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SCIONLab: A Next-Generation Internet Testbed

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ETH zürich
Network Security Group

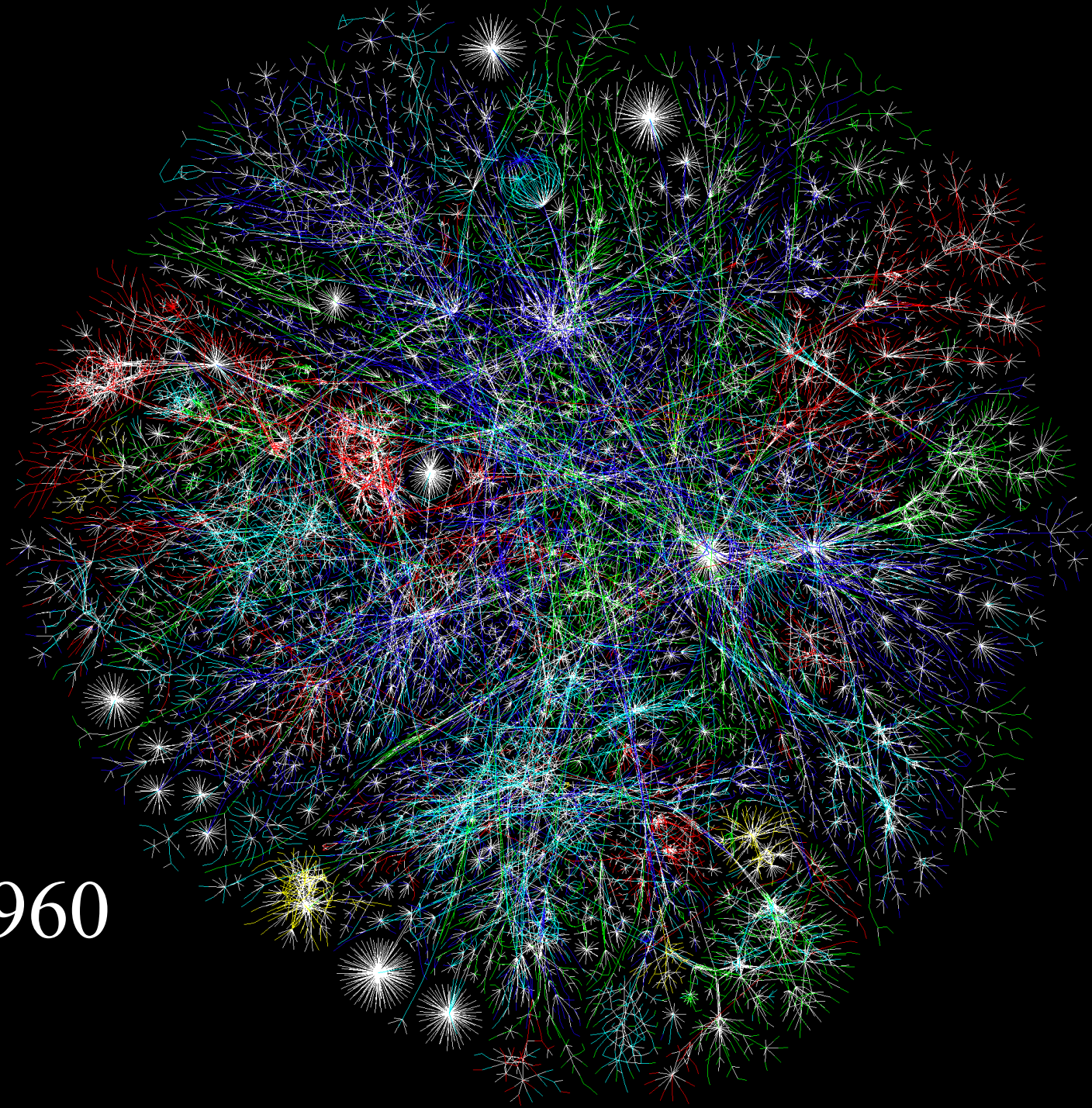
OTTO VON GUERICKE
UNIVERSITÄT
MAGDEBURG

Scientists need a proper research environment to carry out experiments to validate or refute a hypothesis

A **network testbed** for network researchers

Internet

More than 4.57 B active users
362 M registered domains
6.5 hours per day
88 TB every second
1239% growth (2000-2020)

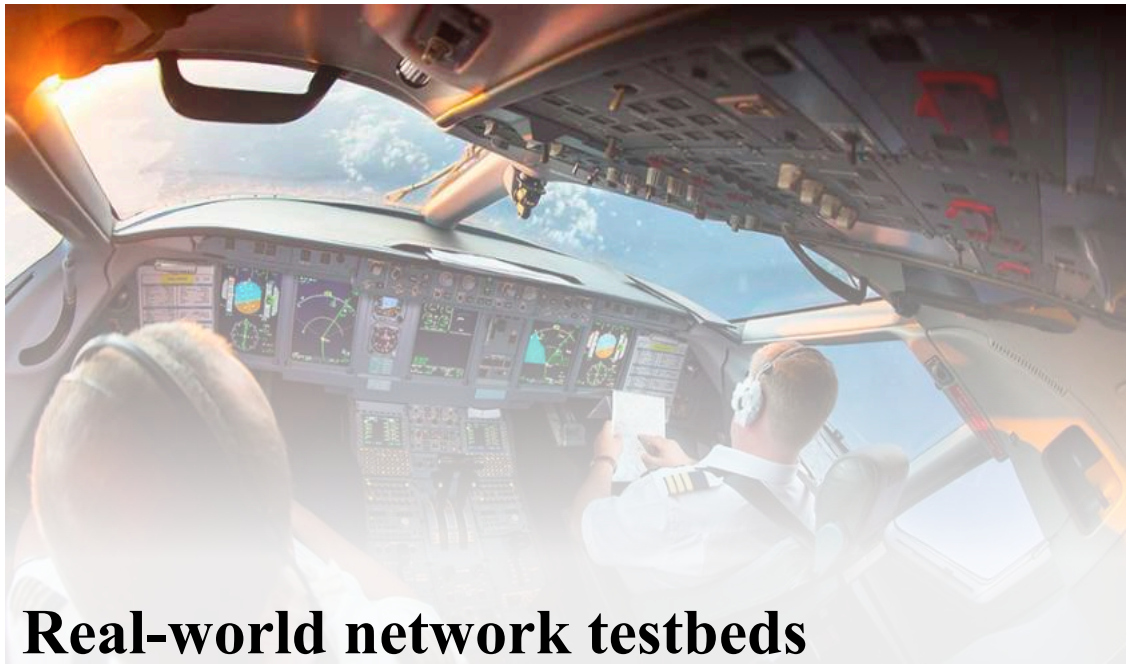


Internet was born in 1960
as a research testbed

Network Testbeds at a Glance

Network simulators & emulators

- Mimic the behavior of a live network
- Easy to conduct large-scale experiments
- Provide reproducibility
- Abstraction that cannot model all real-world aspects
- Emulab [OSDI'02], Mininet [HotNet'10]



Real-world network testbeds

- Exposure to real-world effects
- Experiments might not reproducible
- Higher cost for deployment and management
- PlanetLab [OSDI'06], VENI [SIGCOMM'06], GENI [ComNet'14], Peering [CoNEXT'19]

New Research Opportunities

Path-aware networking

- Network provides path information
- End hosts select communication paths
- Source-routing [CCR'77], Pathlet [CCR'09]

- Path transparency
- Fine-grained path control
- Fast failover
- Geofencing

Multipath communication

- End hosts select path on a per-packet basis
- MPTCP [RFC8401], QUIC [CoNEXT'17]

- High Bandwidth
- Efficient link utilization
- Improved reliability

Secure inter-domain routing

- PKI certifies control plane messages
- SCION [S&P'11], RPKI [RFC6810]

- Control-plane security
- Hijacking resilience
- DDoS resilience

Network researchers need a new playground

SCIONLab: A Next-Generation Internet Testbed

Enabling new research in computer networks, network security, and networked applications

Secure and fine-grained inter-domain routing control along with true multi-path communication

Explained: SCION in One Slide

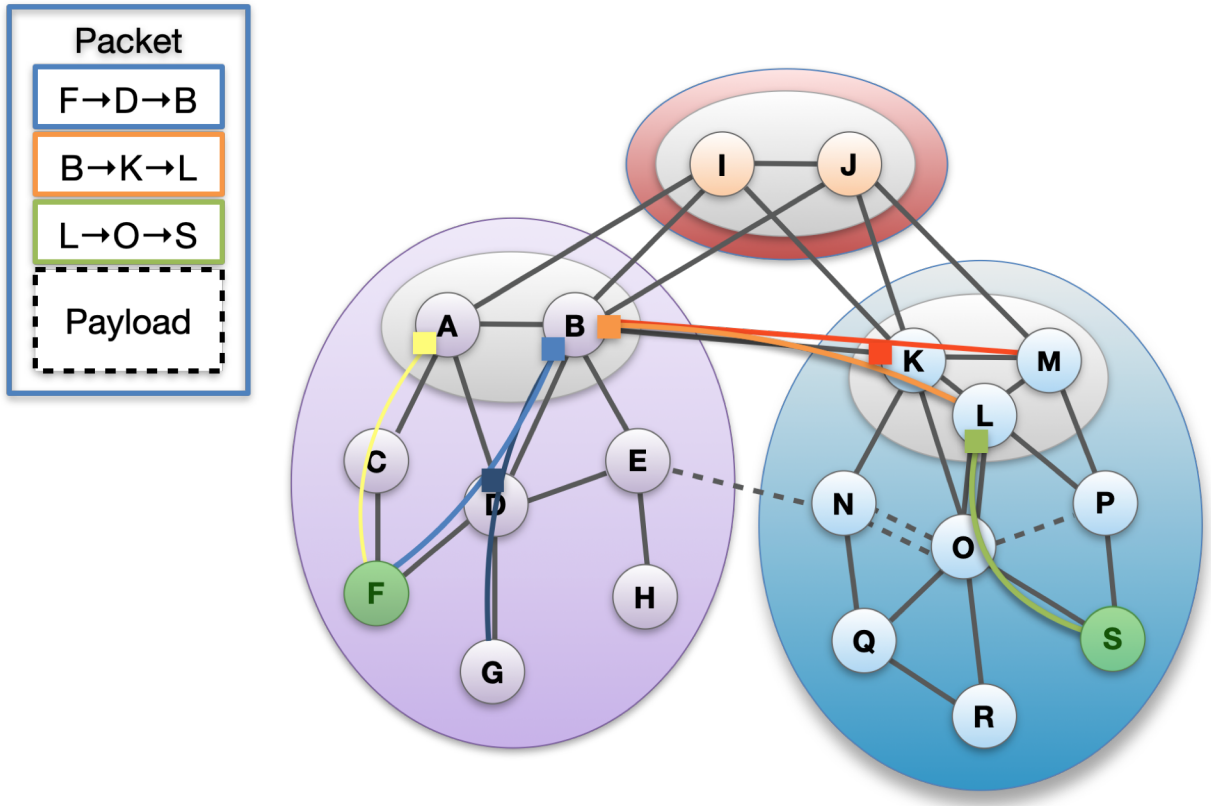
- Path-based Network Architecture

Control Plane – Routing

- Construct and disseminate path segments
  - Path exploration
  - Path registration
  - Path resolution

Data Plane – Packet forwarding

- Combine path segments for end-to-end path
- Packets contain path
- Routers forward packets based on AS path
  - Simple routers, stateless forwarding



Scalability, Control, and Isolation on Next-generation Networks

SCIONLab Overview

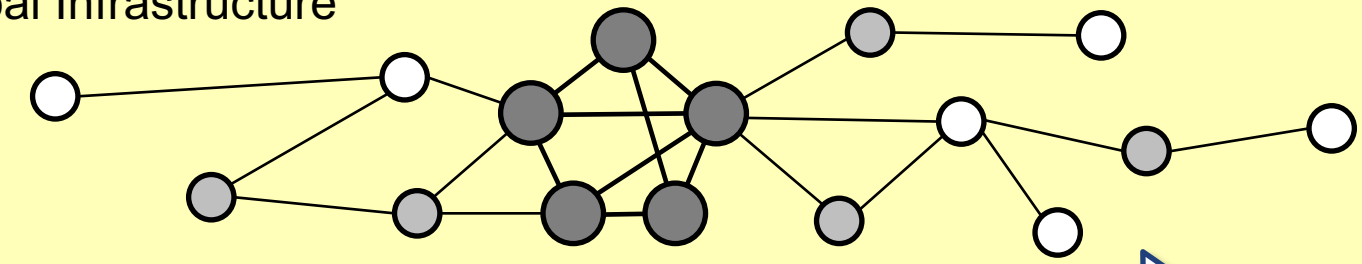
Global Infrastructure

User Infrastructure

Coordinator

SCIONLab Overview

Global Infrastructure



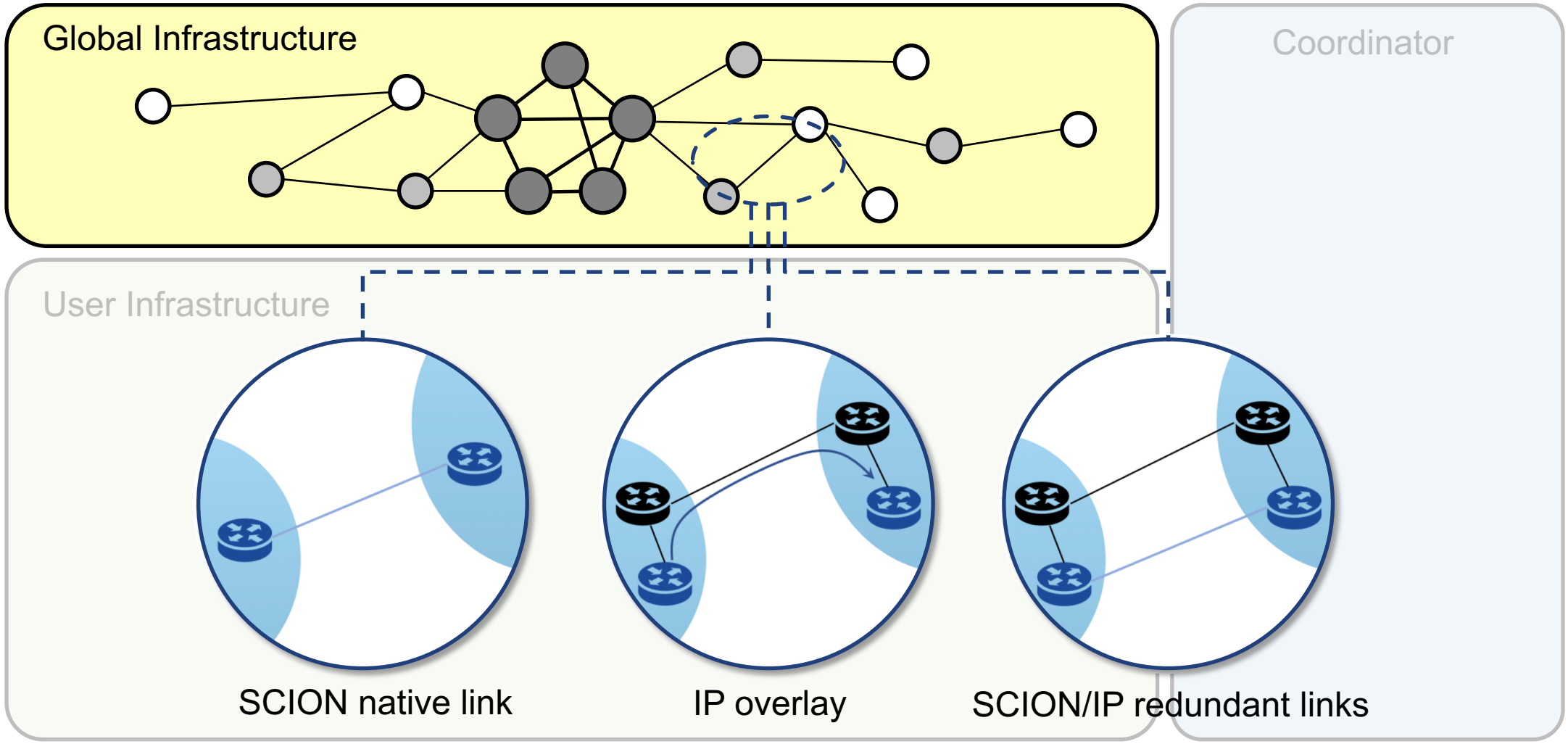
Coordinator

User Infrastructure

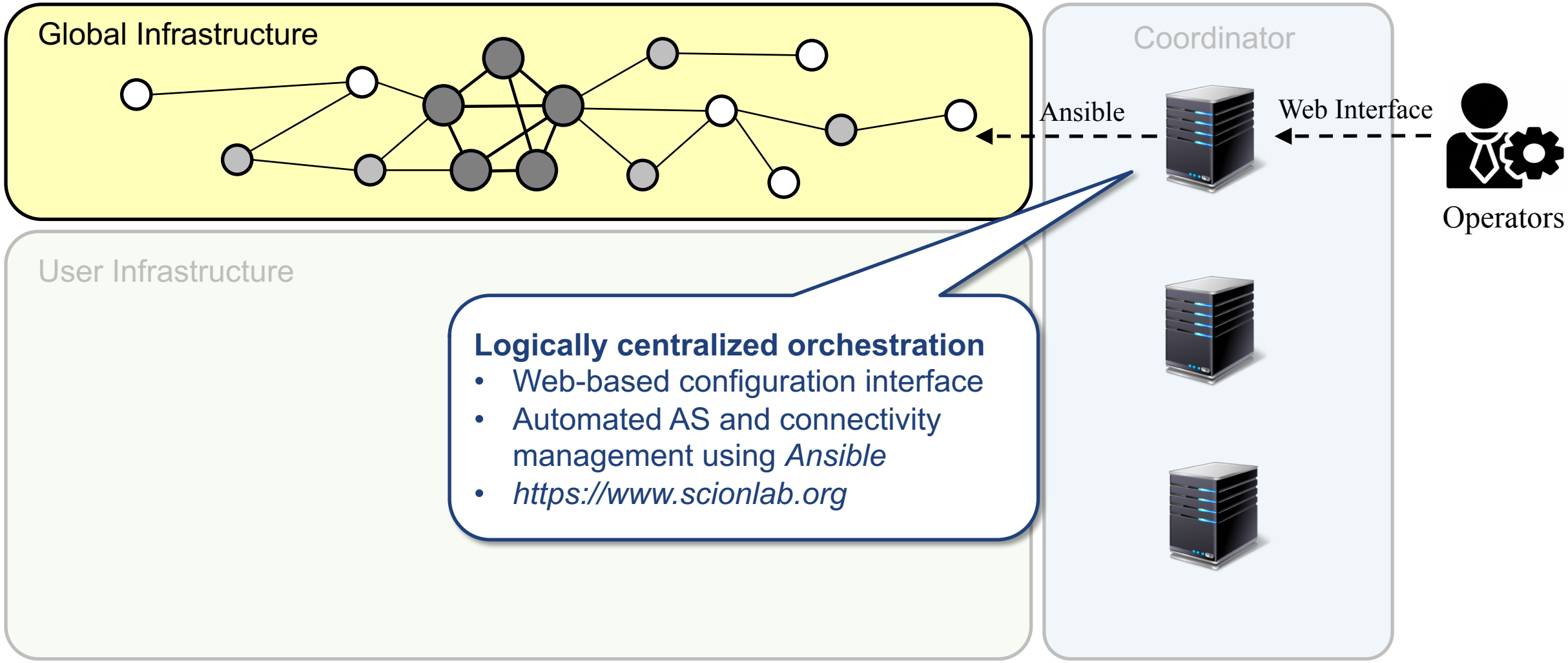
Inter-continental routing infrastructure

- Path diversity
- Rich connectivity
- Reliable communication
- Distributed attachment points

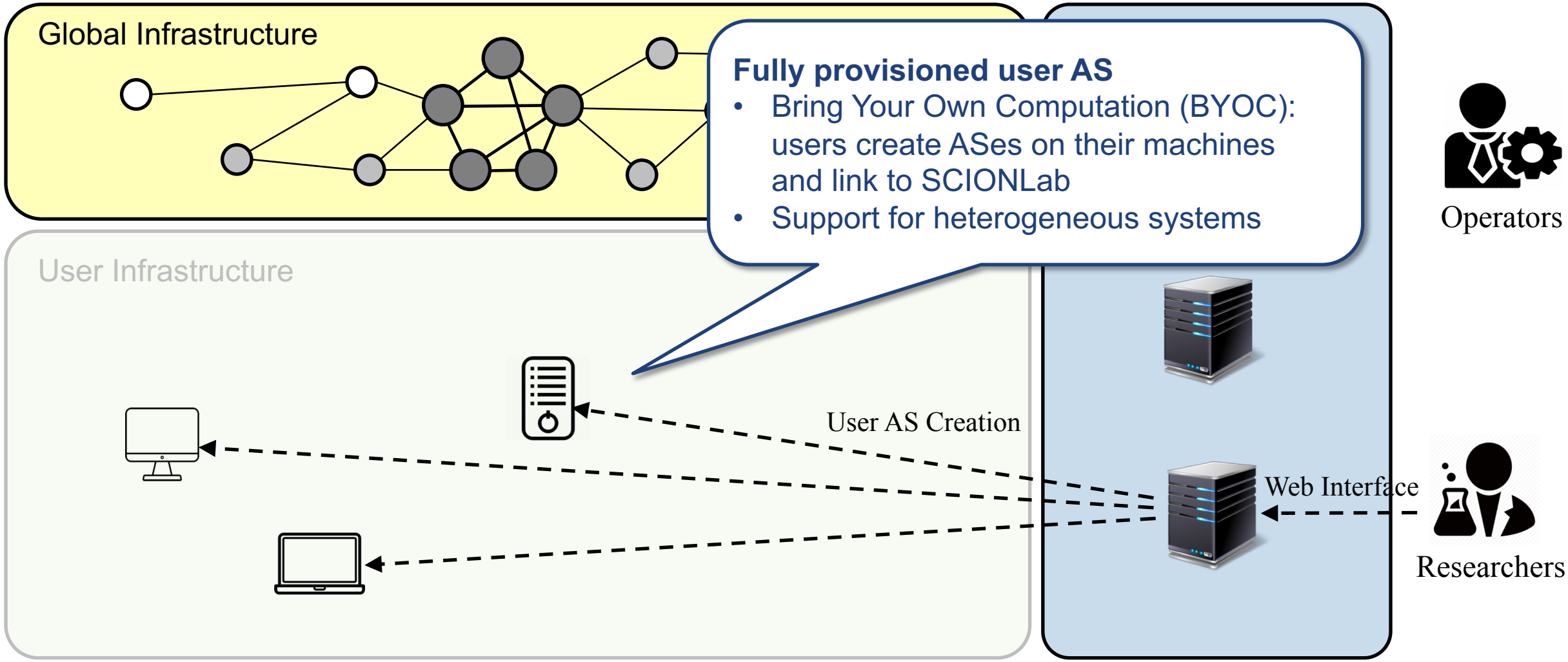
SCIONLab Overview



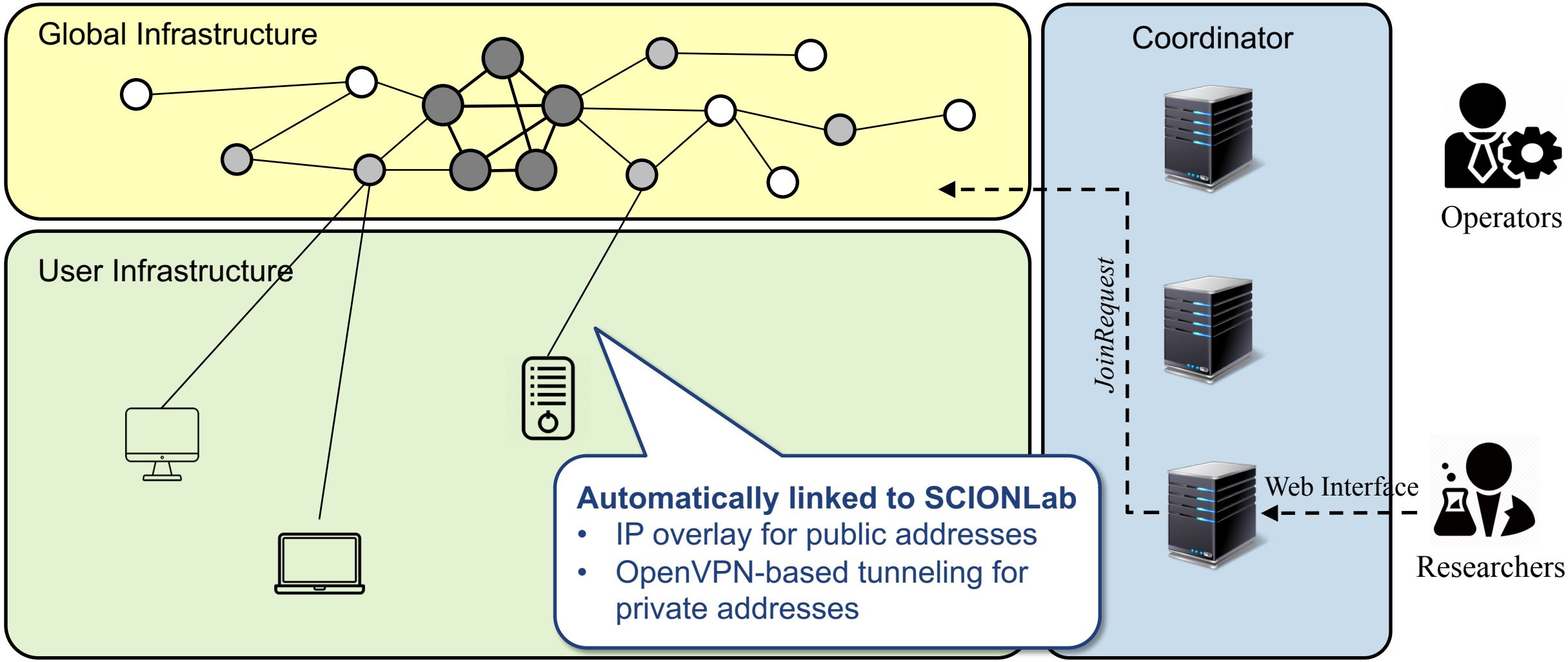
SCIONLab Overview



SCIONLab Overview

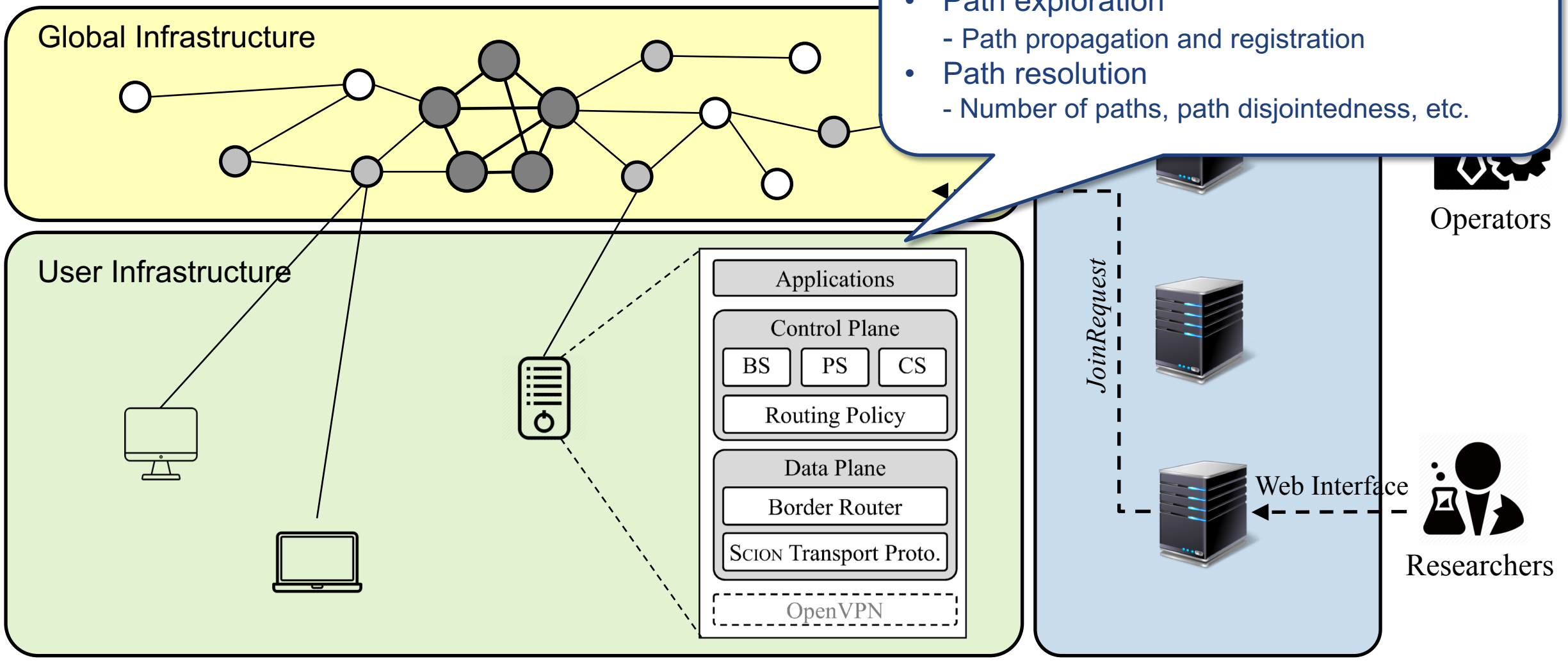


SCIONLab Overview



SCIONLab Overview

Fully configurable routing policy
- Path exploration
  - Path propagation and registration
- Path resolution
  - Number of paths, path disjointedness, etc.



SCIONLab | Home - SCIONLab Tutorials | Applications - SCIONLab Tutor

scionlab.org

Bookmarks | Study | Project | IDA | ETH | SCION | Imp Tip | Misc | SwissLife | Photography | iLO | netsec SVN repo:... | AWS Management...

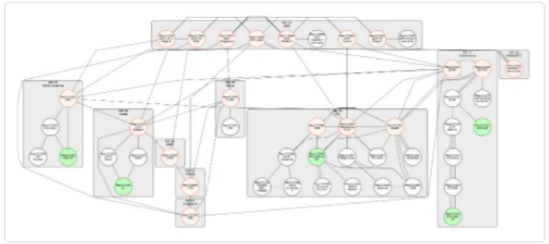
SCIONLab — Documentation | SCION | Log in

Welcome to SCIONLab

SCIONLab is a global research network to test the SCION next-generation internet architecture.

You can join the SCION network with your own computation resources and can set up and run your own autonomous systems (ASes). Your ASes will actively participate in routing in the SCIONLab network and enable realistic experimentation with the unique properties of the SCION architecture.

Join SCIONLab | Login



The topology of the SCIONLab infrastructure ASes and the ISD boundaries. Core ASes are red. SCIONLab attachment points are green.

About SCION

SCION (*S*calability, *C*ontrol and *I*solation on next-generation *N*etworks) is an inter-domain network architecture, designed to provide route control, failure isolation, and explicit trust information for end-to-end communication.

SCION organizes ASes into groups of independent routing planes, called isolation domains (ISDs), which interconnect to provide global connectivity. ISDs naturally provide isolation of routing failures and misconfiguration, give endpoints strong control for both inbound and outbound traffic, provide meaningful and enforceable trust, and enable scalable routing updates with high path freshness.

As a result, the SCION architecture provides strong resilience and security properties as an intrinsic consequence of its design. Besides high security, SCION also provides a scalable routing infrastructure, and high efficiency for packet forwarding.

SCION is a path-aware architecture: end hosts learn about available network path segments, and combine them into end-to-end paths that are carried in packet headers. Thanks to embedded cryptographic mechanisms, path construction is constrained to the route policies of ISPs and receivers, offering path choice to all the parties: senders, receivers, and ISPs. These features also enable multi-path communication, which is an important approach for high availability, rapid failover in case of network failures, increased end-to-end bandwidth, dynamic traffic optimization, and resilience to DDoS attacks.

SCION is designed to interoperate with the existing networking infrastructure. Deployment of SCION can utilize existing internal routing and forwarding infrastructure of an AS, and only require installation or upgrade of a few border routers. A SCION-IP-Gateway (SIG) in the local infrastructure allows legacy end hosts and applications to be unaware of SCION.

Please refer to the SCION Architecture main page for more information.

About SCIONLab

SCIONLab is a global research network to test and experiment with the SCION internet architecture. As a participant of SCIONLab, you will be able to create your own ASes that actively participate in the SCION inter-domain routing. Your AS will be running on your own hardware, under your full control.

The infrastructure of SCIONLab comprises a network of globally connected ASes. A number of SCIONLab ASes are configured to act as "Attachment Points", and you can choose one as the uplink for your AS. The link between your AS and the attachment point AS is established as an overlay link over the legacy Internet.

The SCIONLab website serves to simplify and coordinate the setup of experimental ASes. Once created and configured in the SCIONLab website, you will be able to download the bundled configuration files for the SCION services and run your AS. Please refer to the Tutorials for setup instructions.

Oracle VM VirtualBox Manager

Tools

Preferences | Import | Export | New | Add

DEMO

Welcome to VirtualBox!

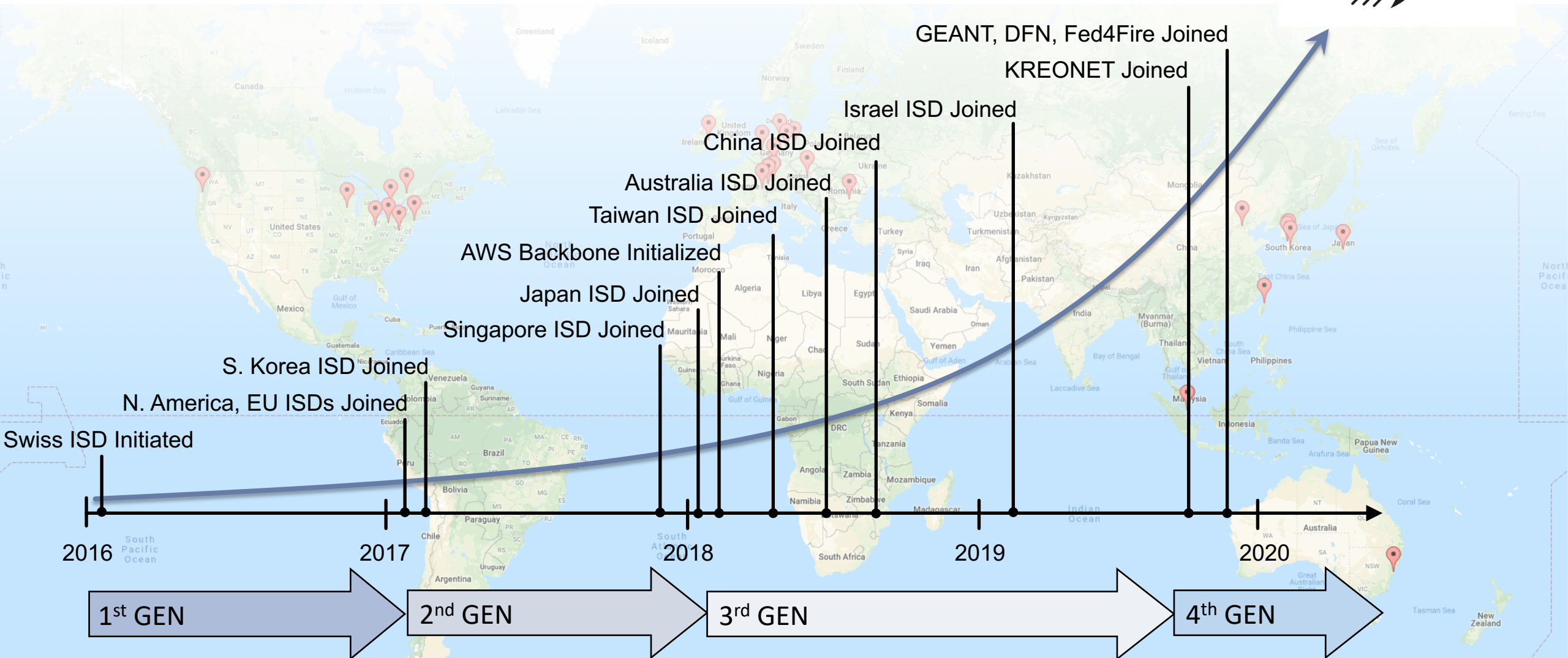
The left part of application window contains global tools and lists all virtual machines and virtual machine groups on your computer. You can import, add and create new VMs using corresponding toolbar buttons. You can popup a tools of currently selected element using corresponding element button.

You can press the **⌘?** key to get instant help, or visit www.virtualbox.org for more information and latest news.

다운로드 — vagrant@scionlab-ffaa-1-e: ~ — -zsh — 181×49

```
jkwon@ict-networks-192-168-001-002 Downloads %
```

Brief History of SCIONLab



1st Generation: Initial Infrastructure

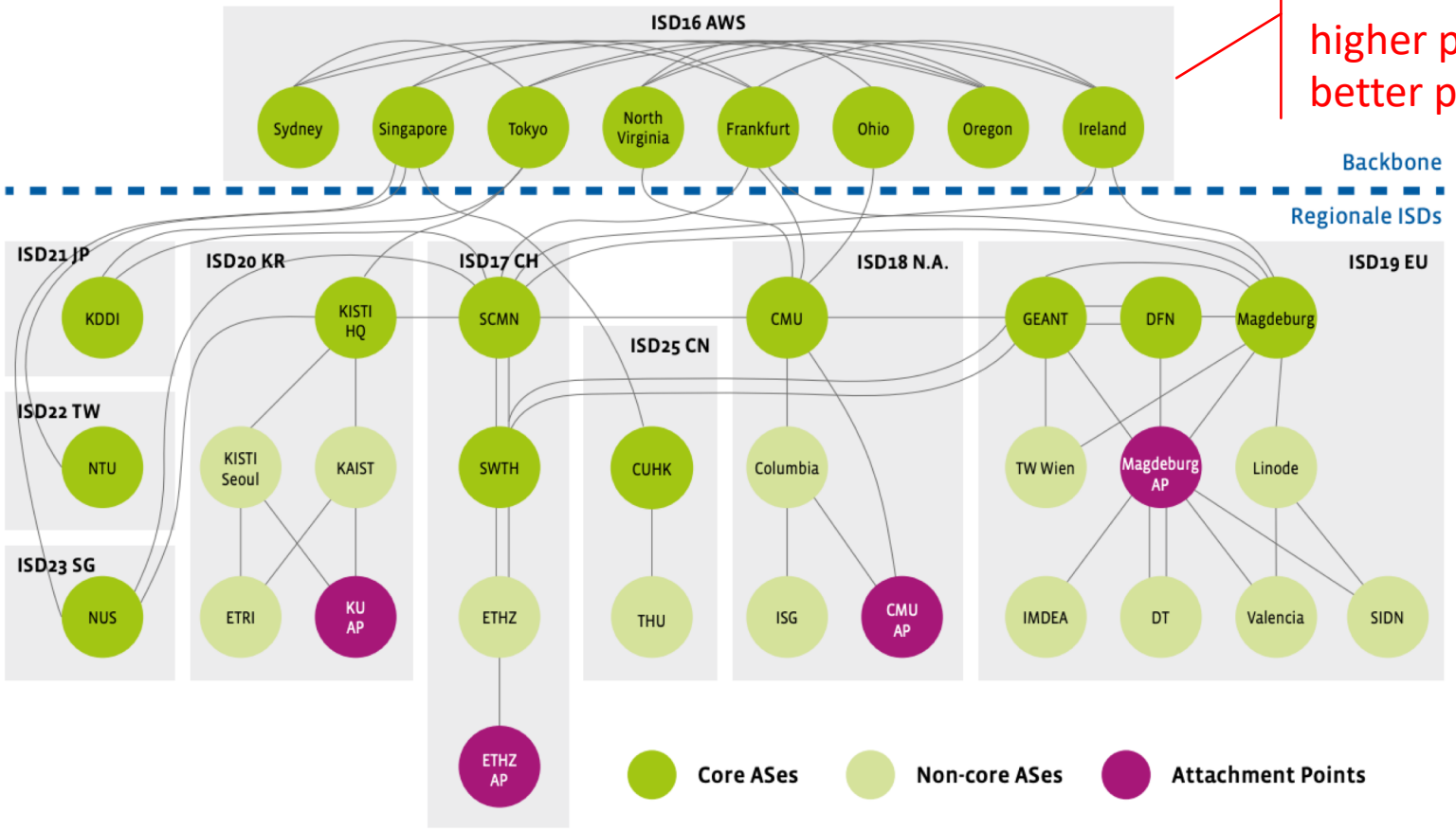
- Started as a *Proof-of-Concept* of SCION network
  - Single ISD with three ASes
- Few participants
  - Swisscom, SWITCH, ZKB
- Focused on building infrastructure
  - Control-plane only
- Expanded to 4 ISDs after one year
  - Swiss, EU, N. America, and Asia
  - Achieving connectivity across northern hemisphere

2nd Generation: Coordination Service

- Allowing users to create SCIONLab ASes and join SCIONLab
  - By simply filling a few necessary information (network setting / machine type)
  - One click download and installation
  - https://www.scionlab.org
- Email verification system for the coordination service
  - User verification
- Notification system
  - Notify users of released updates, breaking changes, etc.
  - Status of Join and Connection requests
- Automatic update for SCIONLab nodes
  - Fully automated update procedure
  - Updating live SCIONLab ASes every 12 hours (on bootup update for pending ASes)
- Image builder for various platforms

3rd Generation: AWS Backbone

Thanks to the dedicated lines that AWS provides, backbone ISD provides higher path diversity and better path quality



4th Generation: Native SCIONLab Backbone

- Global research networks improve SCIONLab backbone

Korea **R**esearch **E**nvironment **O**pen **Net**work 2

- 10 - 100Gbps high-speed research network
- Started from GLORIAD project (Global Ring Network for Advanced Applications Development)
- Interconnected with more than 35 global research networks across the world
  - GÉANT, Internet2, CERN, etc.

GEANT: European research & education network

- 10 - 100Gbps high-speed research network
- Connecting 50M users in over 10K institutions
- Reaches more than 100 countries worldwide

Fed4FIRE: Federation of NGI testbeds

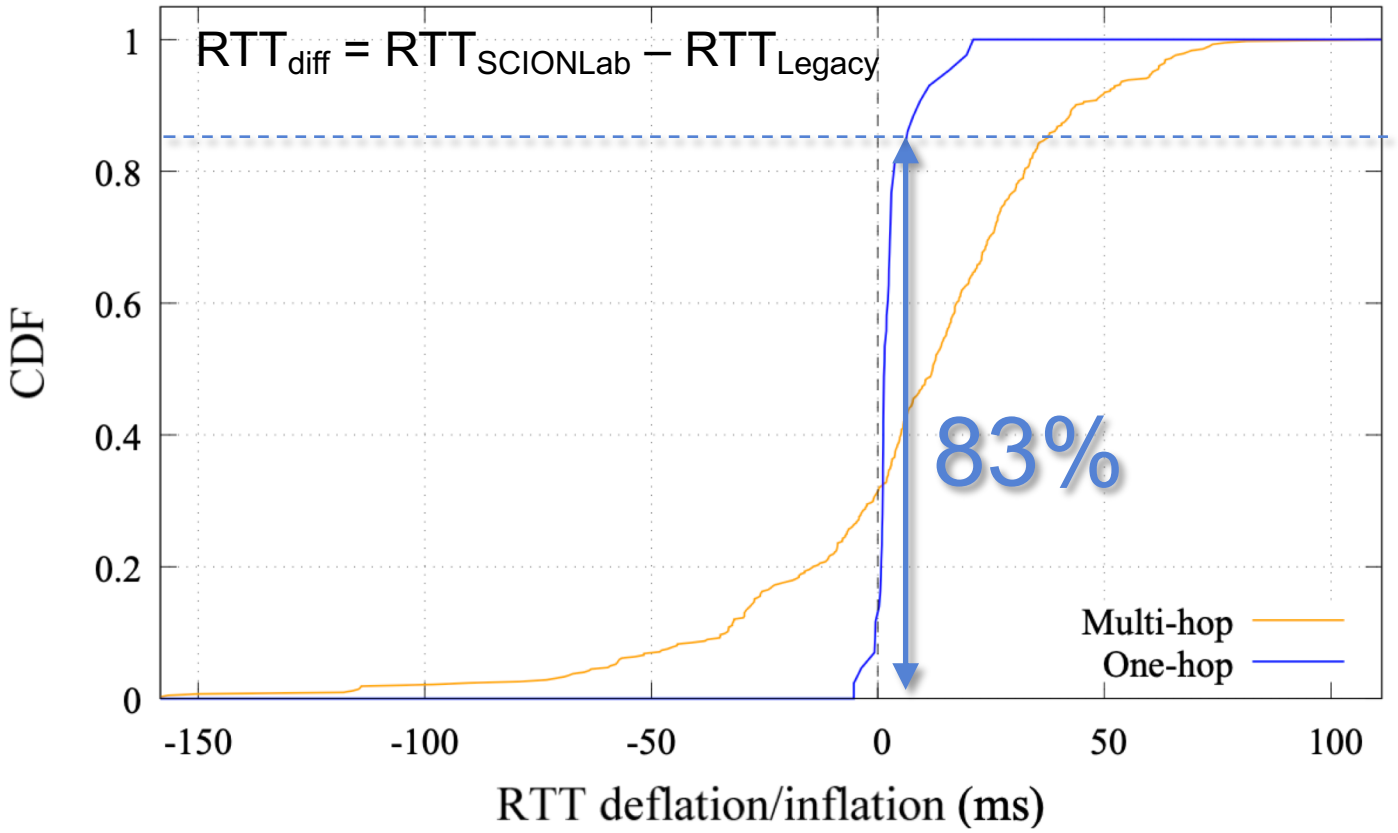
- Access to >16 testbeds (ExoGENI, Grid5000, etc.)


PERFORMANCE
EVALUATION

Network Latency Inflation: One-hop Communication

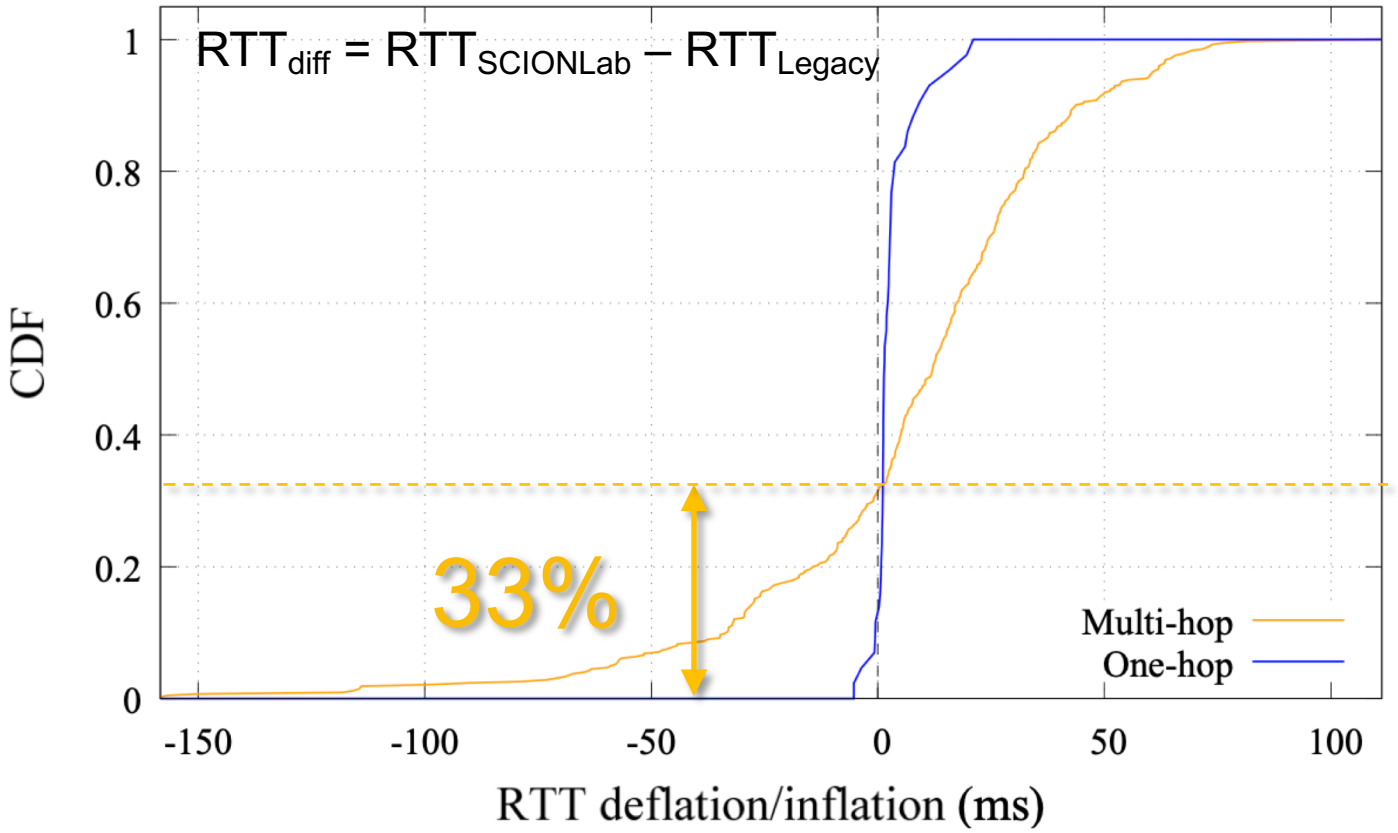
- 83 % of node pairs show tolerable latency overhead:

$RTT_{diff} \leq 5$ ms.



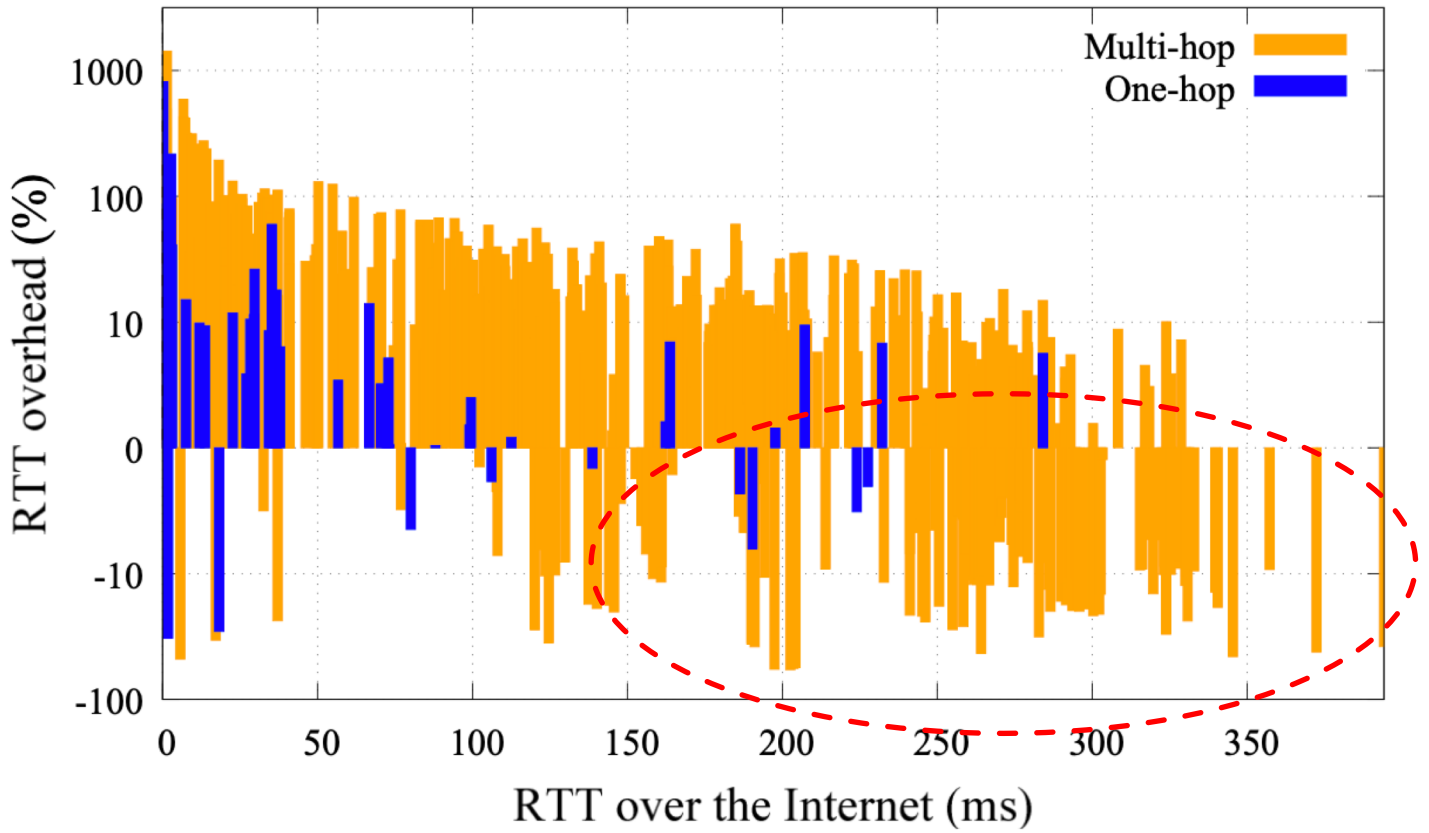
Network Latency Inflation: Multi-hop Communication

- Apx. 33 % of node pairs show better latency



Network Latency Inflation: Multi-hop Communication

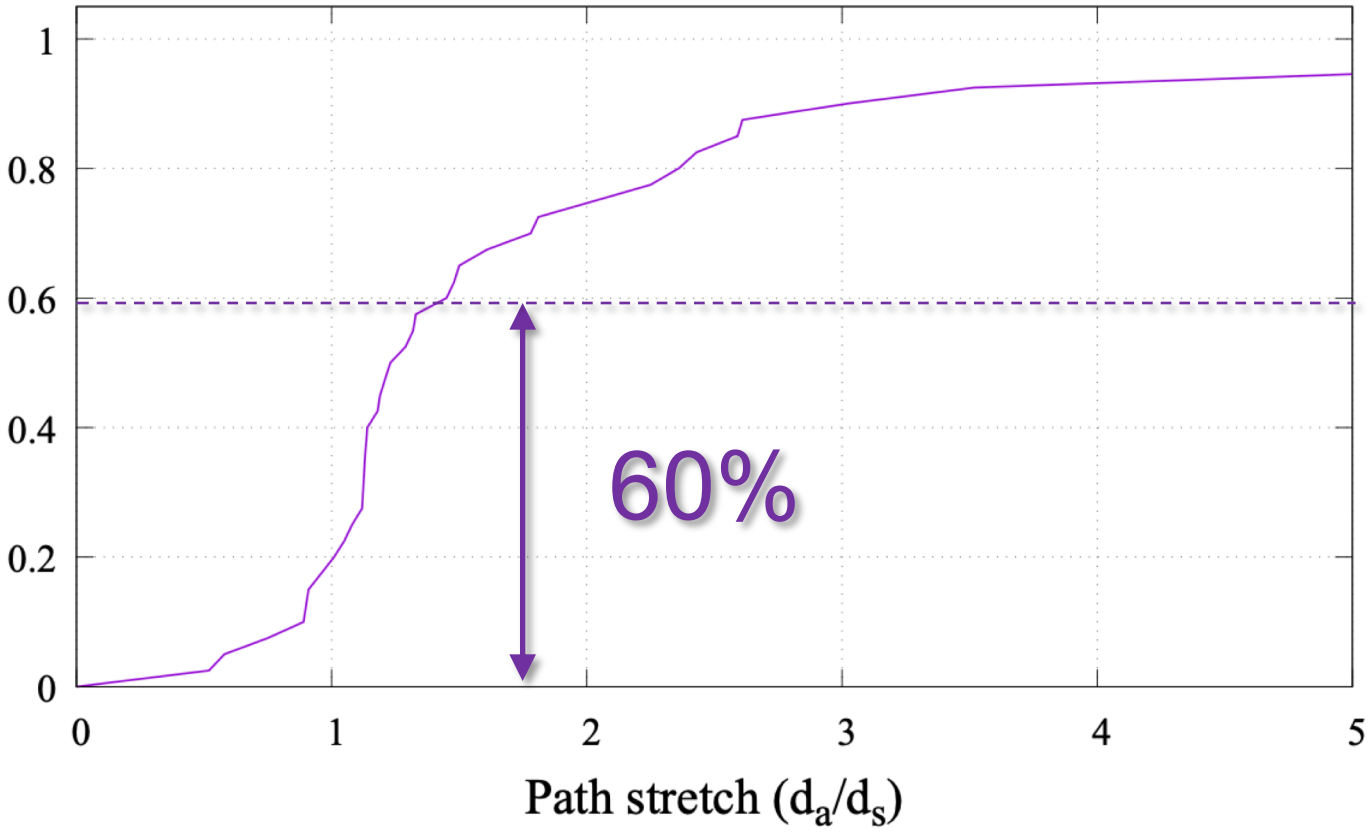
- Better latency for majority of high-latency node pairs



Path Stretch: Path Diversity with Alternatives

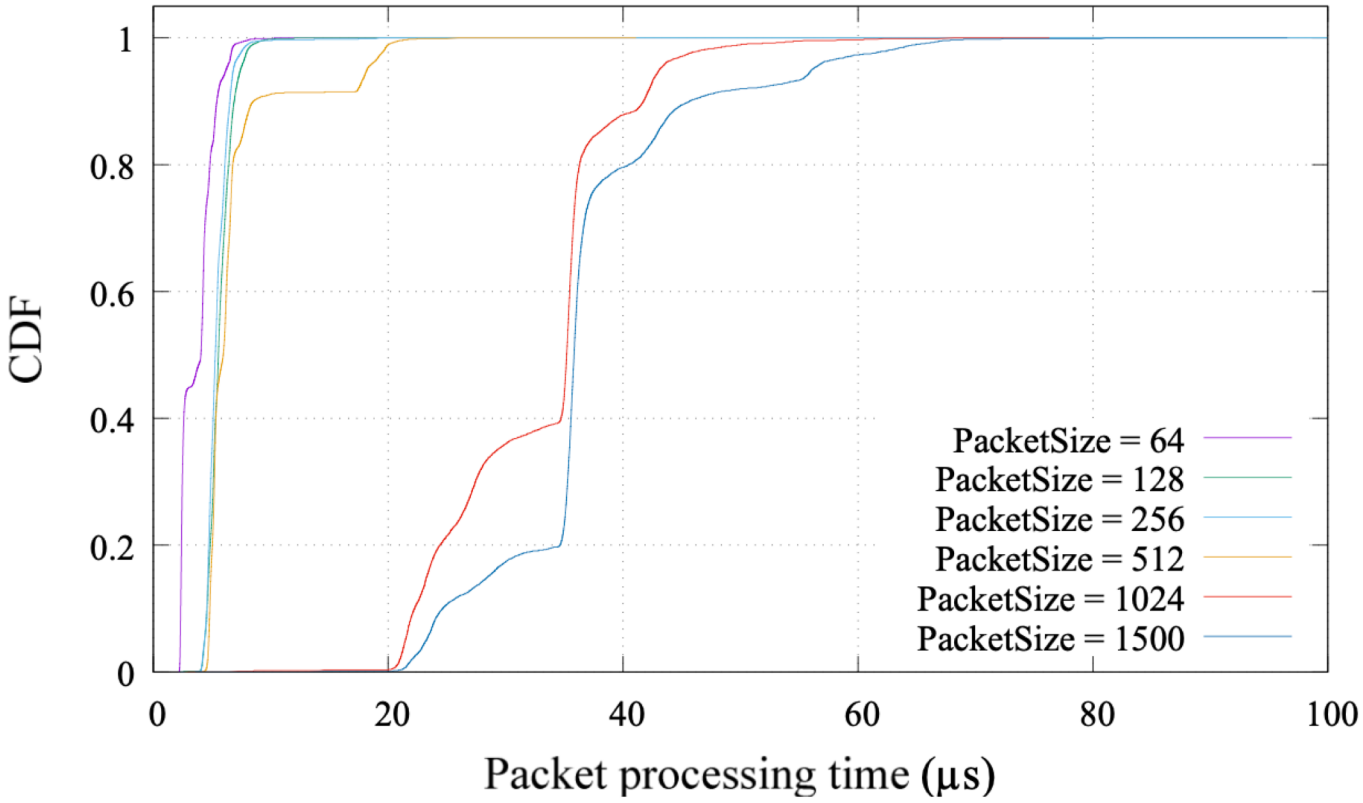
- Aprox. 60 % of paths show an alternative path with:

$$d_a/d_s \leq 1.4$$



Packet Forwarding Performance

- Less than 20 µs of packet processing time for over 90 % of cases (10.17 µs on average)



More in the Paper

Details about implementation and deployment

- Implementation on heterogeneous systems
- Large-scale ISP deployment

More experiments

- Microbenchmarks
- Control-plane scalability

Lessens we have learned as a operator

- Operational insights and challenges
- Long-term viability

Ongoing research projects

- New research topics leveraging SCIONLab

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***Abstract*—Network testbeds have empowered networking research and facilitated scientific progress. However, current testbeds focus mainly on experiments involving the current Internet. In this paper, we propose SCIONLAB, a novel global network testbed that enables exciting research opportunities and experimentation with the SCION next-generation Internet architecture. New users can join SCIONLAB as a full-fledged autonomous system with minimal effort and administrative overhead, and directly gain unfettered access to its inter-domain routing system. Based on a well-connected network topology consisting of globally distributed nodes, SCIONLAB enables new experiments, such as inter-domain multipath communication, path-aware networking, exploration of novel routing policies, and new approaches for DDoS defense. SCIONLAB has been operational since 2016 and has supported diverse research projects. We describe the design and implementation of SCIONLAB, and present use cases that illustrate exciting research opportunities.**

***Index Terms*—Global Network Testbed, Future Internet, Multi-path Communication, Path-aware Networking, Secure Routing**

I. INTRODUCTION

The rapid growth of the Internet is driving the adoption of various network services at a global scale, including content delivery networks (CDNs) [47], cloud storage systems [32], video conferencing [45], and software-defined networking in wide area networks [39]. All these services demand highly reliable, performant, and secure communication with flexible routing strategies. Network testbeds have facilitated experimentation and have thus contributed to the emergence of new network services. In particular, Emulab and PlanetLab [15], [44], [48], [57] were instrumental in supporting researchers with readily accessible testbeds.

Over the past two decades the majority of networking research was focused on intra-domain or data-center networking instead of inter-domain networking [18], [30], [61]. While the diameter of the Internet is indeed shrinking, inter-domain communication continues to be an important aspect of communication, as applications continue to exist that do not directly communicate with cloud, CDN, or hyperscaler data centers. As a result of the relative lack of progress in inter-domain research and innovation, problems continue to affect a diversity of applications. Fortunately, next-generation Internet architectures supporting new networking paradigms such as path-aware networking, multipath communication, and novel security approaches are promising to address these challenges and have the potential to drive the next generation of applications [10], [11].

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Path-aware networking enables end-hosts to obtain information about network paths leading to the destination, and to select the path among a set of paths offered by the network [20], [52]. Path awareness offers exciting properties to applications, such as path transparency, fine-grained path control, fast failover or route optimization to alternate paths, or geofencing [50], [51], [63]. These properties enable the creation of new transport protocols and advanced application features. Path-aware networking also enables multipath communication: in case the end-host obtains multiple paths from the network, it can select the path on a per-packet basis. Multipath communication can provide increased bandwidth, improved reliability, and more efficient link utilization [46], [59]. Ongoing efforts at the IETF, e.g., TSVWG [12], MPTCP [17], and QUIC [21], [34], [54], have shown its feasibility and practicality.

Advanced security features built into many path-aware network architectures enable the creation of new applications and services, where the network provides built-in trust-establishment and key-distribution mechanisms, defenses against distributed denial-of-service (DDoS) attacks, and privacy-enhancing techniques. However, to tap the full potential of all these opportunities, further research is required and open questions need to be answered, such as the following: Which paths and which additional information should be disseminated to end-hosts? What is the API between network, transport, and application layer? How do the different layers work together to select the best paths with limited overhead? What congestion-control algorithms are suitable when end-hosts can switch paths or use multiple paths at the same time?

To enable researchers to explore path-aware networking architectures and support research trying to answer these questions, we propose SCIONLAB—a novel design for a flexible, scalable, and expandable global network testbed that is easy to use. SCIONLAB is based on the SCION Internet architecture, and thus inherits scalability, security, and efficiency properties. SCION improves security on various levels, e.g., by providing protection against malicious autonomous systems (ASes) and offering transparency and control over forwarding paths and trust roots. At the same time, the SCION approach ensures scalability and efficiency by placing forwarding information into packet headers to eliminate packet state in routers (see §II for an overview of SCION). The SCIONLAB network infrastructure is based on 35 ASes widely distributed across the world, and connects over 600 user ASes running on heterogeneous systems. The central coordination service, the SCIONLAB *Coordinator*, orchestrates the infrastructure and

Interested to join the SCIONLab Network?

Join as User AS

- You want to simply try out or do **exciting research experiments** with a full fledged SCION AS
- You want to connect to SCIONLab in less than 10 minutes and **few clicks only**
- You don't have any specific hardware available, other than your laptop (with VirtualBox)

Join as Infrastructure AS

- You intend to run your SCION AS 24/7
- Your border router can have a public static IP address
- Your firewall can be configured to meet the SCIONLab connectivity requirements
- **You want to be eligible for a PC Engine device**

➔ https://www.scionlab.org/

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Thank you for your attention!

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