EBERHARD KARLS UNIVERSITÄT TÜBINGEN

FACULTY OF SCIENCE
Communication Networks

Robust LFA Protection for Software-Defined Networks (RoLPS)

Daniel Merling, **Steffen Lindner**, Michael Menth

http://kn.inf.uni-tuebingen.de

Agenda

- Motivation
- LFAs: State of the Art
- Robust LFA Protection for Software-Defined Networks (RoLPS)
- Evaluation
- Hardware Prototype

Motivation

- Packet forwarding in networks is disrupted when a next-hop becomes unreachable
  - Link failure
  - Node failure

- Upon failure detection, IGP or controller recomputes forwarding rules
  - Failure detection & computation takes time

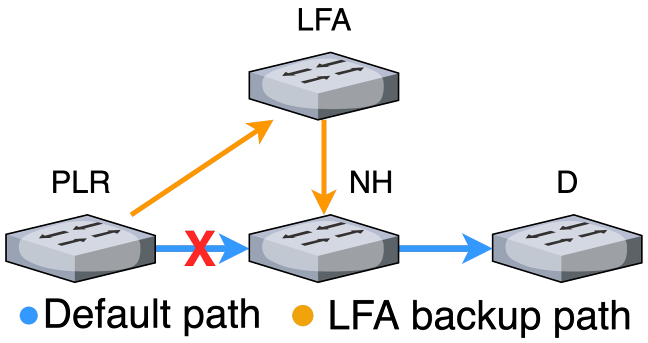
- Fast Reroute (FRR) mechanisms are used in IP networks to quickly reroute packets
  - Pre-computed backup paths are used while forwarding entries are recomputed

- Desirable: FRR in SDN without controller interaction
  - High coverage
  - Limited forwarding table sizes in SDN forwarding devices

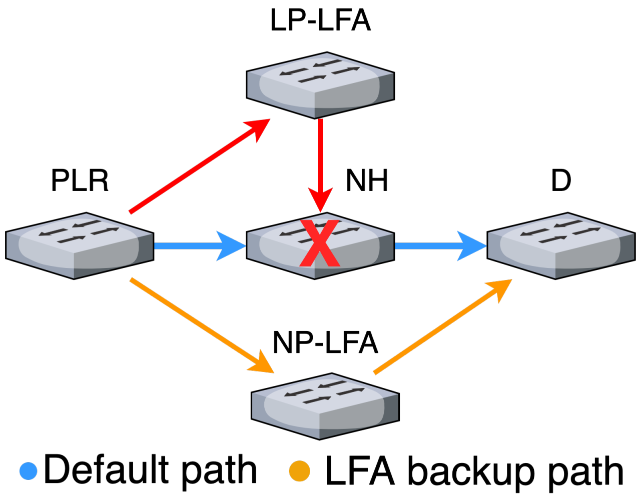
LFAs: State of the Art (I)

- Loop-free alternates (LFAs) are a well-known FRR method for IP networks
  - Traffic is sent to alternative next-hops without creating routing loops

- Two different protection levels
  - Link protection
  - Node protection



Link protecting LFA (LP-LFA)

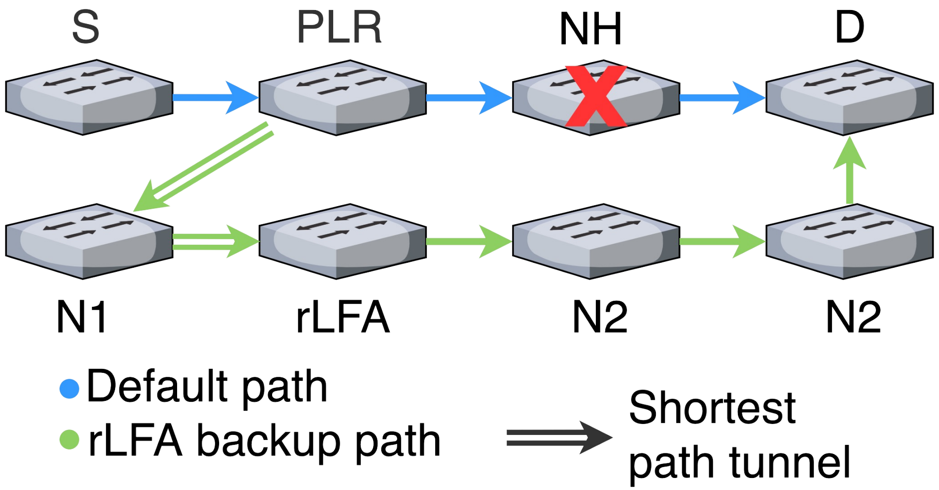


Node protecting LFA (NP-LFA)

LFAs: State of the Art (II)

- ▶ Sometimes, no (LP/NP-)LFA is available for a given destination

- ▶ Remote LFAs (rLFAs) protect more destinations than LFAs
  - Based on shortest path tunnels to remote nodes



Node protecting rLFA (NP-rLFA)

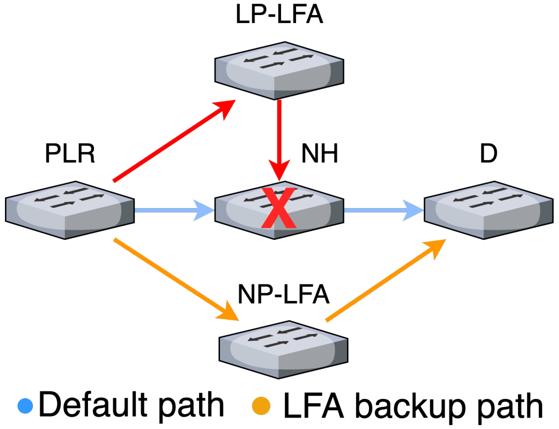
LFAs: State of the Art (III)

- Sometimes, even no (LP/NP-)rLFA is available for a given destination

- Topology-independent LFAs (TI-LFAs) leverage segment routing (SR)
  - Backup path is encoded as stack of forwarding actions in packet
  - Based on IPv6 (Srv6) or MPLS (SR-MPLS)

LFAs: State of the Art (IV)

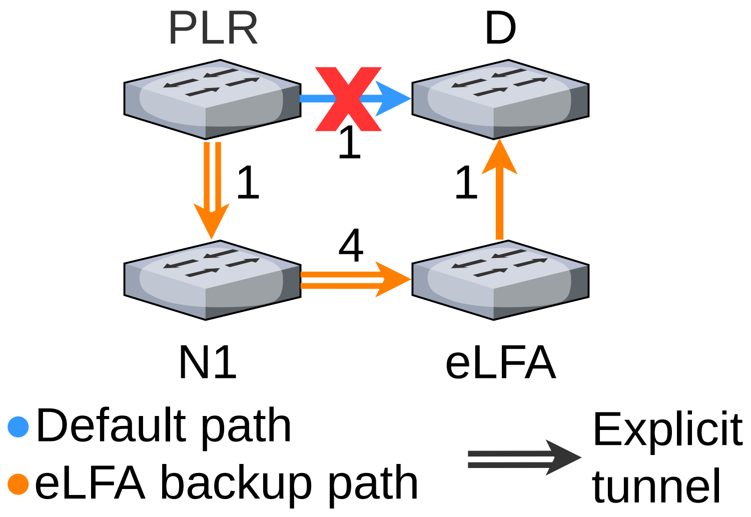
- (r)LFAs may create routing loops in failure scenarios
  - LP-LFAs in node failure cases
    - PLR might be a LP-LFA for its own LP-LFA
  - Double link failures
  - Single link and single node failure



RoLPS (I)

- Robust LFA Protection for Software-Defined Networks (RoLPS)
  - Explicit LFAs
  - Advanced Loop Detection
  - LFA Ranking

- Explicit LFAs
  - Based on explicit tunnels, e.g., unique IP addresses
  - Uses rLFAs if available
  - Multipoint-to-point tunnels for less forwarding entries



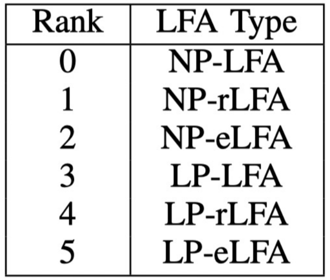
Link protecting eLFA (LP-eLFA)

RoLPS (II)

- Advanced Loop Detection
  - Packets should be dropped if they are rerouted more than *n* times
  - Requires only a counter in the packet header
  - Implementable in Openflow & P4

RoLPS (III)

- LFA Ranking
  - Controller classifies nodes for different PLRs into LP/NP-(e/r)LFAs
  - LFAs can be ranked according to their
    - protection level
      - NP is better than LP
    - Complexity
      - Simple LFAs do not require tunneling / additional forwarding entries
      - eLFAs are most complex
  - RoLPS ranks LFAs first according to their protection level

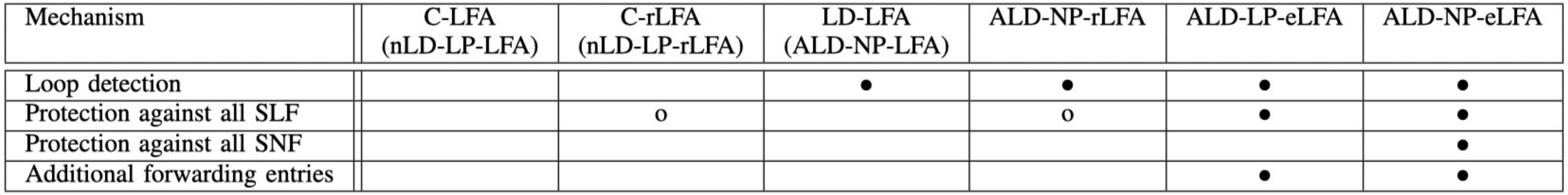


Rank	LFA Type
0	NP-LFA
1	NP-rLFA
2	NP-eLFA
3	LP-LFA
4	LP-rLFA
5	LP-eLFA

Table 1: Ranking of LFA types according to protection level and complexity. Preference is given to LFAs with lower rank number.

RoLPS (IV)

- Protection Variants
  - Many different protection possibilities (loop detection, LP/NP, (e/r)LFAs)
  - Naming scheme: {nLD, ALD}-{LP, NP}-{LFA, rLFA, eLFA}



Mechanism	C-LFA (nLD-LP-LFA)	C-rLFA (nLD-LP-rLFA)	LD-LFA (ALD-NP-LFA)	ALD-NP-rLFA	ALD-LP-eLFA	ALD-NP-eLFA
Loop detection			●	●	●	●
Protection against all SLF		o		o	●	●
Protection against all SNF						●
Additional forwarding entries					●	●

Table 2: Properties of protection variants.
Legend: o = only for unit link costs; ● = independent of link costs.

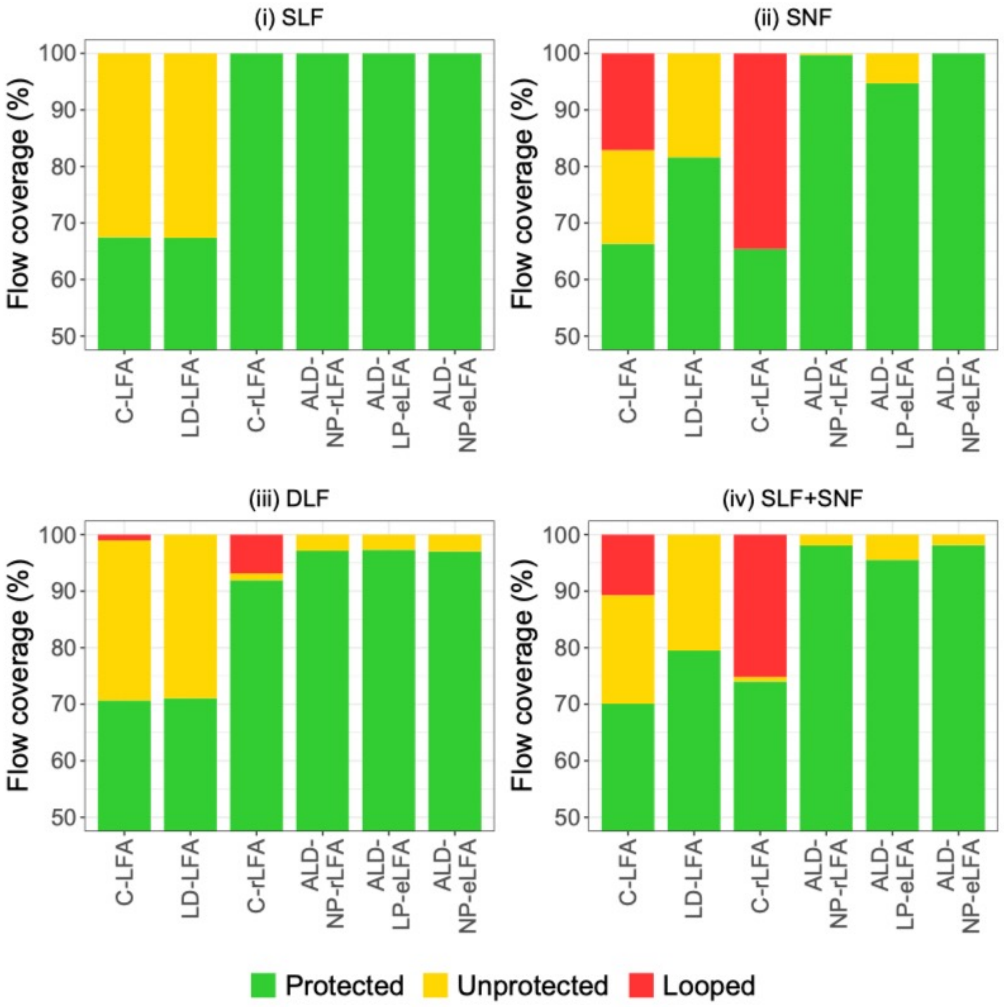
Performance Evaluation (I)

- Performance Evaluation of LFA-Based Protection
  - Evaluated on the Internet topology zoo
  - 205 wide area, commercial, research, and academic networks

- Metrics of interest
  - Protection coverage
  - Additional forwarding entries

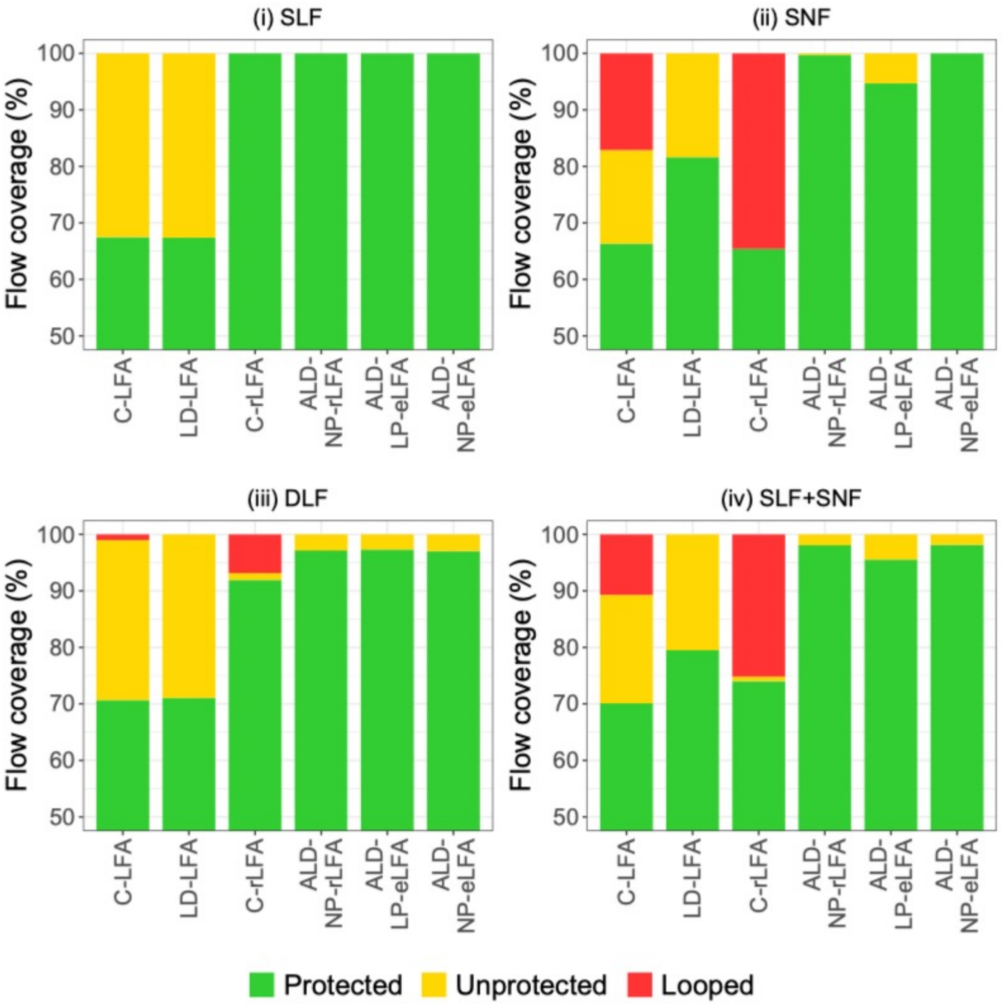
Performance Evaluation (II)

- Protected
  - Packet is successfully delivered
  - Packet is dropped to prevent a loop
- Unprotected
  - Packet is dropped although the destination is reachable
- Looped
  - Microloop was caused by local rerouting



Performance Evaluation (II)

- Single Link Failure (SLF)
  - Simple LFAs (C-LFA, LD-LFA) can not cover all single link failures
  - (r/e)LFAs cover all single link failures
- Single Node Failure (SNF)
  - LP-LFAs (C-LFA, C-rLFA) may result in routing loops
  - Only ALD-NP-eLFA covers all destinations
- Dual Link Failure (DLF)
  - Variants without loop detection (C-LFA, C-rLFA) may result in microloops
  - Simple LFAs (C-LFA, LD-LFA) have lowest coverage
- Single Link + Single Node Failure (SLF + SNF)
  - LP-LFAs (C-LFA, C-rLFA) may result in routing loops



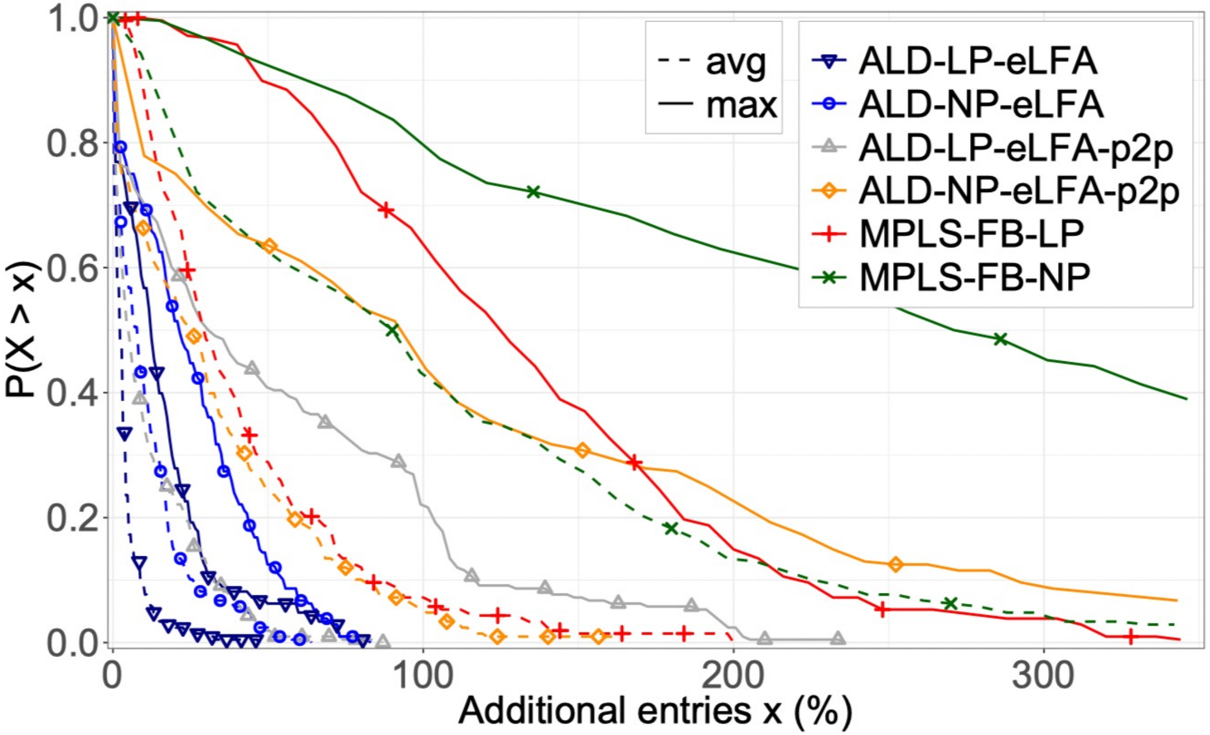
Performance Evaluation (III)

- Additional Forwarding Entries
  - LFAs and rLFAs are based on shortest paths → no additional forwarding entries
  - eLFAs require additional forwarding entries
  - Compared to MPLS-facility-backups (MPLS-FB-{LP, NP})

Performance Evaluation (III)

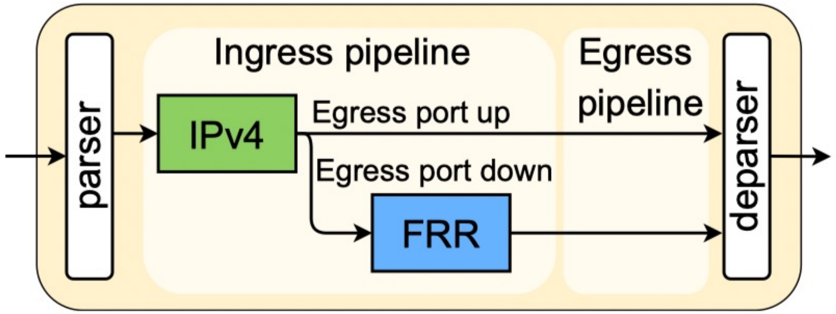
- MPLS-FB-LP
  - 55% of networks have at least one node with 120% more additional entries
  - 8% of networks have more than 100% additional entries on average

- ALD-LP-eLFA
  - No topology with a node that requires more than 80% additional entries
  - 95% of networks require less than 15% additional entries on average



Hardware Prototype (I)

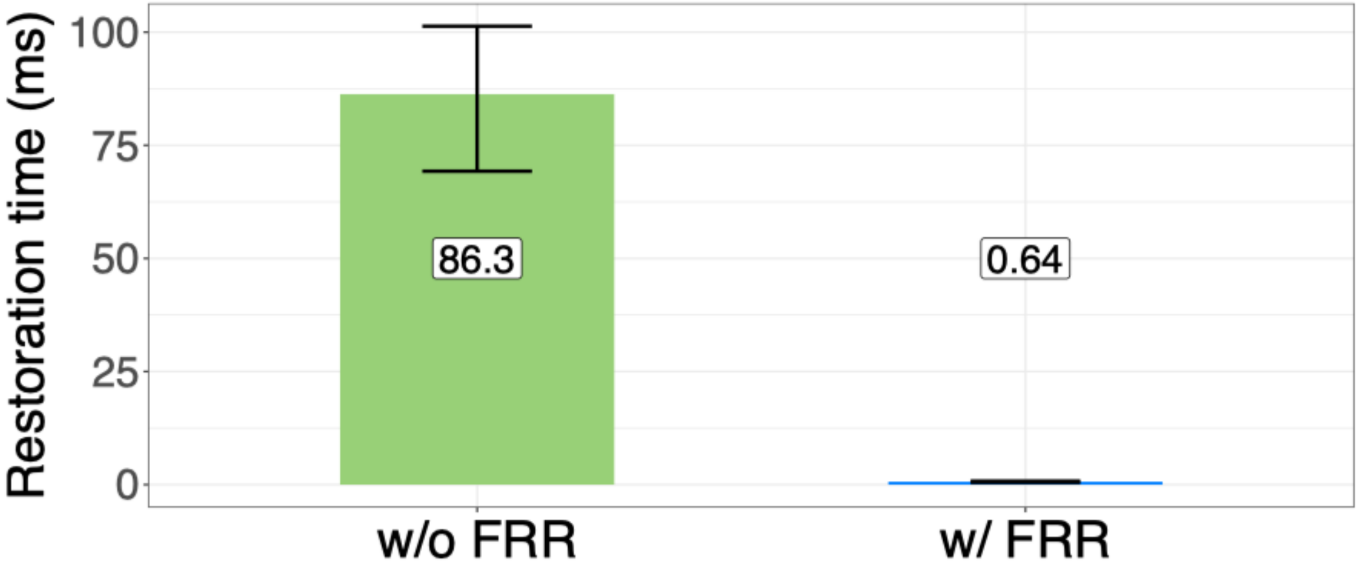
- We implemented ALD-(e/r)LFAs in P4 for the Tofino ASIC with up to 3.2 Tbit/s throughput
  - Tofino generates a special packet when ports are up/down
  - We store this information in registers to apply FRR



- RoLPS based SDN controller

Hardware Prototype (II)

- Restoration time
  - Time until traffic is received after a failure
  - With and without FRR



Conclusion

- RoLPS leverages (e/r)LFAs with advanced loop detection (ALD)
- Evaluation shows that existing (r)LFAs do not cover all destinations and may result in routing loops
- P4-based prototype that features RoLPS-based protection variants and runs at 100 Gbit/s
- Connectivity is restored in less than 1 ms

https://github.com/uni-tue-kn/p4-lfa

https://ieeexplore.ieee.org/document/9461214

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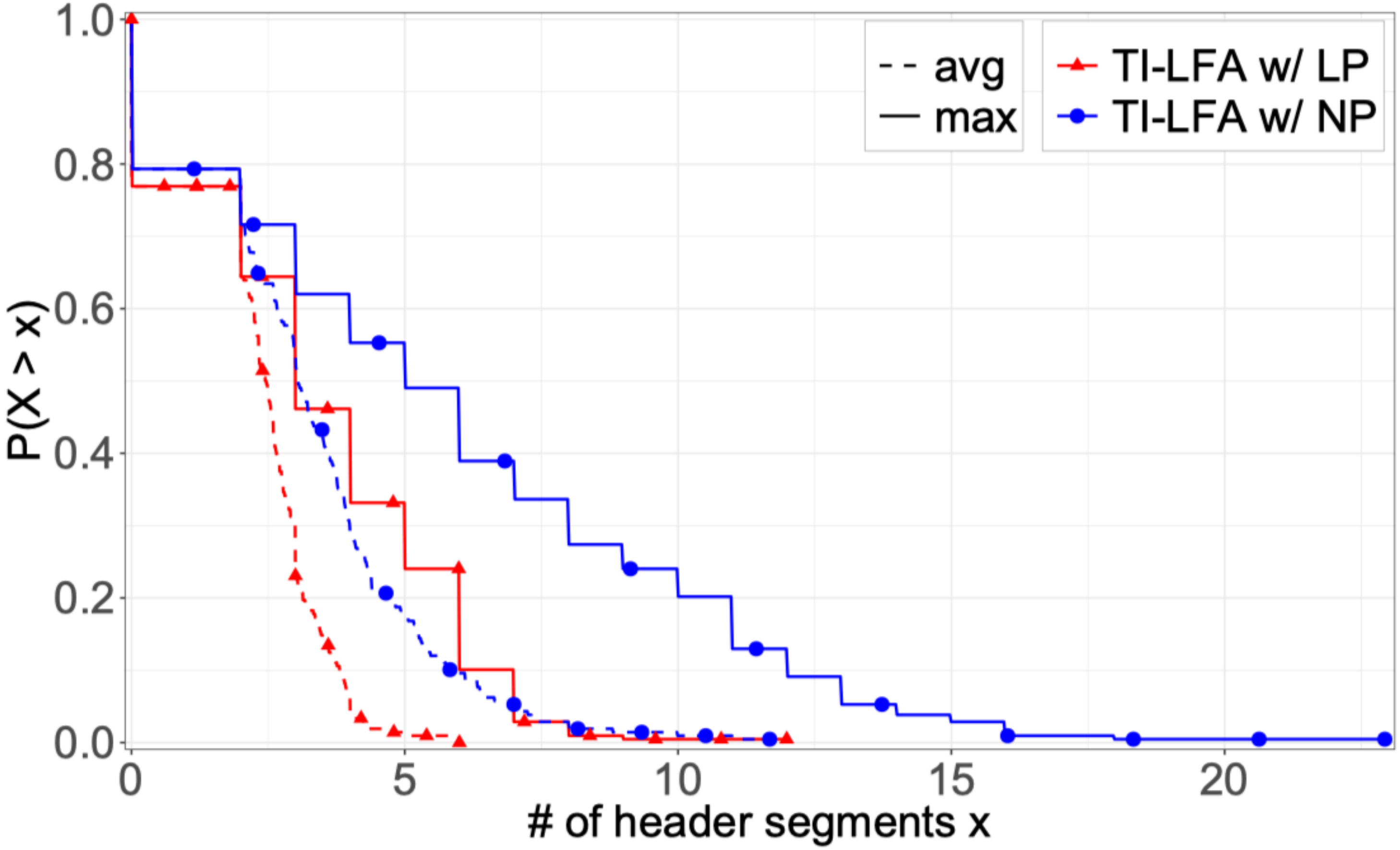
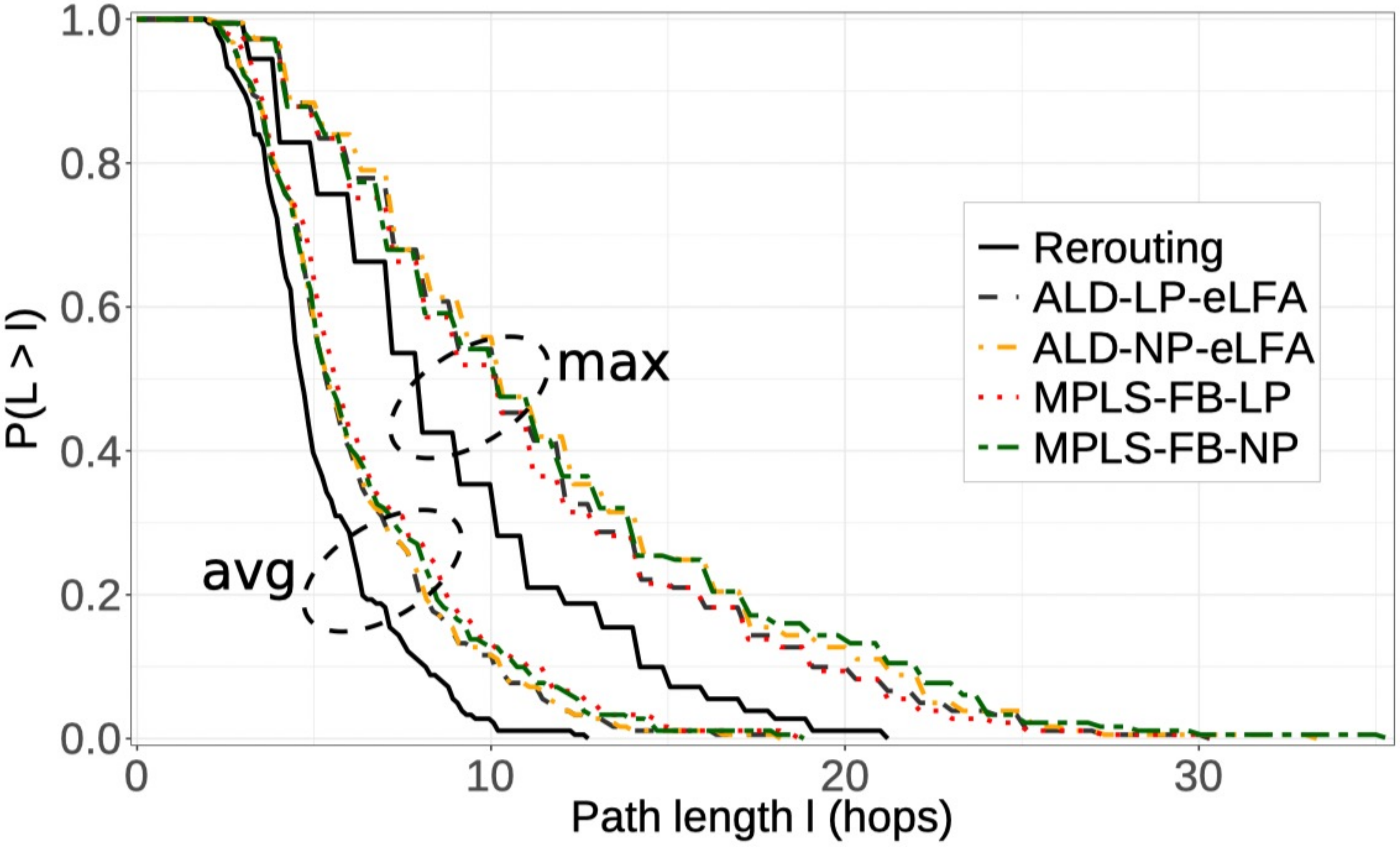
Steffen Lindner
University of Tuebingen
Faculty of Science
Department of Computer Science
Chair of Communication Networks

TI-LFA Header Stack



Backup Path Length


P(L > l)
Path length l (hops)
max
avg
Rerouting
ALD-LP-eLFA
ALD-NP-eLFA
MPLS-FB-LP
MPLS-FB-NP