermediate System* (IS-IS) [18].

Research projects where the main topic is IPFRR: LFA routes and have also been carried out [10, 23, 24]. IPFRR mechanisms offer similar services to those of *MPLS Fast Re-Route* (MPLS FRR). Although these mechanisms do not have the flexibility of MPLS FRR, due to its programmability of additional features such as *Label Switched Paths* (LSPs), which enable mechanisms such as bandwidth allocation, primary and secondary paths. IPFRR requires no additional configuration other than OSPF configuration on the routers in the same area. Juniper's network device operating system *JunOS* provides three mechanisms to configure route redundancy for OSPF through alternate loop-free routes, which are 1) Link protection, 2) Node-link protection and 3) Per-prefix LFAs. When OSPF is configured within *JunOS* backup loop-free routes are precomputed, which are stored in the *Packet Forwarding Engine* (PFE) [11, 24]. MPLS FRR on the other hand requires configuration in the form of enablement within the LSP configuration on the ingress router. Providing that all routers in the area/routing domain are enabled for MPLS including *Resource Reservation Protocol* (RSVP) or *Label Distribution Protocol* (LDP) then MPLS FRR will function correctly. [10, 11].

The proposed optimisation from Lemeshko et al. to MPLS FRR has an in-depth look into the MPLS FRR algorithm suggesting some optimisations. Optimisations that are claimed to improve quality of service in IP/MPLS networks; throughput, delay and jitter can be adapted for multi-level solving problems of routing. There are some good example structures of MPLS networks with LSP's in-place (both primary and secondary). These structures relate closely to the testbed used for the experiments within this paper.

Hundessa et al. has focused the ordering of packets and their round-trip-delay works [9]. They suggest adjusting or replacing the existing mechanisms involved in the process for FRR. Their future work has elements relevant to this paper, looking into average delay time during the restoration period. There are relevant sections giving in-depth knowledge of subjects such as, LSPs and how they operate.

Although there is research based on the performance of MPLS such as [5, 21], in most cases either software has been used to carry out these experiments [13, 14, 22] or some performance characteristics like FRR are not examined. Overall, most of those research experiments are using simulators and not real devices in a real network setup. Experiments with real network devices like the ones that were used in our experiments are quite difficult to be replicated in a simulated environment. This is due to the complexity and the interaction of multiple systems in a real router that becomes even more complicated to replicate when multiple routers are connected in a specific architecture. Additionally, simulators can be prone to errors or miscalculations that are hard to diagnose or even be aware of [13, 14, 20, 22].

## II. Methodology and Testbed

Experiments carried out in this performance evaluation, evaluate the performance of MPLS FRR with both ring and partial mesh topologies. Replicating link failures and documenting the performance of MPLS FRR with RSVP. On one hand, it is logical that we are limited to experiments replicating one link failure for a ring topology. On the other hand, it is possible to investigate more than one link failure with the partial mesh. Therefore, we have evaluated and documented the results for both one and two link failures for the partial mesh topology. These topologies both use a range of *User Datagram Protocol* (UDP) traffic for the experiments, after setting a baseline with only ICMP traffic generated from ping to perform the measurements.

We used multiple Juniper Networks routers SRX340 in order to produce two topologies selected for configuring the networks, and implementing the configurations required to carry out the experiments. These SRX340 routers, which are shown in Figure 1, can function as routers, switches and firewalls [6].

*Figure 1. Juniper Networks routers SRX340*

For each testbed there was a traffic generator and a receiver. The generator was producing traffic connected to R1. The receiver was connected to R4, receiving the generated traffic. The traffic generator was a laptop running *LANTraffic V2*, the receiver was also a laptop with the same software installed. Before the UDP traffic was introduced the experiments were carried out with ICMP traffic only, for the baseline experiments. The laptop traffic generator was then introduced transmitting UDP traffic ranging from 5 – 80 Mbps (Megabits Per Second). The ranges of UDP traffic were 5, 10, 15, 20, 50 and 80 Mbps, this traffic is referred to as *the range of testing traffic* throughout the rest of this report. To ease the perception of the graphs the label 0 is where there is ICMP traffic only.

For the purpose of these experiments, the routers feature as Layer 3 routing devices. The devices (Figure 1) are the six Juniper SRX340's used for the experiments, they are setup in the Mesh topology architecture, configured and ready for the experiments. Each router is configured as required according to the experiments. The MPLS LSP experiments of the Mesh topology were the most complex with OSPF, MPLS, RSVP and LSP's configured on top of basic configuration. LSP configuration only needed on R1/ingress router as mentioned previously with the egress router IP address configured within the LSP or LSP's. In order for MPLS FRR to work effectively, it is necessary to configure a secondary LSP to route internet traffic in the case of primary route/LSP failure. This is the transition that is measured within these experiments. (How long it takes MPLS FRR to reroute *the range of testing traffic* from the failed primary LSP to the secondary and vice versa.) Figure 3 is a photograph of the partially connected mesh topology.

The topologies utilised for the experiments are the ring network shown in Figure 2, and the partially connected mesh shown in Figure 3. The traffic generator in the logical topology is based

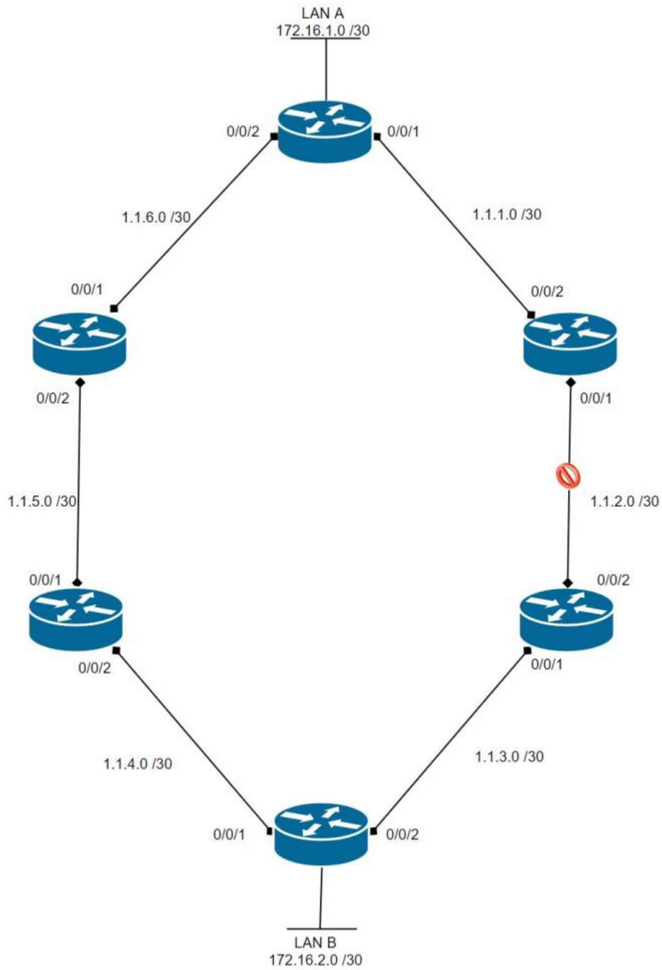


*Figure 2. Testbed with ring structure*

on the client-server model and is located in LAN A, while the client is located in LAN B. This is also shown in Figure 2 and

Figure 3, where the link failures were located for these experiments in particular.

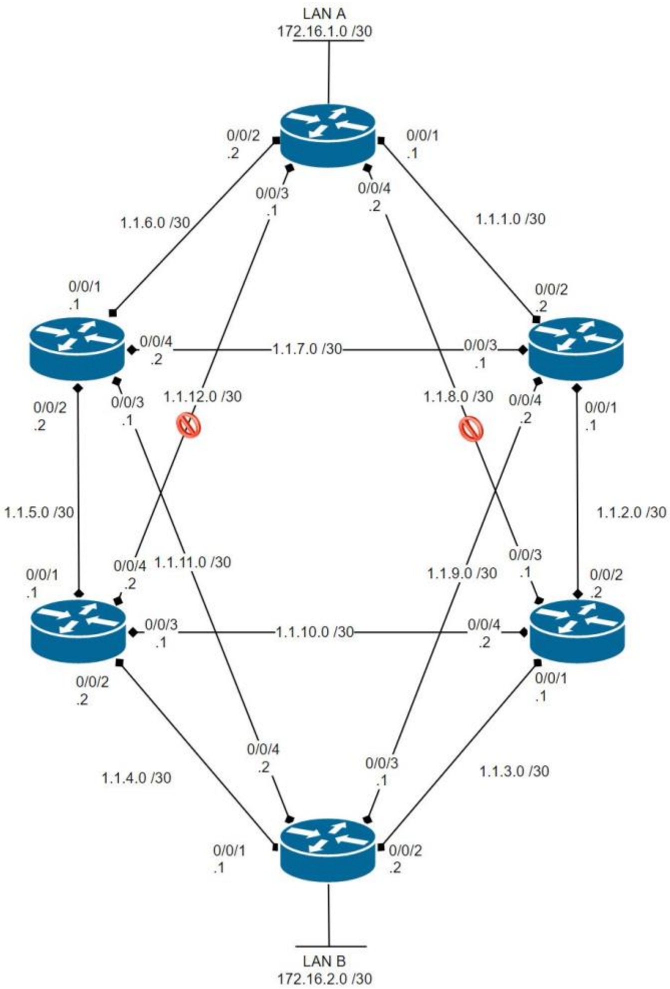


*Figure 3. Testbed with mesh structure*

The limitation to one link failure on the ring topology with rerouting capability enabled, led to the partial mesh experiments (Figure 3) being carried out. First, without extra traffic to start, only ICMP traffic from Ping, gradually increasing for *the range of testing traffic* on the partial mesh topology with two link failures. As mentioned previously, each failure will produce an event entry into the "`show mpls lsp extensive`" command output, enabling the measurement of the total recovery time for the link at those events.

First, a baseline of how efficiently traffic is forwarded with OSPF configured. Against, how efficient is traffic forwarding with MPLS and OSPF configured through the network. This was calculated by the output of ping, then the output of ping with *the range of testing traffic* flowing through the topology.

Reporting the effect of topology, and different amounts of UDP packet traffic flows, has on the end-to-end delay of *Internet Control Message Protocol* (ICMP) packets. Experiments were performed on the two different topologies that have been produced, as well as two scenarios on the Mesh topology (one link failure and two link failures). The first set of FRR experiments were performed on the Ring topology. One link failure occurring on the ring network with no additional traffic. To begin with, only ICMP traffic from ping. Then increasing the traffic generator speed gradually after each test for *the range of testing traffic*. The same was carried out for the Mesh topology with one link failure. Due to the number of paths available it was decided to test more than one link failure in the Mesh topology. Another set of the same experiments were carried out to test the other scenario for the mesh topology (two link failures). This enables the testing of whether topologies influence the performance of FRRr, as well as the bandwidth consumed by traffic. After each failure an entry is entered into the event log. This event log is called with the command "`show mpls lsp extensive`" within Juniper's operating system JunOS. This information was used to create the results of these experiments. Each entry was recorded after each failure to avoid confusion and ensure the mechanism was working efficiently.

## III. Experiments and Results

### A. *End to end delay (Baseline Experiment)*

For results of the baseline experiments with OSPF only and OSPF with MPLS see Figure 4. This Figure provides evidence that with MPLS the ICMP packets have less end to end delay than OSPF on its own. For the majority of the tests ICMP packets via MPLS are faster. Although, there are a few instances such as Test 4 in this case, where only having OSPF configured was performing faster than with MPLS. This only occurred with 7 out of 35 ICMP packets recorded. In our experiments the ICMP packets transmitted with MPLS were faster in 80% of the cases.

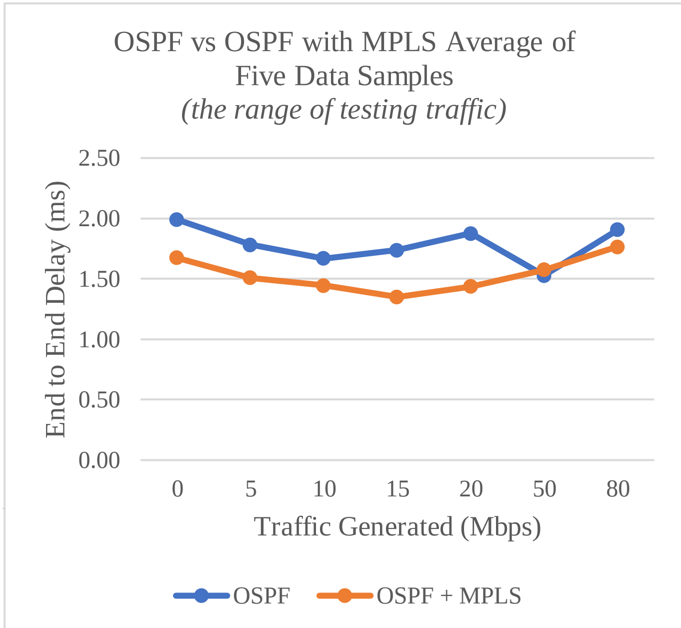


*Figure 4. Influence of MPLS on End-to-End delay of OSPF*

The output mapped in Figure 5 illustrates that ICMP packets with 80 Mbps of UDP traffic and MPLS FRR implemented outperforms OSPF without MPLS, for 3 of the 5 samples.

The average output for 5 data samples, representing each of the tests on *the range of testing traffic*, is illustrated in Figure 6.

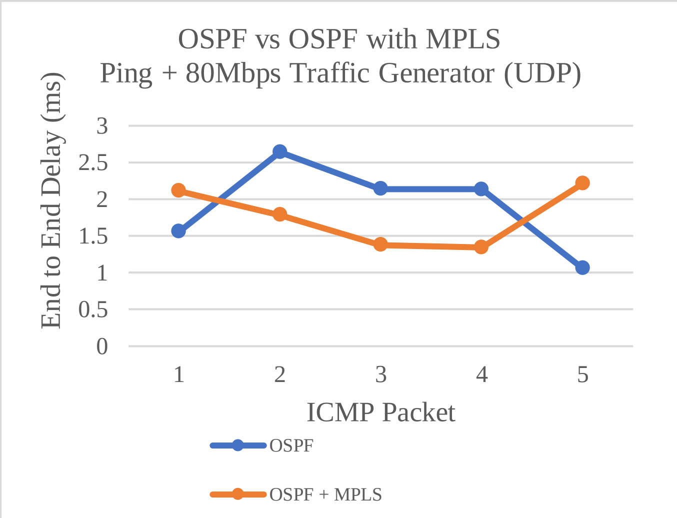


*Figure 5. Comparison of End-to-End Delays*

Here it is visible that the ICMP traffics' end to end delay outperforms OSPF on its own with one exception, the calculation of average samples for 50 Mbps. Therefore, on average the ICMP traffic is more efficient for OSPF with MPLS than without MPLS implemented.

### *B. Fast Re-Route*

The next set of experiments performed were with the Fast Reroute mechanism and LSP's for MPLS. This involved measuring the switch from the Primary to Secondary LSPs. This is achieved by inspecting and plotting the input to the event log triggered by the failure of the LSP "show MPLS LSP extensive," as mentioned previously. Figure 6 shows that for the majority of the tests performed on MPLS FRR the protocol mechanism managed to fore-fill its objective of providing a failure recovery time of less than 50 ms.

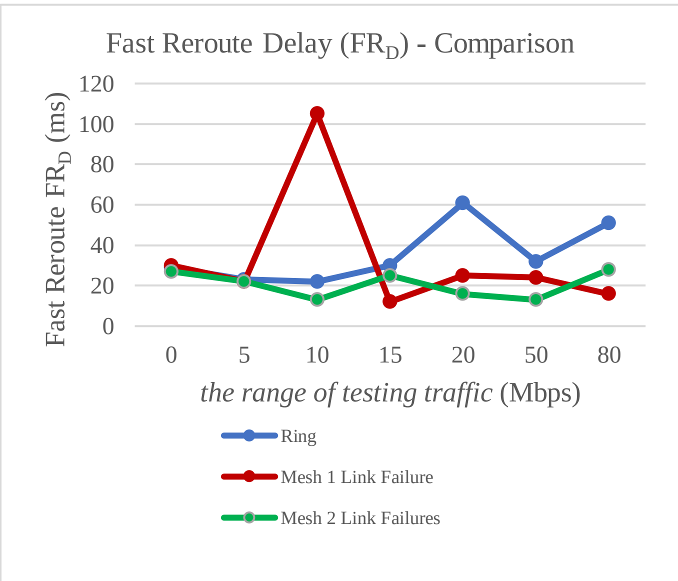


*Figure 6. Comparison of Fast Re-Route Delays*

Although again with this experiment there are still anomalies were MPLS FRR failed to deliver its target, in one case by an additional 55 ms. The other two instances not being so severe one with just eleven milli-seconds above the target. The other instance being just 1 ms away from the target. Failing just 3 out of 21 tests performed, it is still an 87.5% success rate of finding the alternate path within the reported 50 ms. The main purpose of Figure 6. Being that the graph shows an overview of the MPLS LSP's recovery time for all traffic speeds and topological scenarios tested. This view is all the results in one graph to produce an overview of the experiments.

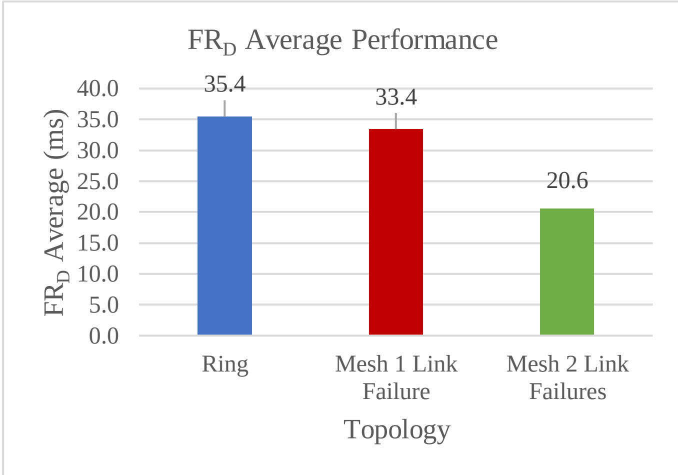


*Figure 7. Comparison of Average Fast Re-Route Delays*

Once all the results are combined for the various topologies and an average is calculated, for the most complex network $FR_D$ performed most efficiently. As exhibited within the output of Figure 7.

## IV. Conclusions and Future work

In this paper we investigated the hypothesis that MPLS with Fast Re-Route (FRR) provides a recovery time of within 50 ms [3], using real hardware equipment. Focusing on the results from the MPLS FRR experiments, MPLS FRR could be considered successful in achieving the recovery time of 50 ms, making it interesting for distributed real-time applications. It could have been expected that the simplest/least complicated topology would deliver the most efficient performance parameters with the most convenient pathways available for MPLS FRR to perform. Unexpectedly, this is not the case, at least within these experiments.

As future work, we plan to perform further experiments with MPLS FRR, adjusting the LSP configurations and possibly more traffic-engineering. Traffic engineering introduces a new range of experiments that have the potential to generate some interesting results along with MPLS FRR.

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