

-  Loop-Free IP Fast Reroute Using Local and Remote LFAPs  
draft-hokelek-rlfap-01.txt

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Applied Research

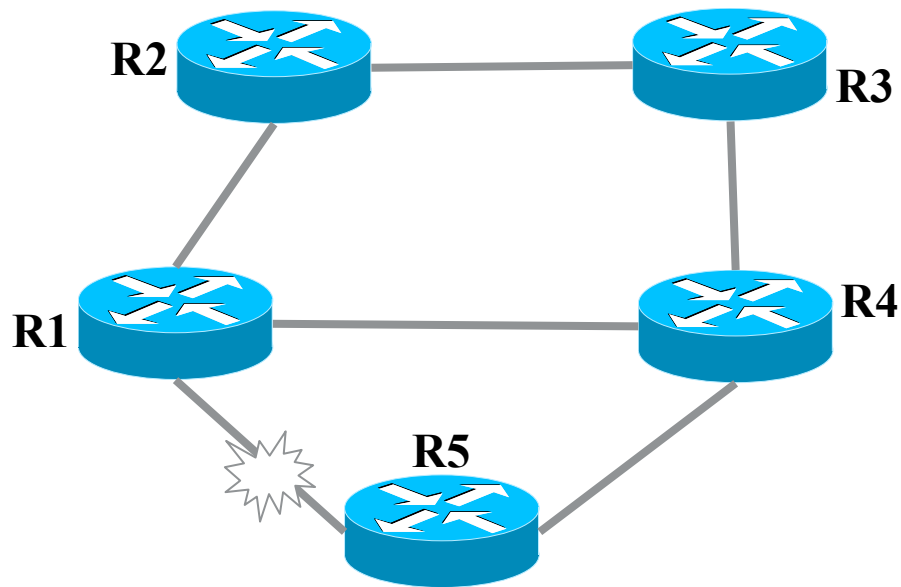
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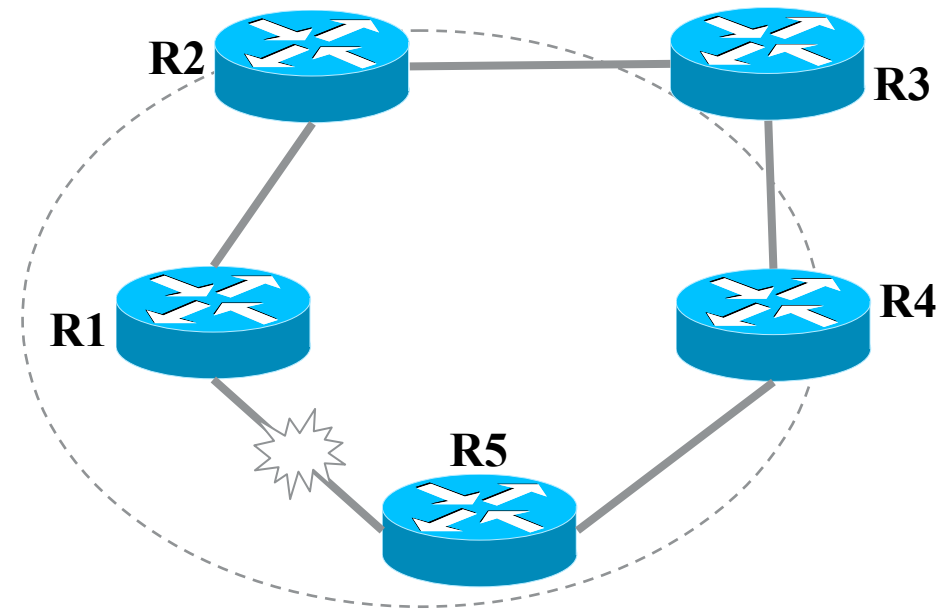
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11/18/2008

# rLFAP Overview



- **R1 (R5)** pre-computes next hop **R4** for its traffic destined to **R5** (**R1**) if link between **R1** and **R5** fails (local LFAP is an RFC now)
- Topology dependent partial coverage
  - ~70-85% for single link failure



- **No local LFAP exists**
- **R1** and **R2** pre-compute next hops **R2** and **R3**, respectively, for their traffic destined to **R5**
- **R5** and **R4** pre-compute next hops **R4** and **R3**, respectively, for their traffic destined to **R1**
- Upon failure detection, this info is sent to R2 and R4 (i.e., X=1)

## Extensions to local LFAP

- X-hop neighborhood parameter (e.g., X=1 represents 1-hop neighborhood)
  - routing tables of nodes within X-hop neighborhood are locally calculated (use LSDB and calculate SPT for X-hop neighbors – no information exchange among nodes)
  - does not affect convergence time since all LFAPs are pre-computed
  - interoperability can be supported if routers can have different X
    - router should disseminate parameter X at the beginning – e.g., for router with X=0, rLFAP is not supported
    - router with X=0 will be excluded from X-hop neighborhood even they are physically in neighborhood
- Failure notification mechanism
  - a new packet format including interface identifier field
  - assign as a control packet for expedite forwarding
  - send redundant failure notifications to increase reliability against a lost (receiver will use only the first notification arrived, others will be ignored)
- All LFAPs are installed locally (no information exchange other than failure notification)

# rLFAP Benefit

- Realistic topologies using BRITE topology generator
- N: # of nodes in network
- $E_{\text{mean}}$ : average # of outgoing edges per node
- Coverage depends on  $E_{\text{mean}}$  rather than N
- 100% coverage using small neighborhood size (i.e., X=2)

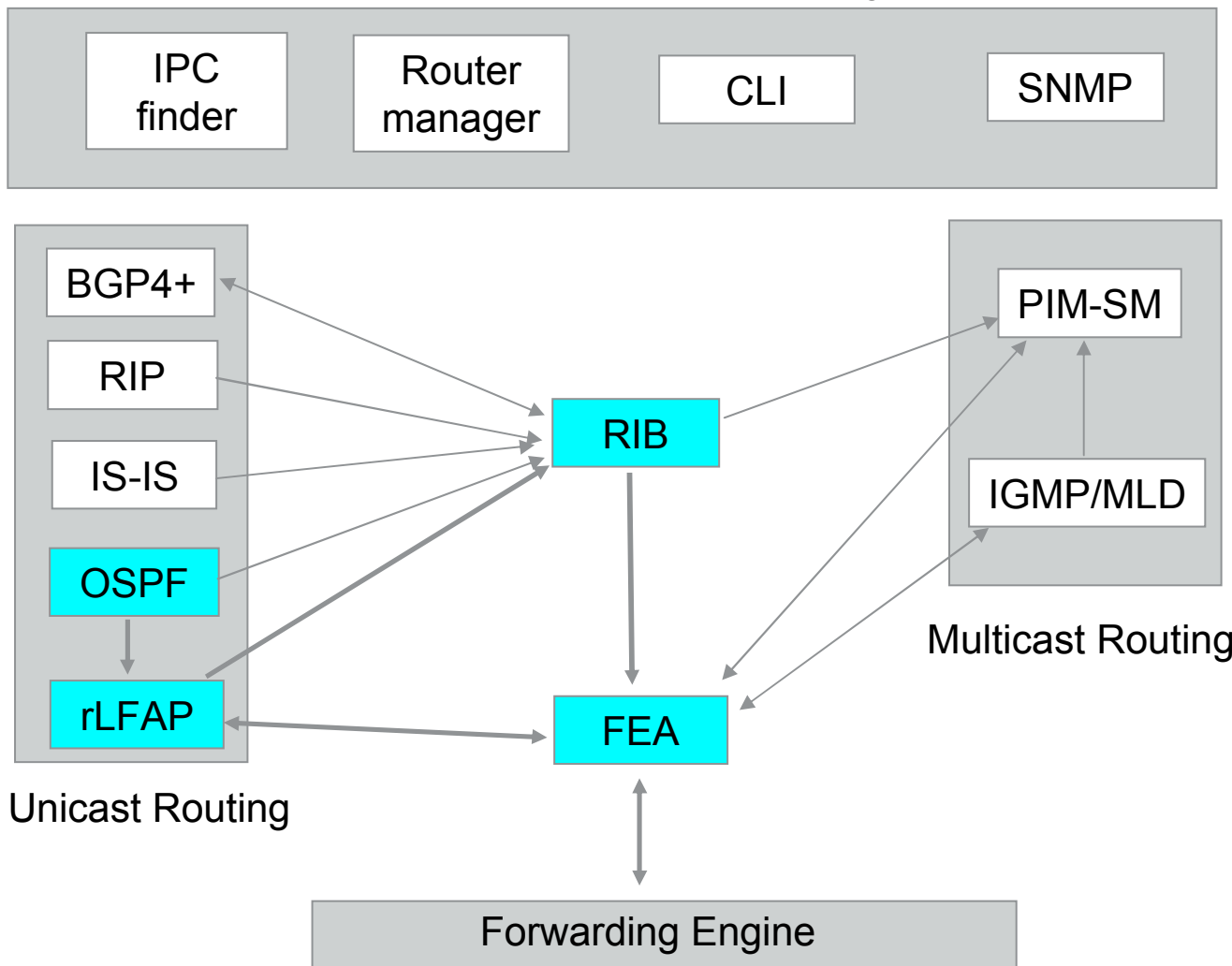
	N	$E_{\text{mean}}$	LFAP Coverage Percentage (%)		
			X=0	X=1	X=2
p (add)=0.01 beta=0.01	20	3.64	82.39	98.85	100.0
	50	3.86	82.10	98.69	100.0
	100	3.98	83.21	98.03	100.0
p (add)=0.05 beta=0.05	20	3.70	85.60	99.14	100.0
	50	4.01	84.17	99.09	100.0
	100	4.08	83.35	98.01	100.0
P (add)=0.1 Beta=0.15	20	5.52	93.24	100.0	100.0
	50	6.21	91.46	99.87	100.0
	100	6.39	91.17	99.86	100.0

	N	$E_{\text{bar}}$	Coverage Percentage (%)		
			X=0	X=1	X=2
p (add)=0.42 beta=0.62	154 (AT&T)	6.88	91.04	99.81	100.0
	30 (DFN)	8.32	93.76	100.0	100.0

# rLFAP in XORP

REFERENCE: [www.xorp.org](http://www.xorp.org)

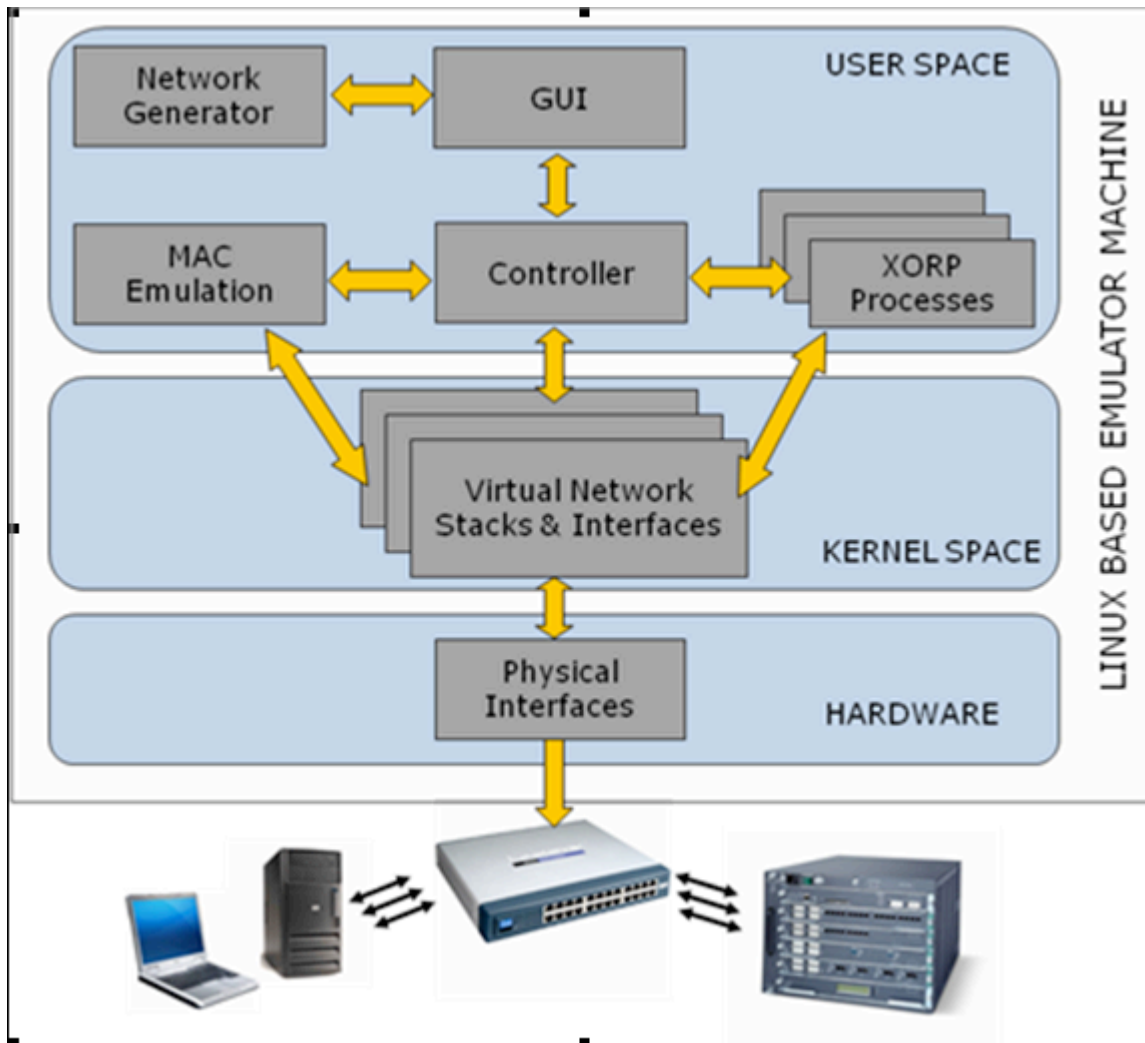
Management processes



## rLFAP

- Receive LSDB from OSPF
- Calculate LFAPs
- Verify interfaces via FEA
- Upon failure detection
  - Send failure notification via FEA
  - Install LFAPs to RIB
- Upon failure notification reception
  - Install LFAPs to RIB

## WISER emulation tool



- **Modified Fedora Core 8 kernel for Virtual Network Stacks & Interfaces**
- **Support unicast and multicast routing protocols through XORP**
- **Support 100 nodes in a single box**
- **Interoperability with External Devices**
- **Wireless MAC emulation**

# WISER GUI

WISER Emulation Tool
\_ □ ×

File Mode Run

**Satellite (node #16):**  
 Name: Ka\_Band\_1  
 Type: KA-SATCOM

Pointer coordinates (lon, lat): -110.590, 37.876

**Display**

Link color:  None  Schedule  Demand  Bit error ratio  Bandwidth  Load

Hide satellite links  Hide zero demand links Show schedules

Show only net group: All

**Mobility**

Reset

Pause time flow

Normal time flow

Time flow x10

Time Flow x100

emulation time

00:00:00.000

**Zoom**

**Node/Link Info**

Node #4:  
 Name: 4-94FA (MLRS)\_TOC  
 Type: TCN-E  
 Interface: VIRTUAL  
 Position (lon, lat): -110.668

Mode: running emulation | Connected to: 192.4.20.188 | Scenario file name: none

BEFORE dev 4.6.4 FAILED (OSPF routes)

AFTER dev 4.6.4 FAILED (OSPF + rLFAP routes)

```

Message from LANforge-Server
Routing table for Virtual Router: Router-4 (4)
10.2.4.0/24 dev 2.4.4 scope link
10.2.5.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.2.2.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.2.3.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.3.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.3.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 3 notify
10.1.4.0/24 dev 1.4.4 scope link
10.1.5.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.1.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.2.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.6.7.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 2 notify
10.6.6.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 2 notify
10.7.8.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.7.7.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.6.9.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 2 notify
10.6.8.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 2 notify
10.4.5.0/24 dev 4.5.4 scope link
10.4.4.0/24 dev br4 scope link
10.4.7.0/24 dev 4.7.4 scope link
10.4.6.0/24 dev 4.6.4 scope link
10.5.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.11.14.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.11.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
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10.10.14.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 5 notify
10.10.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.10.12.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.10.13.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
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10.10.11.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.9.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 3 notify
10.9.12.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 3 notify
10.9.13.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 3 notify
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10.8.8.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 3 notify
10.15.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.14.14.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 5 notify
10.13.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.13.13.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.12.15.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.12.14.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.12.13.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
10.12.12.0/24 via 10.4.6.6 dev 4.6.4 proto xorp metric 4 notify
OK

```

```

Message from LANforge-Server
Routing table for Virtual Router: Router-4 (4)
10.2.4.0/24 dev 2.4.4 scope link
10.2.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.2.2.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.2.3.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.3.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.3.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 3 notify
10.1.4.0/24 dev 1.4.4 scope link
10.1.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.1.1.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.2.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.6.7.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 2 notify
10.6.6.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 3 notify
10.7.8.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.7.7.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.6.9.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 3 notify
10.6.8.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 3 notify
10.4.5.0/24 dev 4.5.4 scope link
10.4.4.0/24 dev br4 scope link
10.4.7.0/24 dev 4.7.4 scope link
10.4.6.0/24 dev 4.6.4 scope link
10.5.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.11.14.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.11.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.11.13.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.11.11.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.10.14.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 6 notify
10.10.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.10.12.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.10.13.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.10.10.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 6 notify
10.10.11.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.9.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 4 notify
10.9.12.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 4 notify
10.9.13.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 4 notify
10.9.11.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 4 notify
10.9.9.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 4 notify
10.8.8.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 3 notify
10.15.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.14.14.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 6 notify
10.13.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.13.13.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.12.15.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.12.14.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.12.13.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
10.12.12.0/24 via 10.4.7.4 dev 4.7.4 proto xorp metric 5 notify
OK

```

28 LFAPs are successfully installed

RIB update time for 28 LFAPs is ~5-7ms





## ■ ■ ■ Convergence results

- rLFAP implementation in XORP
  - Remote LFAP computation within X-hop is completed
    - X is a configurable parameter
    - It is set to the same number for all nodes
  - LFAP installation to RIB is implemented
  - Failure notification mechanism is being implemented
  - Failure detection mechanism (similar to BFD) is being implemented
- 7 XORP processes (e.g., xorp\_rtrmgr, xorp\_ospfv2, xorp\_rlfap, etc.) for each virtual router
  - 105 processes for 15-node topology in a single box
- RIB update times are ~5-7ms for 28 LFAPs for RT4 and ~4-6ms for 14 LFAPs
- Number of LFAP updates will be less for remote routers (routes affected from a remote failure will be subset of routes affected from a local failure)
  - Implies that less time required for LFAP installation in remote router compared to LFAP installation in router local to failure

## ■ ■ ■ Switching from LFAPs to primary paths

- IGP convergence from temporary alternate paths to primary routes (e.g., OSPF routes) should also be loop free
- What percentage of rLFAP routes are exactly the same as OSPF new routes after failure?
  - Results show that the percentage of the routes that is the same increases as X increases (For X=infinity, rLFAP paths = OSPF paths)
- Safe convergence from LFAPs to OSPF when OSPF new routes are calculated

```

Message from LANforge-Server
Routing table for Virtual Router: Router-4 (4)
10.2.4.0/24 dev 2.4.4 scope link
10.2.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.2.2.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.2.3.0/24 via 10.2.4.2 dev 2.4.4 proto xorp metric 2 notify
10.3.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.3.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 3 notify
10.1.4.0/24 dev 1.4.4 scope link
10.1.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.1.1.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.2.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.1.3.0/24 via 10.1.4.1 dev 1.4.4 proto xorp metric 2 notify
10.6.7.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.6.6.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 3 notify
10.7.8.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.7.7.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 2 notify
10.6.9.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 3 notify
10.6.8.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 3 notify
10.4.5.0/24 dev 4.5.4 scope link
10.4.4.0/24 dev br4 scope link
10.4.7.0/24 dev 4.7.4 scope link
10.5.5.0/24 via 10.4.5.5 dev 4.5.4 proto xorp metric 2 notify
10.11.14.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
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10.11.13.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.11.11.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.10.14.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 6 notify
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10.9.13.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 4 notify
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10.8.8.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 3 notify
10.15.15.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.14.14.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 6 notify
10.13.15.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.13.13.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.12.15.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.12.14.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.12.13.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
10.12.12.0/24 via 10.4.7.7 dev 4.7.4 proto xorp metric 5 notify
    
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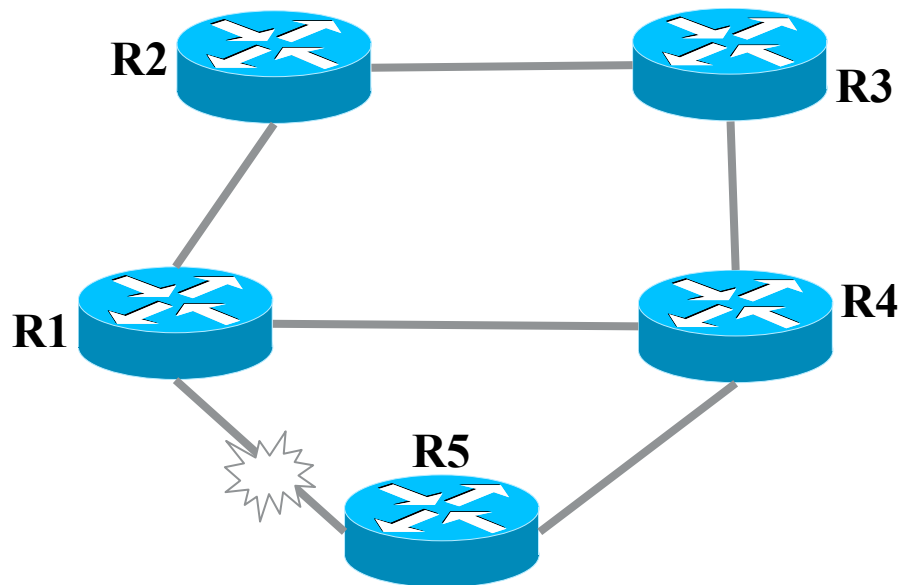
```

Message from LANforge-Server
Routing table for Virtual Router: Router-6 (6)
10.2.4.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 3 notify
10.2.5.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.2.2.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.2.3.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.3.5.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.3.3.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 5 notify
10.1.4.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 3 notify
10.1.5.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.1.1.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.1.2.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.1.3.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.6.7.0/24 dev 6.7.6 scope link
10.6.6.0/24 dev br6 scope link
10.7.8.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 2 notify
10.7.7.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 2 notify
10.6.9.0/24 dev 6.9.6 scope link
10.6.8.0/24 dev 6.8.6 scope link
10.4.5.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 3 notify
10.4.4.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 3 notify
10.4.7.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 2 notify
10.5.5.0/24 via 10.6.7.7 dev 6.7.6 proto xorp metric 4 notify
10.11.14.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.11.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.11.13.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.11.11.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.10.14.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 4 notify
10.10.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.10.12.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.10.13.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
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10.10.11.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.9.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 2 notify
10.9.12.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 2 notify
10.9.13.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 2 notify
10.9.11.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 2 notify
10.9.9.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 2 notify
10.8.8.0/24 via 10.6.8.8 dev 6.8.6 proto xorp metric 2 notify
10.15.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.14.14.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 4 notify
10.13.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.13.13.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.12.15.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.12.14.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.12.13.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
10.12.12.0/24 via 10.6.9.9 dev 6.9.6 proto xorp metric 3 notify
    
```

For 15-node scenario, results showed that LFAPs are the same as OSPF new routes after failure

OSPF updates to RIB are safe (does not need to be coordinated)

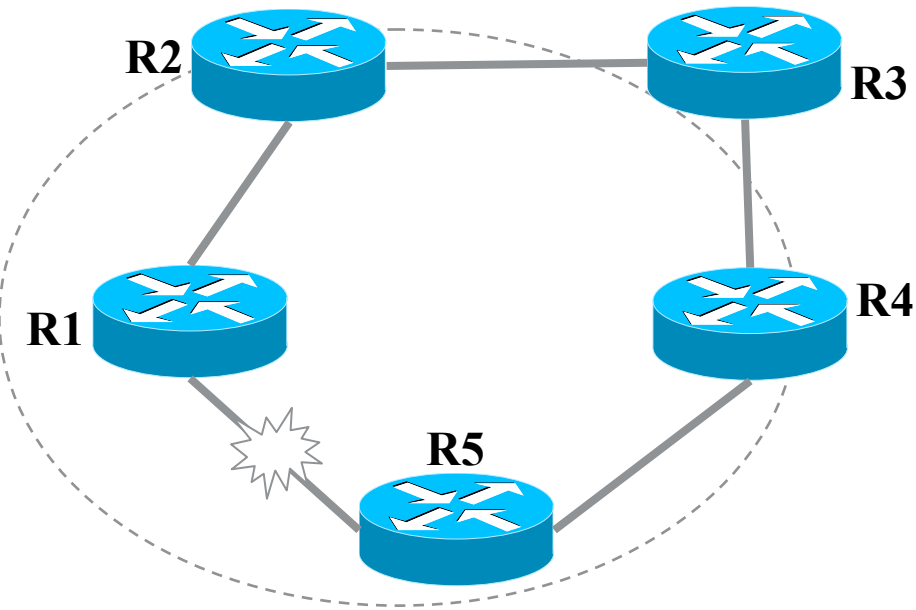
# Loop-free RPF for Multicast Fast Reroute - I



## LAB EXPERIMENTS

- Multicast traffic from sender host connected to R1 to receiver host connected to R5
  - Assume (S,G) represents this session
- Using default COTS router's timers, PIM-SM convergence took longer than OSPF (~40 seconds) after a failure
  - Multicast requires not only unicast convergence but also multicast tree repair (e.g., PIM Join messages)
- The same experiment is repeated but multicast fast reroute enabled
  - R5 pre-computes that new RPF will be R4 if link R1-R5 fails (loop-free)
  - After rLFAP repairs unicast routing, R4 is installed as a new RPF node for this session (S,G) (e.g., static RPF)
  - It took about a second to convergence
    - Multicast fast reroute as external process

# Loop-free RPF for Multicast Fast Reroute - II



- No loop-free RPF for the multicast session from R1 to R5 if link R1-R5 fails
- rLFAP repairs unicast routes so that R4 becomes a loop-free RPF for R5 to receive multicast session (S,G)
- Multicast fast reroute within XORP for sub-100 ms convergence