Fast-Reroute based on Highly Connected Routes & More

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Research Report presented at
The 90th Meeting IFIP W.G. 10.4
Charlotte NC, USA
June 27, 2026

Agenda for this short presentation

- Fast-ReRoute based on highly-connected routes
- NFV-COIN: Network Function Virtualization + COmputing In the Network
  - In-Network Functions for Dependable Distributed Computing
- FIT-SFC: Fault- and Intrusion-Tolerant Service Function Chaining
- VCube related projects:
  - HyperPaxos: Hierarchical Consensus
  - HyperByz: A VCube that Tolerates Byzantine Faults

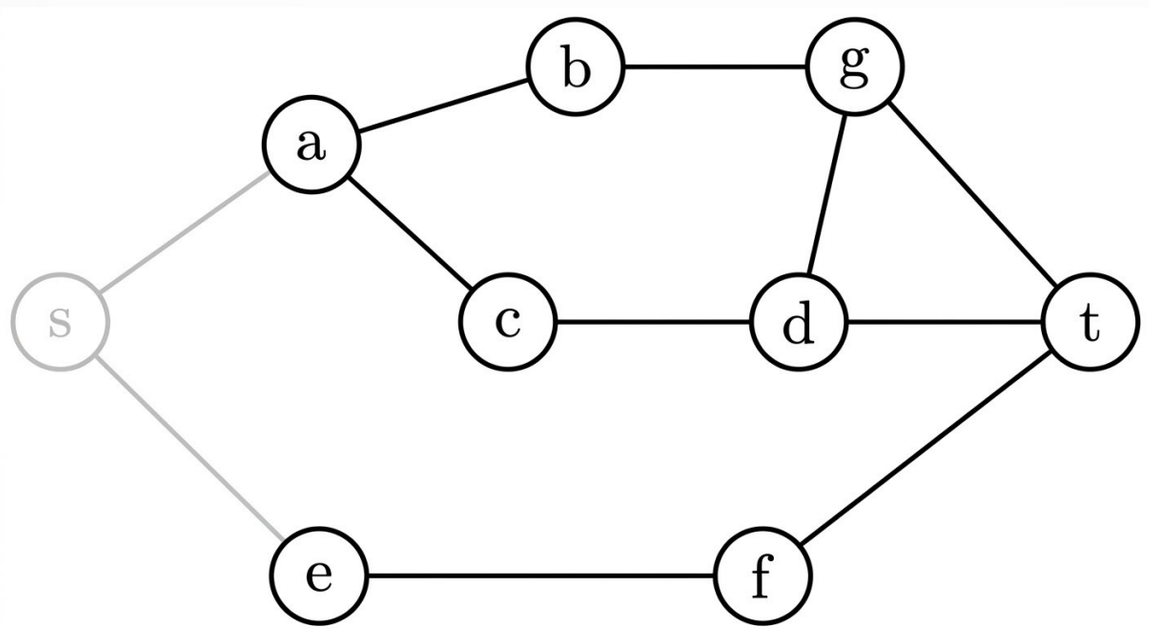
Fast-ReRoute

- Prevalent fault-tolerant routing strategy for the Internet
- The routing table must store pre-computed *primary* routes and *backup* routes to all destination
- Thus providing for immediate failover when the primary fails

Destination	Primary Route	Backup Route
Destination 1	Through neighbor A	Through neighbor B
Destination 2	Through neighbor B	Through neighbor X

FRR based on Highly Connected Routes

- Those routes present a higher probability that there is an alternative in case a link fails



FRR based on Maximum Flow Evaluation

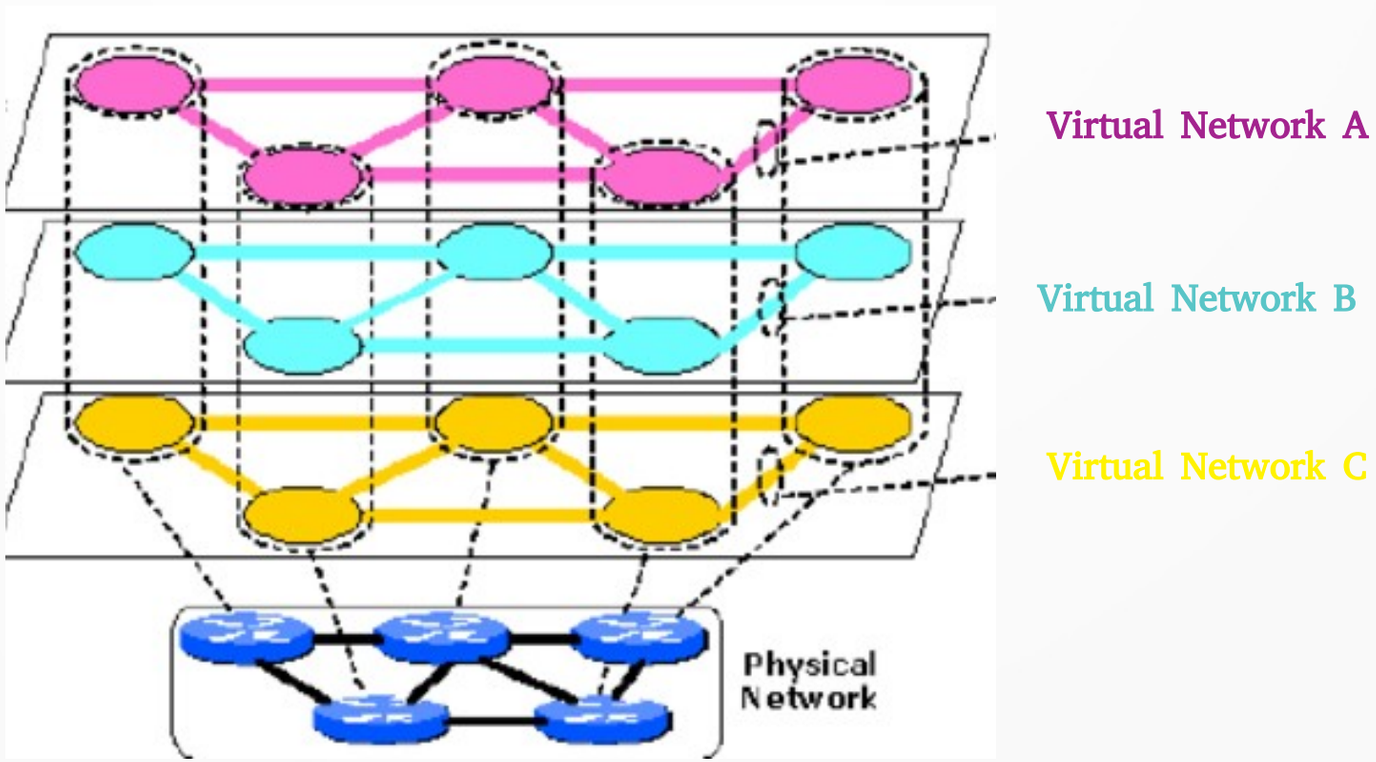
- We compute maximum flow evaluation as well as the route size to select routes that are highly connected
- Executed on several Internet topologies as well as well-known synthetic topologies
- Results look good:
  - Leon Okida, Maverson Schulze-Rosa, Elias P. Duarte Jr., "Fast Reroute with Highly Connected Routes Based on Maximum Flow Evaluation," Corr abs/arXiv:2410.10528, pp. 1-22, 2024.

Network Virtualization

- Network equipment and resources available as software using virtualization
  - A true revolution, several advantages
- Virtual networks are created, provisioned, managed and terminated in software
  - Multiple different virtual networks can co-exist on the same physical infrastructure

Network Virtualization

Virtual Networks A, B and C are on the same physical infrastructure but can run completely different protocol stacks and are mutually isolated from a security point of view



Internet Ossification: Solved! √

- The Internet currently connects around 6.12 billion human beings around the world (total pop. 8.3bi)

  → https://www.internetworldstats.com/stats.htm
- Protocols developed decades ago were threatening the evolution of the Internet
- With virtualization: the network can evolve to multiple directions at the same time, all of which can co-exist

Not only the Internet!

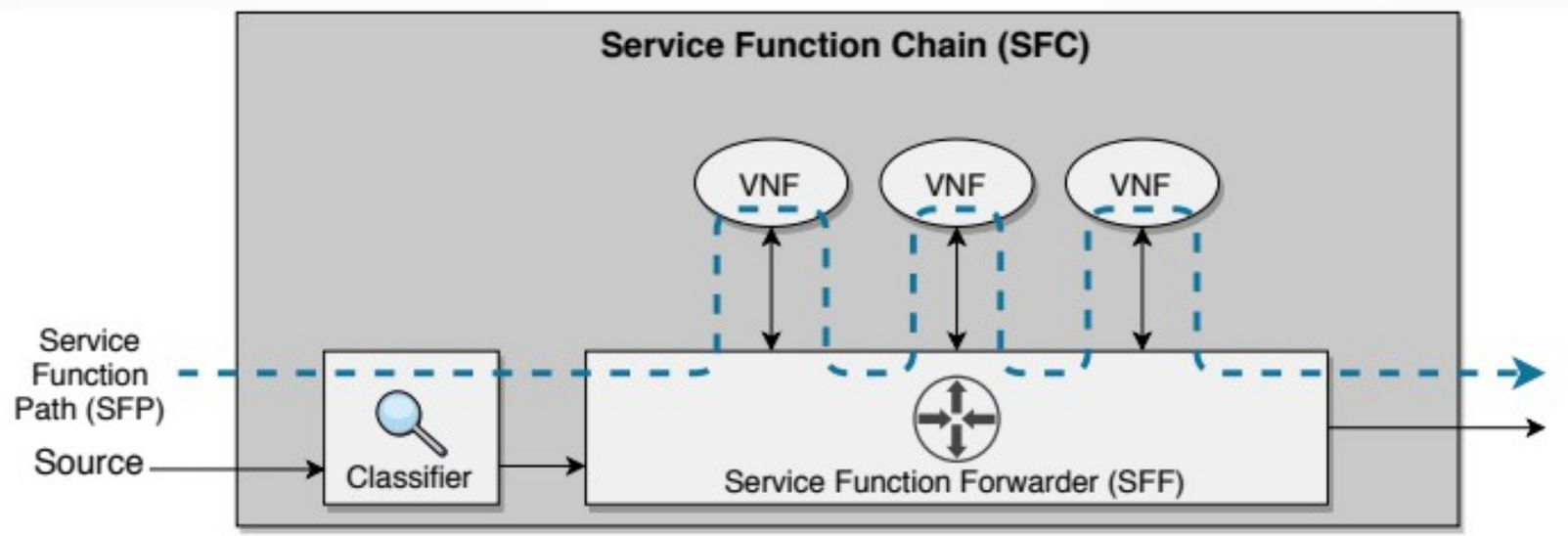
- Virtualization is changing all networks, not only the Internet

Network Function Virtualization

- Middleboxes -- also called “network appliances” or “network functions”
- They are intermediate devices: on the path from an IP source and an IP destination
- Run a myriad of services: IDS, firewall, NAT, proxies, caches,..

SFC: Service Function Chain

- Besides Individual VNFs (Virtual Network Functions)
- Complex network services can be constructed called Service Function Chains by orchestrating multiple VNFs



NFV-*COIN*: Leveraging INC with NFV

- NFV technology used to deploy novel services within the network
- Use NFV to extend the edge-cloud to the **core-edge-core continuum**
- G. Venancio, R. Turchetti, E. P. Duarte Jr., “NFV-COIN: Unleashing the Power of In-Network Computing with NFV Technology,” Journal of Internet Services and Applications (JISA), Vol. 12, No. 1, pp. 46-53, 2022.

NFV-COIN for Distributed Dependable Services

- Failure Detector
  - R. Turchetti, Elias P. Duarte Jr., "NFV-FD: Implementation of a Failure Detector Using Network Virtualization Technology," DSN-W, 2015
- Consensus
  - G. Venancio, E. Camargo, R. Turchetti, E. P. Duarte Jr., "VNF-Consensus: : A Virtual Network Function for Maintaining a Consistent Distributed SDN Control Plane," International Journal of Network Management, 2020.
- Reliable and Ordered Broadcast
  - G. Venancio, R. Turchetti, E. P. Duarte Jr., "NFV-RBCast: Enabling the Network to Offer Reliable and Ordered Broadcast Services," IEEE/SBC LADC, 2019.

Two IETF Drafts Recently Published

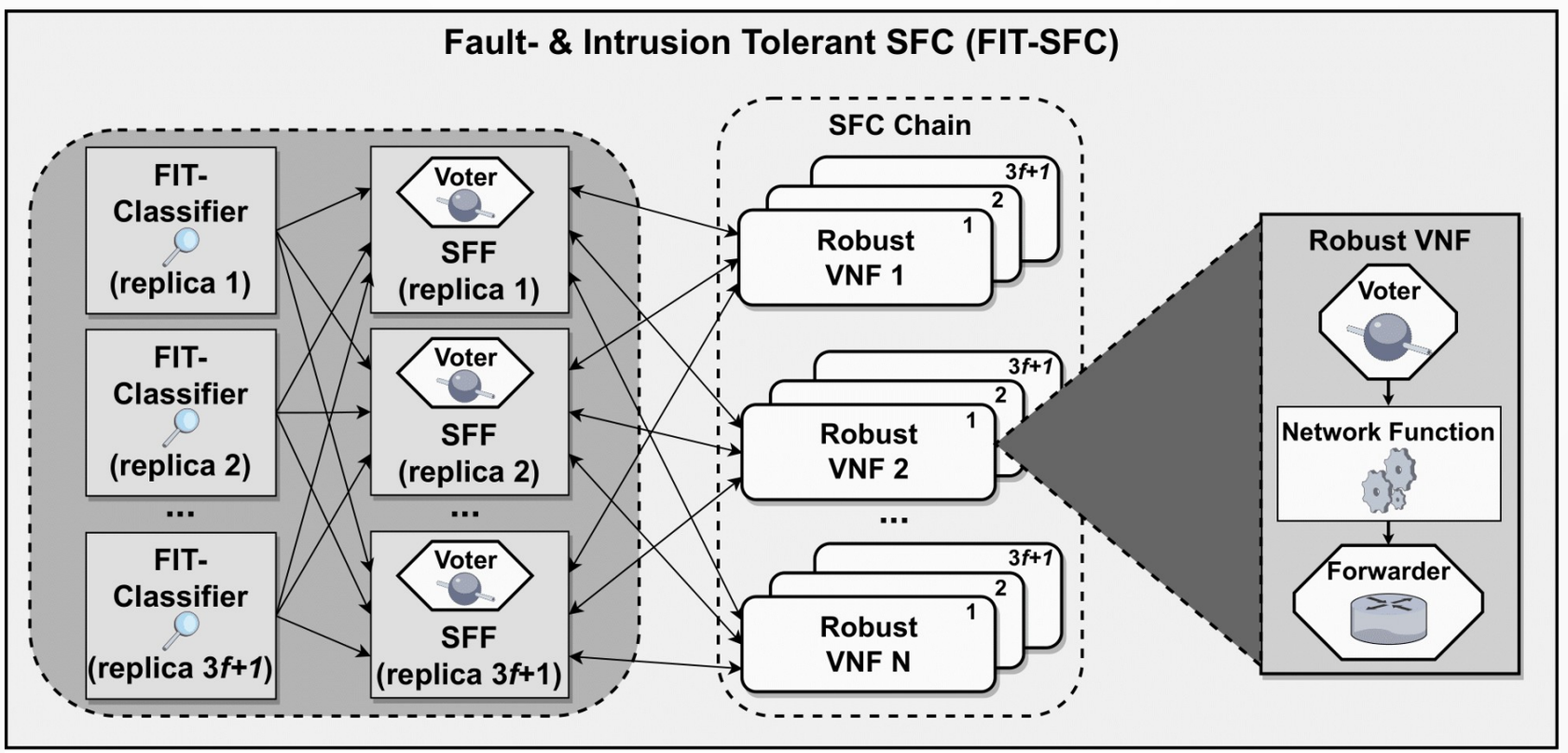
- Jaehoon Paul Jeong, Yiwen Shen, Yoseop Ahn, Younghan Kim, Elias P. Duarte Jr., Kehan Yao, **"Interface to In-Network Functions (I2INF): Problem Statement,"** IETF Draft draft-jeong-opsawg-i2inf-problem-statement, https://www.ietf.org/archive/id/draft-jeong-opsawg-i2inf-problem-statement.txt, 2026.
- Jaehoon Paul Jeong, Yiwen Shen, Yoseop Ahn, Younghan Kim, Elias P. Duarte Jr., Kehan Yao, **"A Framework for the Interface to In-Network Functions (I2INF),"** IETF Draft draft-jeong-opsawg-i2inf-framework, https://www.ietf.org/archive/id/draft-jeong-opsawg-i2inf-framework, 2026.

FIT-SFC

- Fault- and Intrusion Tolerant Service Function Chaining
- The IETF defined an SFC architecture
- Proposal: use replication to tolerate crash & Byzantine failures
- Taking into consideration the components of the architecture itself
- Giovanni Venancio, Vinicius Fulber-Garcia, José Flauzino, Eduardo Alchieri, Elias P. Duarte Jr., "Dependable Virtual Network Services: **An Architecture for Fault- and Intrusion-tolerant SFCs**," The 10th IEEE Conference on Network Functions Virtualization and Software Defined Networking (NFV-SDN'2024), pp. 1-6, 2024.

Different Types of Services: Different Requirements

- Stateless, Stateful per Flow, Stateful among Flows

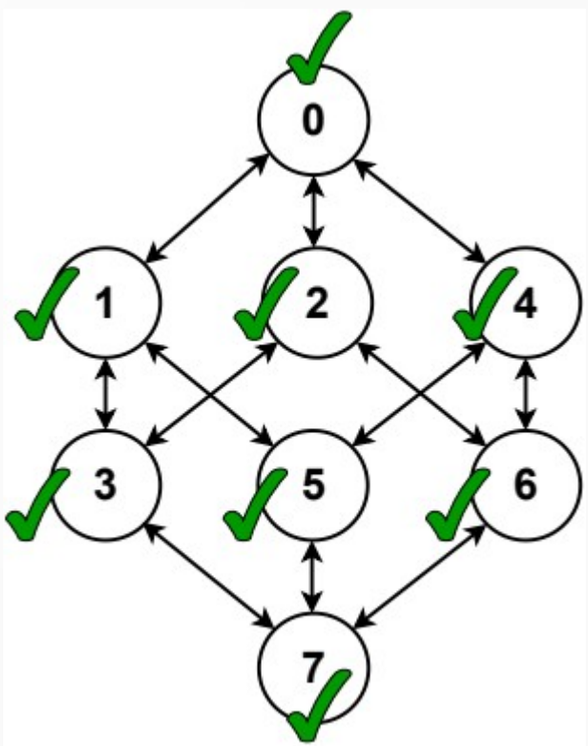


HyperPaxos: Hierarchical Consensus

- A scalable version of Paxos
  - Also working on a VCube that tolerates Byzantine Faults
- Acceptors form a vCube
- VCube is a hiearchical virtual topology
  - Scalable by definition: when

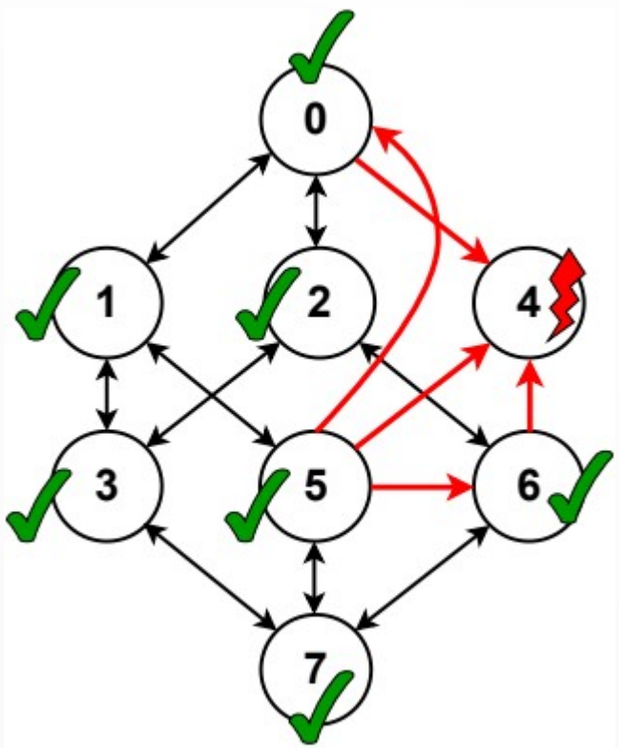
    all processes are correct →

    vCube is a hypercube



vCube: Scalable by Definition

- As processes crash: the topology autonomously reorganizes itself, maintaing several logarithmic properties



Conclusions

- This short research report highlighted a few of our projects:
  - FRR based on highly-connected routes
  - NFV-COIN: exploring the synergy of NFV & COIN, the network can support novel services in a flexible way
  - FIT: Fault- and Intrusion-Tolerant Service Function Chaining
  - VCube based algorithms: HyperPaxos & Byz-VCube

Thank you!

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