nsdi '24

Klonet

an Easy-to-Use and Scalable Platform for Computer Networks Education

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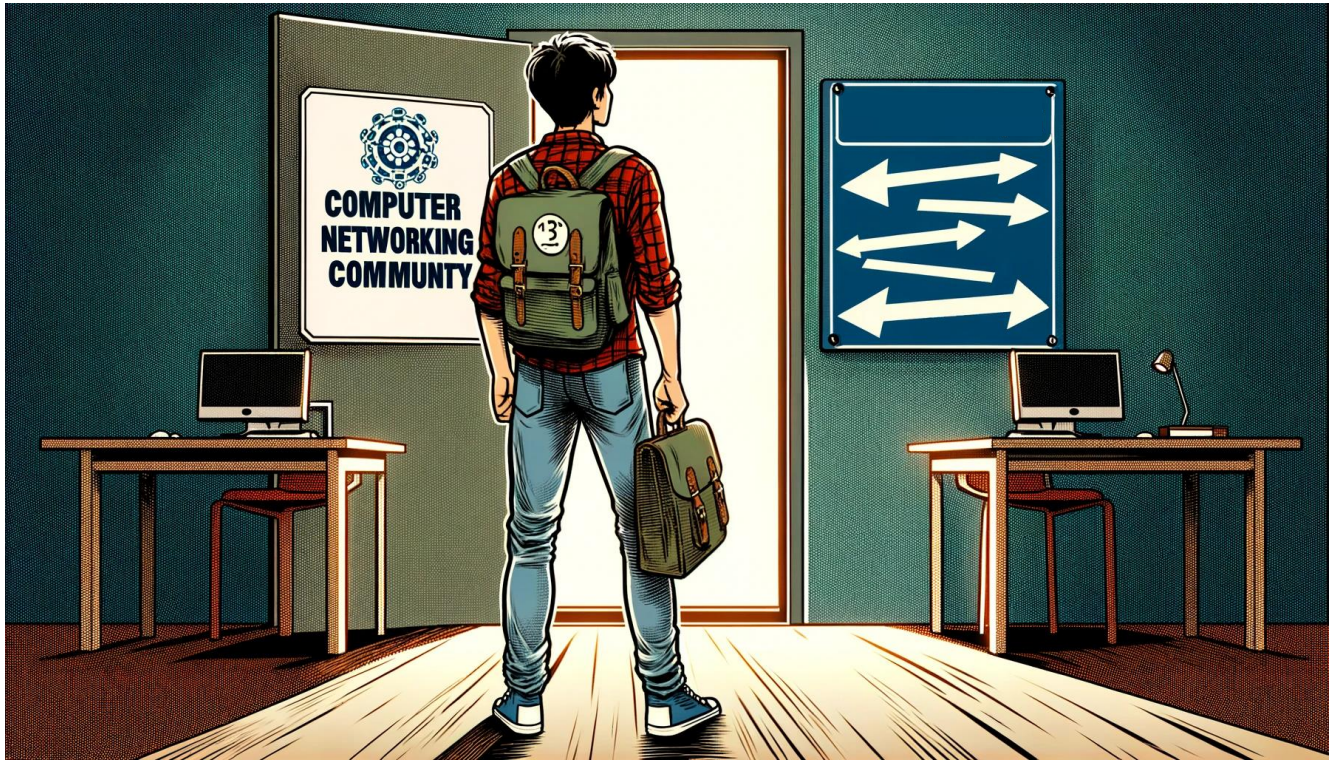
Education is Vital to Our Community



Education is the gateway for newcomers, shaping the future of computer networking!

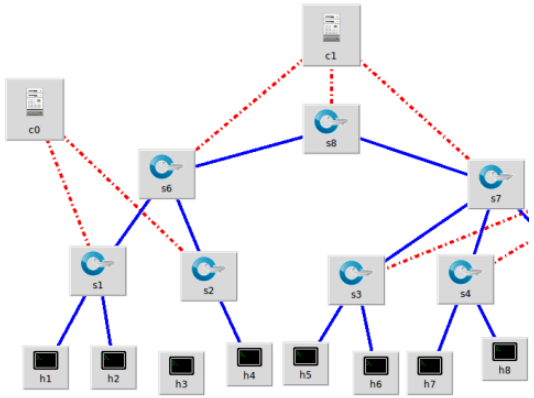
Practice is Important

- Computer Networks: an **abstract** and **complex** discipline
- The **key** to computer networks education: **Practice**
- Ways for students to get practice:

Testbed

Realistic,
but expensive

Emulator



Compromise
choice

Simulator

```
def send():
    msg_send = Message("testMsg");
    scheduleAt(5.0, msg_send)

def handle():
    if recv:
        msg_ack = Message("ack");
        scheduleAt(
            simTime()+1.0, msg_ack)
```

Cheap,
but unrealistic

Practice is Important

- Computer Networks: an **abstract** and **complex** discipline
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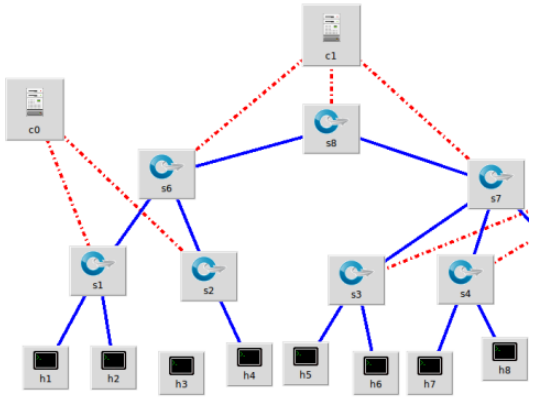

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Cheap,
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We aim to build a network emulation platform for education

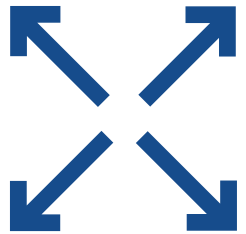
Goals for an ideal education platform

Easy-to-use

- Help students lower the barrier to practice
  - E.g. easy to get started and master basic operations
  - *"The first step is always the hardest"*
- Help tutors improve teaching efficiency
  - E.g. direct students easily and setup environments quickly

Scalable

- Support a large number of concurrent experiments
- Support several large-scale emulated networks



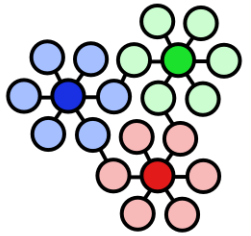
Existing Network Emulators

■ Genaral-purpose Emulators

- Mininet
  - Needs installation (and learning Linux, Virtual Machine, Shell, …)
  - Installing Mininet on a shared server seems a good idea ➡ *Poor isolation and scalability*
  - Lacks a student-friendly GUI
- Emulab
  - Heavy-weight
  - Poor scalability
  - Slow virtual network creation speed
- End-to-end emulators ➡ *Cannot emulate all types of devices (e.g. router)*
- Emulators for special scenarios ➡ *Cannot emulate diverse network scenario*
- …

Beginners

Mininet



StarryNet

Existing Network Emulators

■ Education-purpose Emulators

- Netkit ➡ *Heavy-weight*
- Kathará ➡ *Poor Scalability*
- GNS3 ➡ *Needs installation*
- Mini-Internet ➡ *Poor Network Scenarios*
- SEED ➡ *Lacks Embedding Algorithm*
- IP-mininet ➡ *Needs installation*
- …

SEED Internet Emulator

Existing Network Emulators

Platform Name	Easy-to-use					Scalability
	No Installation Required	GUI and Experiment API	Teaching Tools[1]	Experiment Tools[2]	Rich Node Types	
Mininet [12]	✗	Humble GUI	✗	Limited	✗	✗
Mininet-Hifi [20]	✗	Humble GUI	✗	Limited	✗	✗
Distrinet [15]	✗	No GUI	✗	✗	Limited	✓
Containernet [16]	✗	No GUI	✓	✗	Limited	✗
Vt-Mininet [21]	✗	No GUI	✗	✗	✗	✓
Mininet-Wifi [22]	✗	Humble GUI	✓	✓	✓	✗
Emulab [13]	✓	✓	Limited	✗	Limited	Limited
Netkit [37]	✗	No GUI	✓	✗	✓	✗
Kathará [17]	✗	Humble GUI	✓	✓	✓	✗
Megalos [18]	✗	Humble GUI	✓	✓	✓	✓
GNS3 [19]	✗	✓	✓	✓	✓	✓
SEED [35]	✗	✓	✓	✗	✓	✓
Mini-Internet [36]	✓	No GUI	✓	Limited	✗	✗
IPMininet [14]	✗	No GUI	✓	✓	✗	✗
Klonet (this work)	✓	✓	✓	✓	✓	✓

[1] **Teaching tools** are those designed to facilitate education, *e.g.*, Klonet's scene repository and Mini-Internet's connectivity matrix.
[2] **Experiment tools** are those designed to make experiments easier, *e.g.*, Klonet's traffic generator and IPMininet's IP configuration tools.

Related Network Emulators

Platform Name	Easy-to-use					Scalability
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Mininet-Hifi [20]	✗	Humble GUI	✗	Limited	✗	✗
Distrinet [15]	✗	No GUI	✗	✗	Limited	✓
Containernet [16]	✗	No GUI	✓	✗	Limited	✗
Vt-Mininet [24]	✗	No GUI	✗	✗	✗	✓
Mininet-Wifi [17]	✗	No GUI	✗	✗	✗	✗
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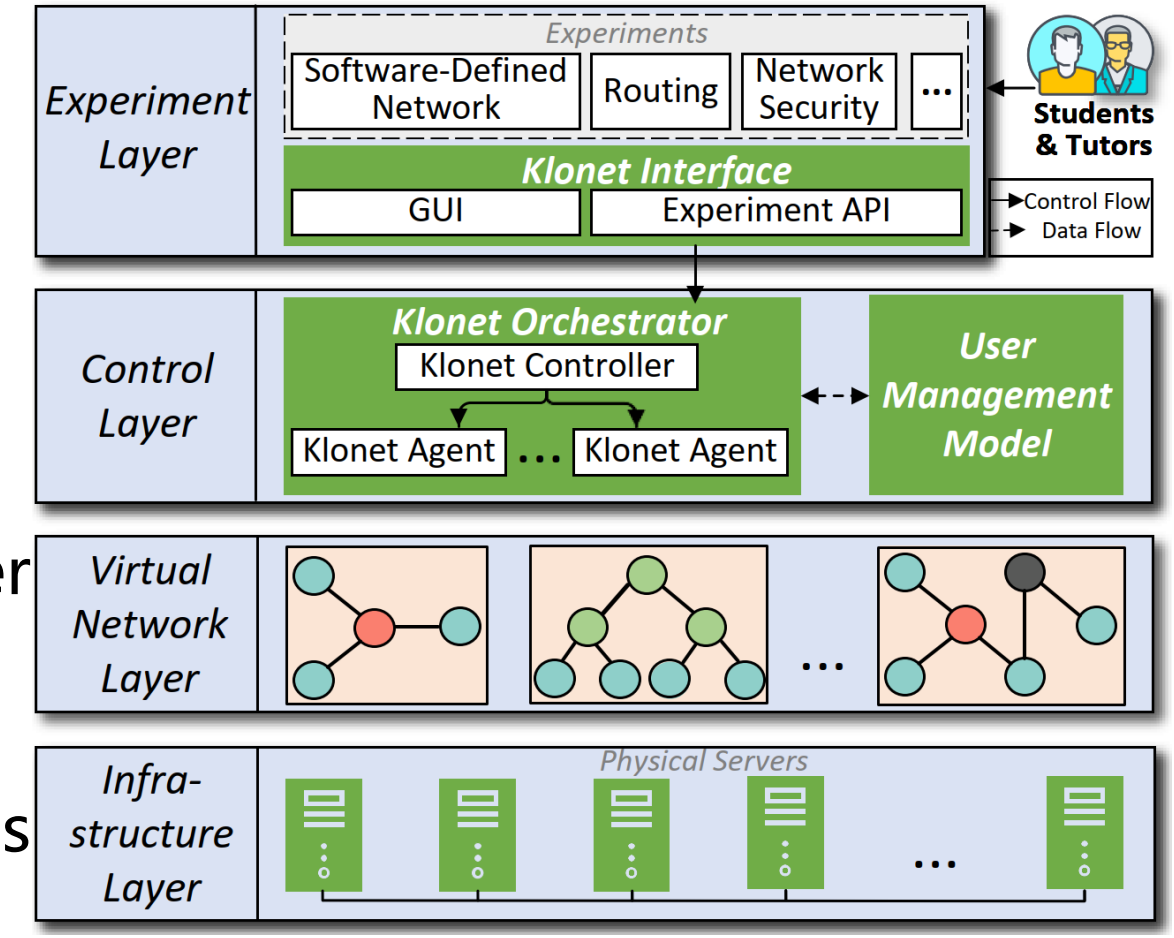
No existing emulator can achieve the two educational goals simultaneously

Klonet in a Nutshell

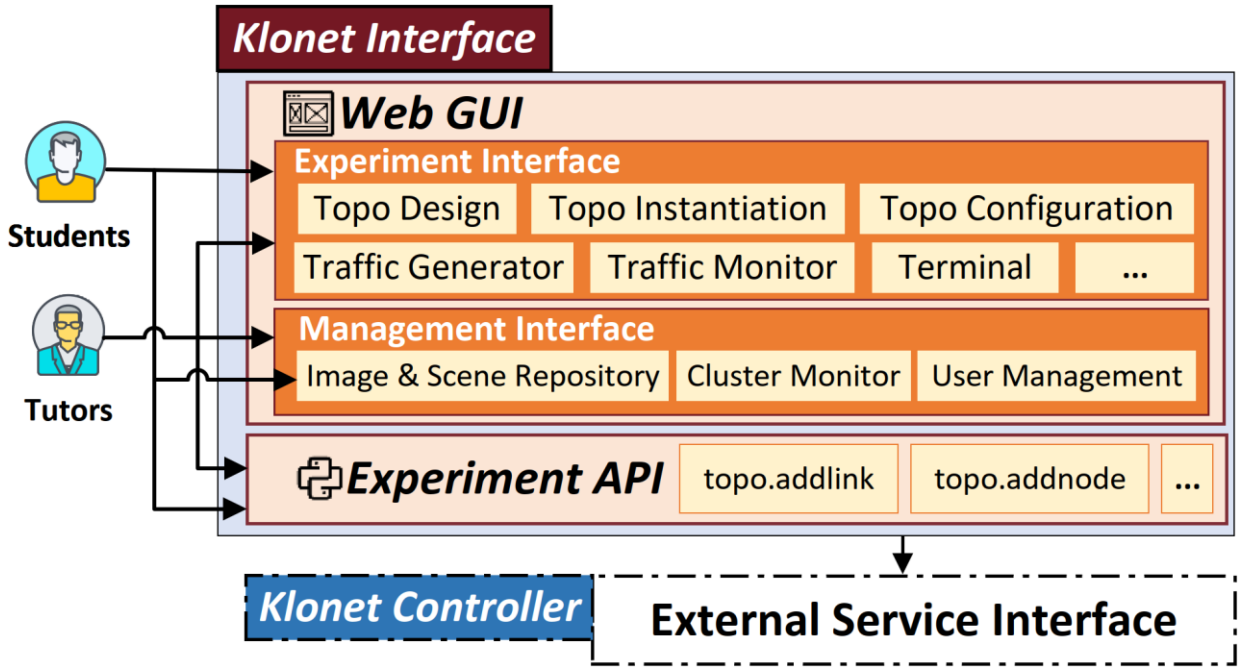
- Adopts a layered architecture
- A shared platform built on a physical cluster, can be easily accessed via its website
- Supports:
  - L2~L7 network experiments
  - Diverse scenarios, e.g. data center networks, wide-area networks
  - Customized topology
  - Mixture of real and virtual devices
  - Rich node types
  - …



Klonet Design Details

■ Achieving Easy-to-use

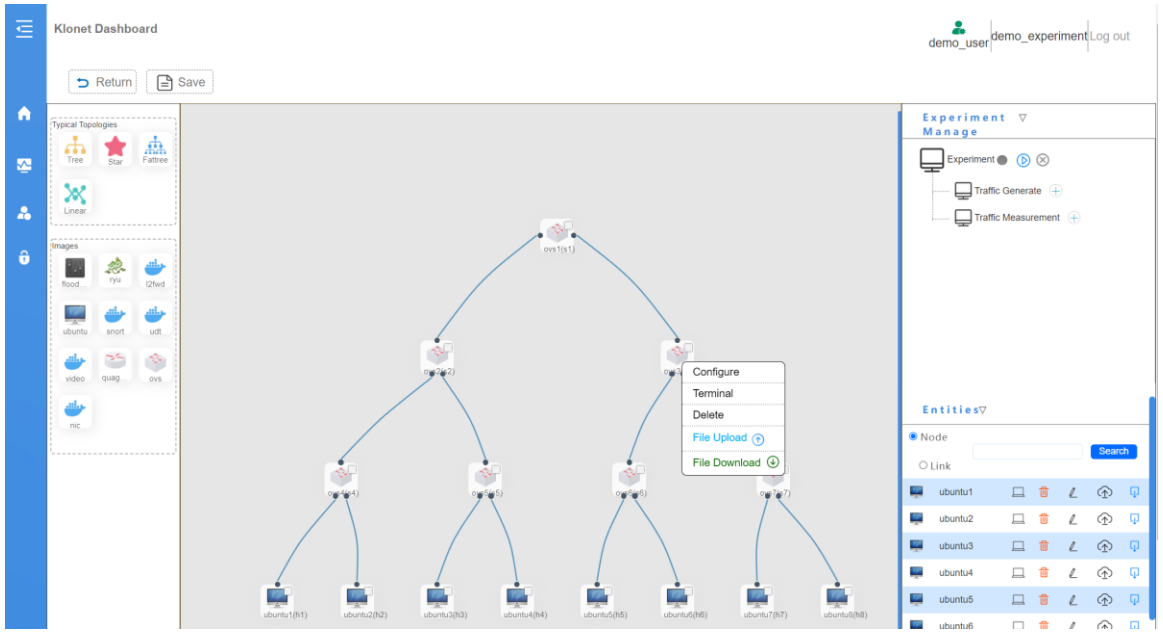
- Browser/Server (B/S) architecture to allow no installation



Klonet Design Details

■ Achieving Easy-to-use

- Browser/Server (B/S) architecture to allow no installation
- Rich Interfaces including Web GUI and Experiment API

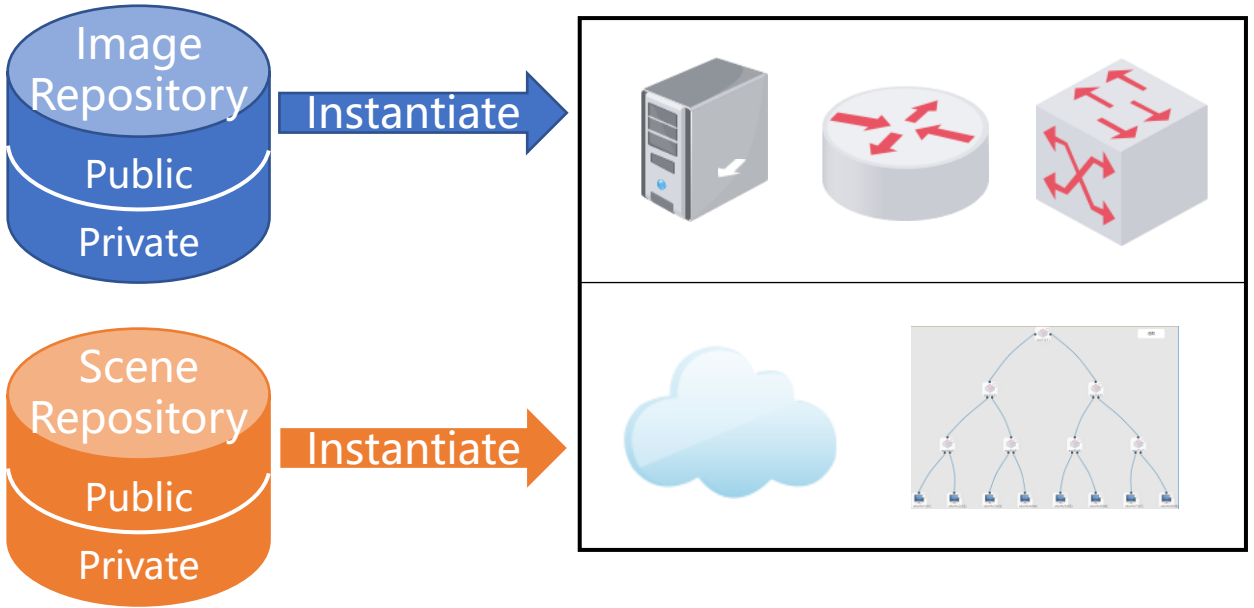



```python
from klonet_api import *
# Get the available images of current student.
images = get_images()
# Select the host(ubuntu) and switch(ovs) image.
ubuntu_image = images["ubuntu"]
ovs_image = images["ovs"]
# Design our topology: h1---s1---h2.
topo = Topo()
h1 = topo.add_node(ubuntu_image, node_name="h1")
h2 = topo.add_node(ubuntu_image, node_name="h2")
s1 = topo.add_node(ovs_image, node_name="s1")
topo.add_link(h1, s1, src_IP="192.168.1.1/24")
topo.add_link(s1, h2, dst_IP="192.168.1.2/24")
# Let Klonet emulate the topology.
deploy(topo)
# Create file in h1 and h2.
exec_cmds_in_nodes(
    {"h1":["touch /log1"], "h2":["touch /log2"]})
```

Klonet Design Details

■ Achieving Easy-to-use

- Browser/Server (B/S) architecture to allow no installation
- Rich Interfaces including Web GUI and Experiment API
- Building image and scene repository to make experiments shareable, scenario-rich, and quick to build



Klonet Design Details

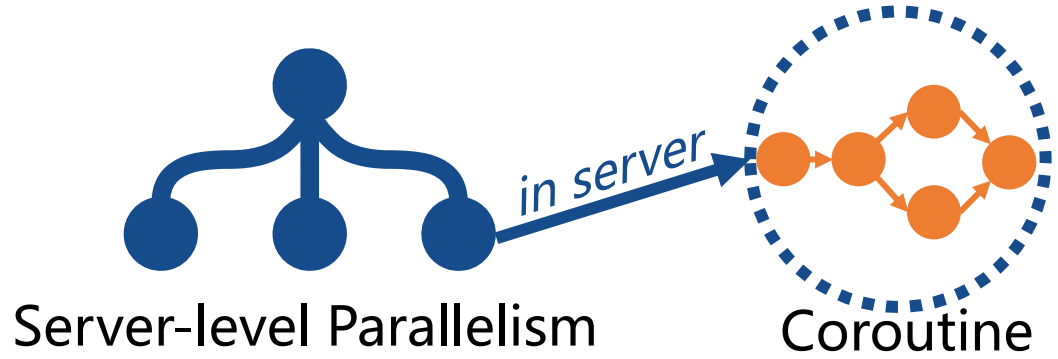
■ Achieving Easy-to-use

- Browser/Server (B/S) architecture to allow no installation
- Rich Interfaces including Web GUI and Experiment API
- Building image and scene repository to make experiments shareable, scenario-rich, and quick to build
- Built-in auxiliary tools (*e.g.* traffic generator, traffic monitor, and typical topology generator, ...) to facilitate experiments

Klonet Design Details

■ Achieving Easy-to-use

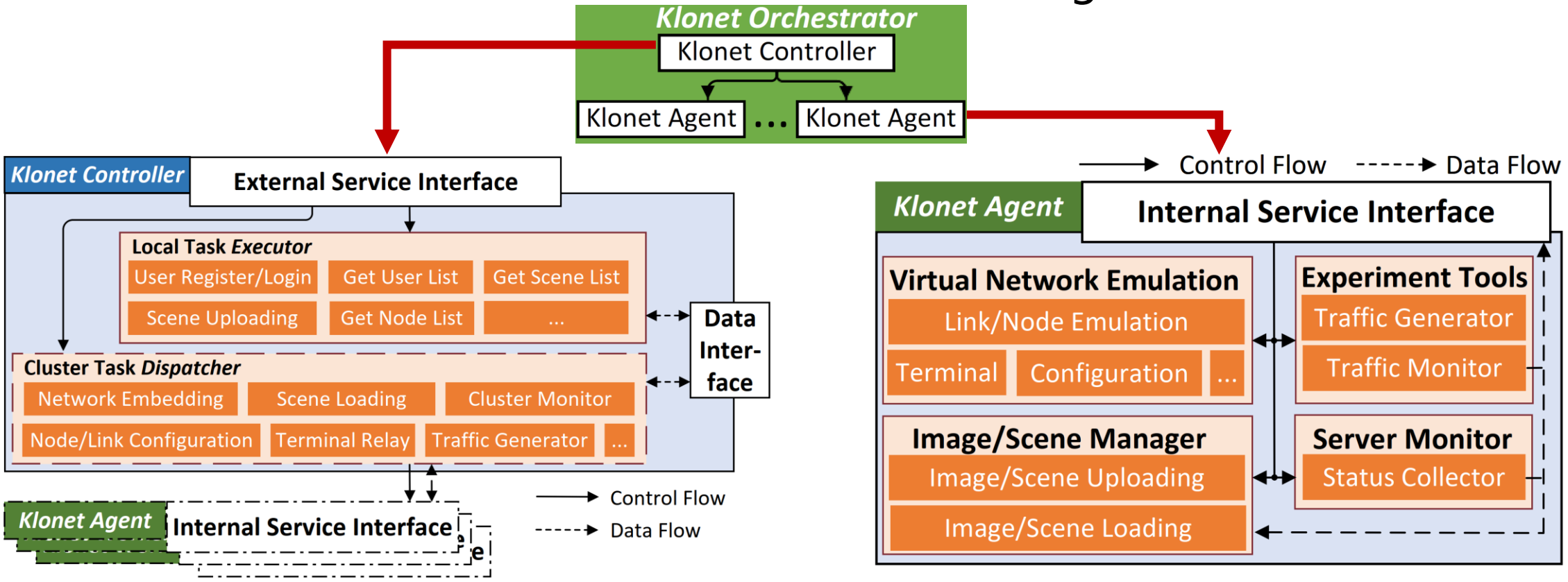
- Browser/Server (B/S) architecture to allow no installation
- Rich Interfaces including Web GUI and Experiment API
- Building image and scene repository to make experiments shareable, scenario-rich, and quick to build
- Built-in auxiliary tools to facilitate experiments
- Apply two parallelization techniques to accelerate creation



Klonet Design Details

■ Achieving Scalability

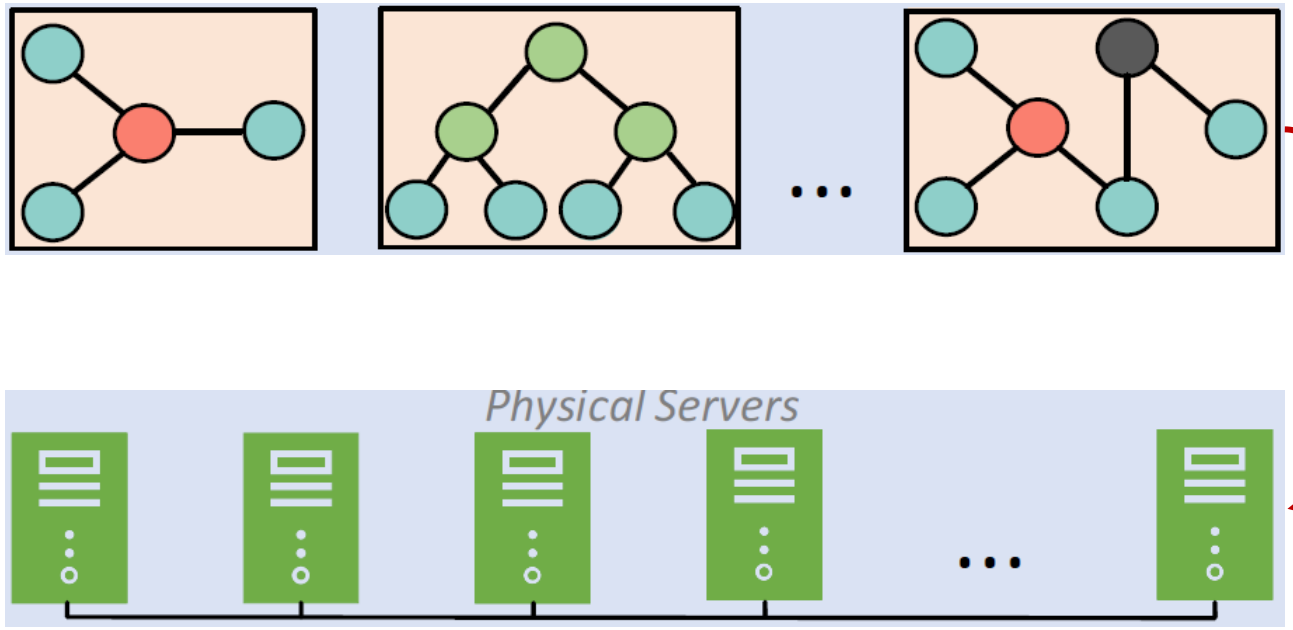
- Distributed orchestrator which enables scaling on clusters



Klonet Design Details

■ Achieving Scalability

- Distributed orchestrator which enables scaling on clusters
- Design a virtual network embedding algorithm to map virtual networks

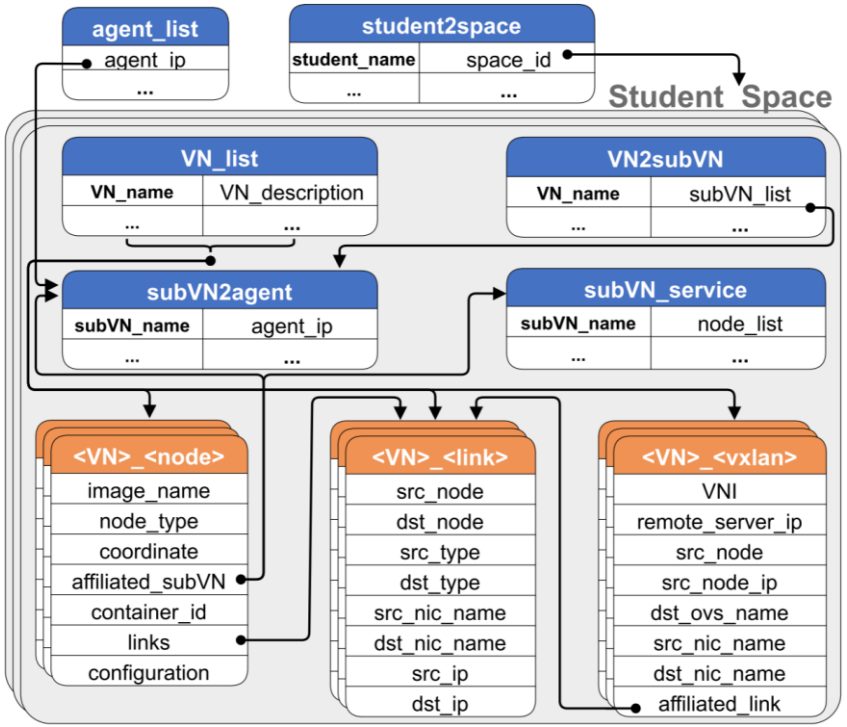


Embed virtual networks without overloading physical servers

Klonet Design Details

■ Achieving Scalability

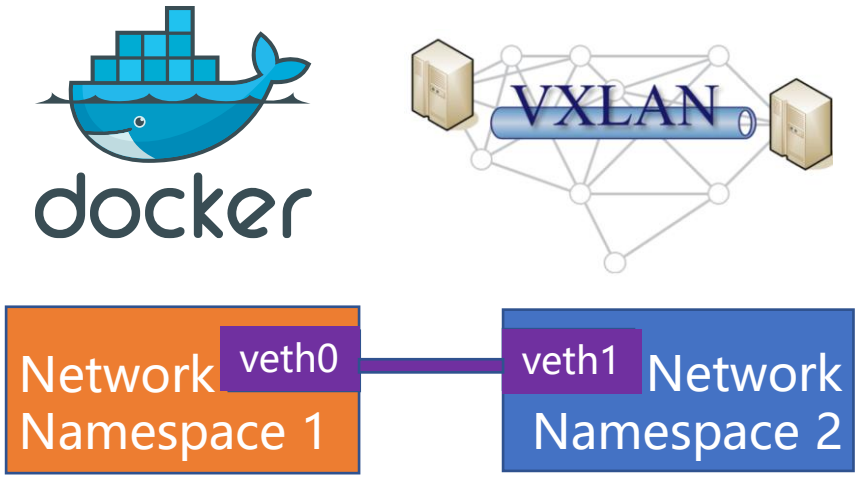
- Distributed orchestrator which enables scaling on clusters
- Design a virtual network embedding algorithm to map virtual networks
- Implement a user management model for multi-user data organization



Klonet Design Details

■ Achieving Scalability

- Distributed orchestrator which enables scaling on clusters
- Design a virtual network embedding algorithm to map virtual networks
- Implement a user management model for multi-user data organization
- Light-weight virtual network emulation
  - Node: Docker container
  - Link: Virtual Ethernet pair and VXLAN
  - Link Properties: Linux traffic control

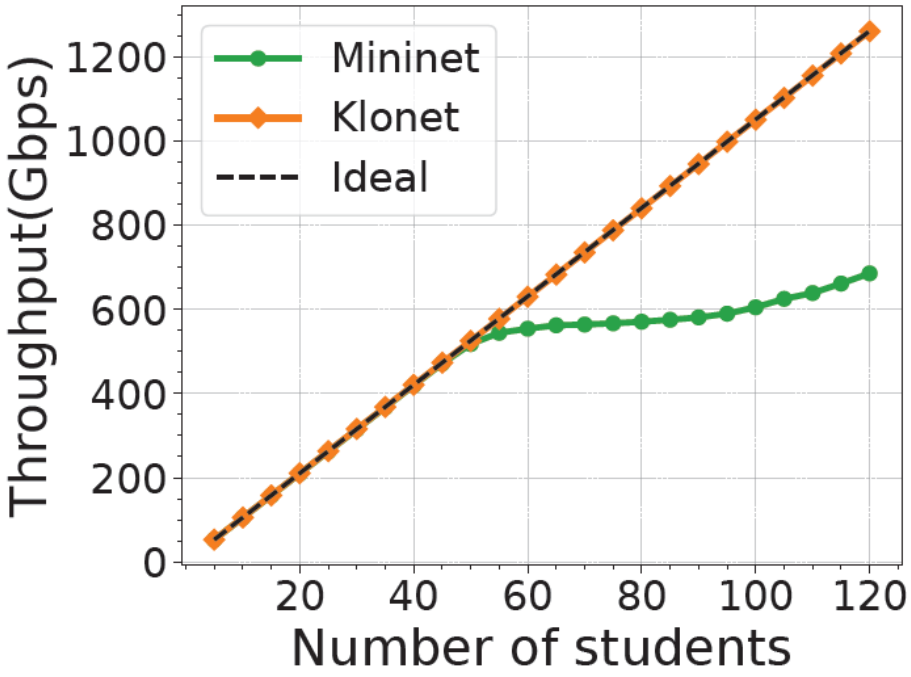


Klonet Design Details

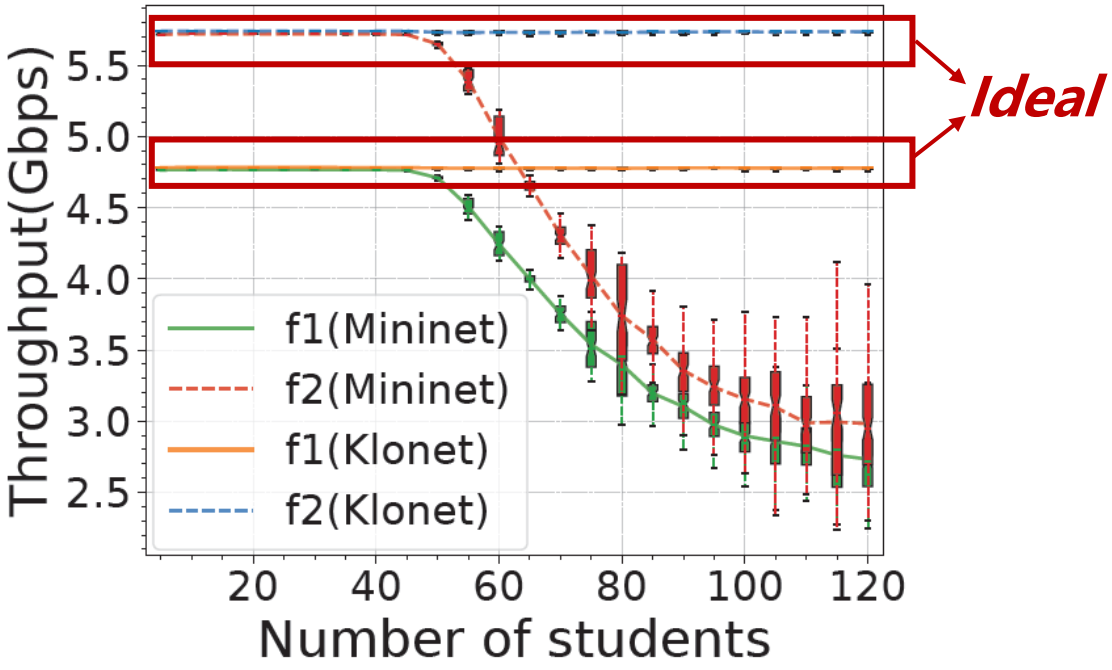
- **Robustness is important for a shared platform**
- **Achieving Robustness from top to bottom:**
  - Klonet orchestrator
  - User management model
  - Virtual networks
  - Cluster

See more details in our paper! (§4.4)

Fidelity Evaluation



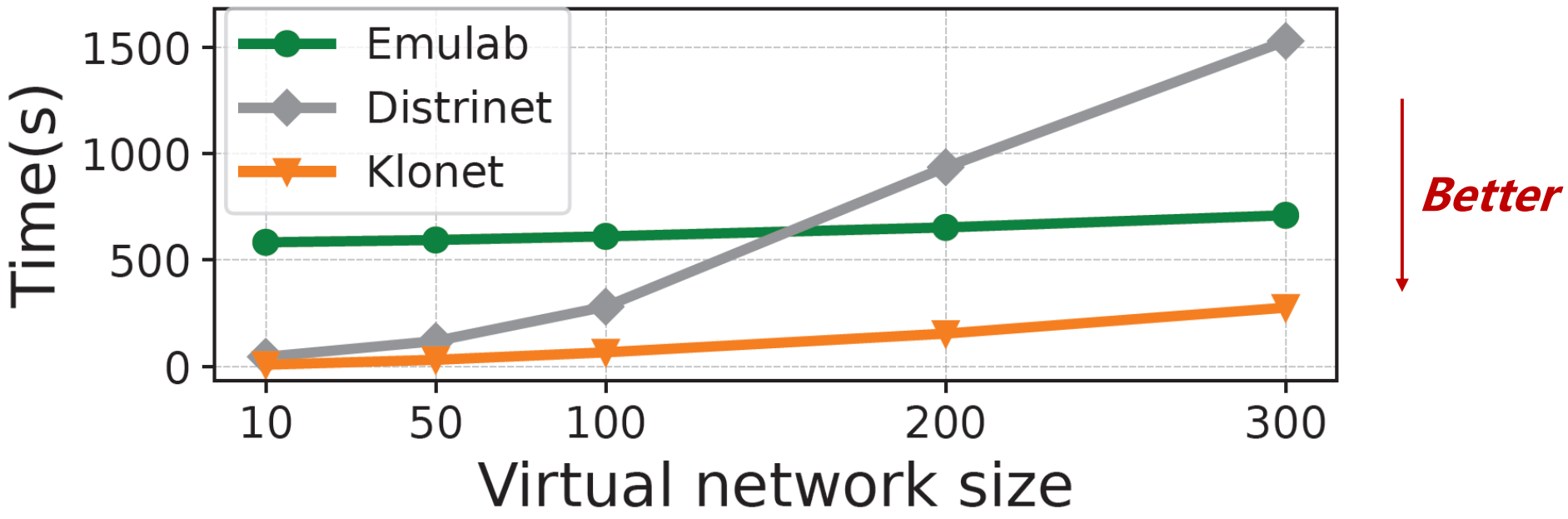
(a) Total throughput.



(b) Throughput distribution.

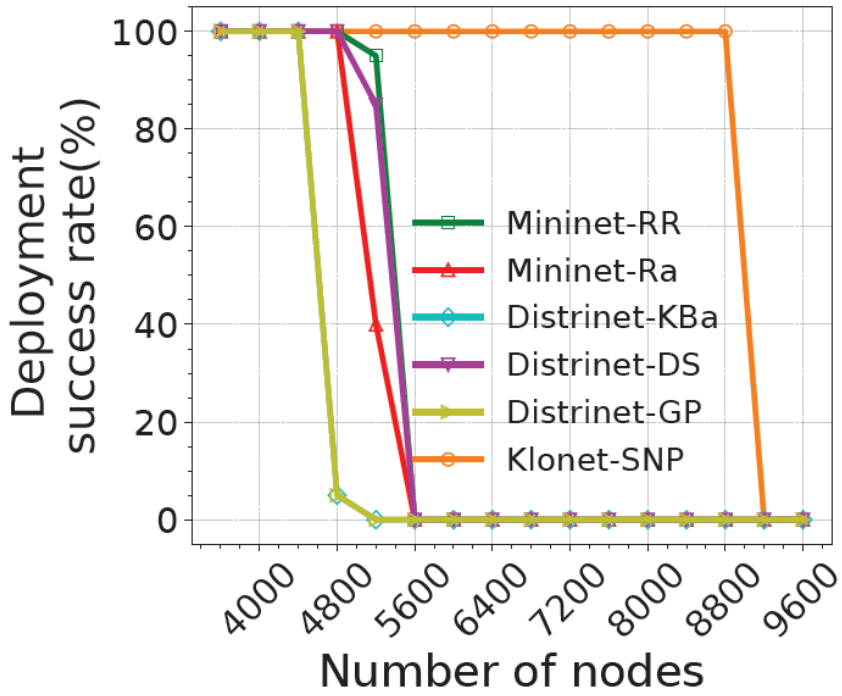
Klonet can support more students to conduct experiments simultaneously

Creation Time Evaluation

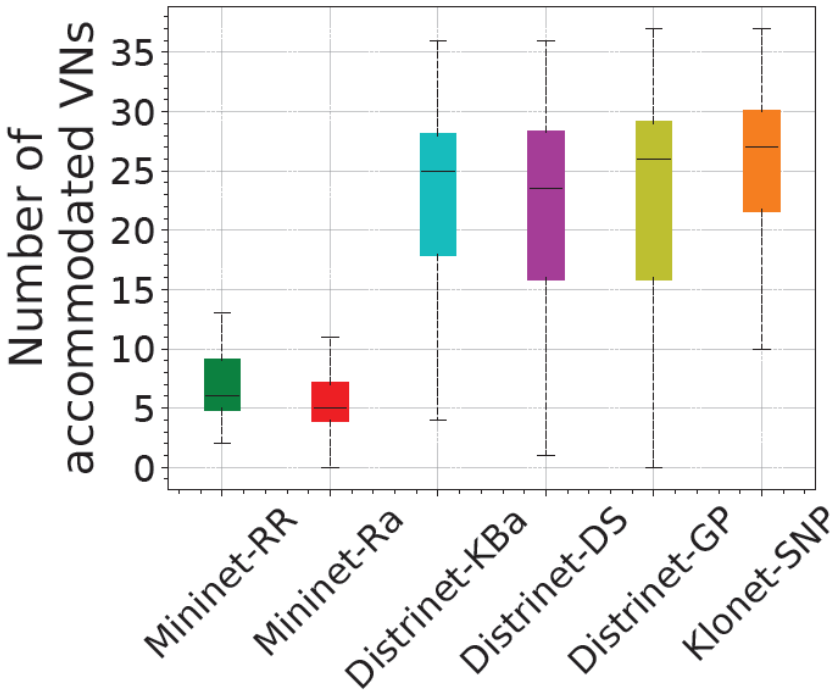


Klonet has a faster speed to deploy VNs

VNE Algorithm Evaluation



(a) Success rate.



(b) Success number.

Better

Klonet has a more efficient Virtual Network Embedding (VNE) algorithm

Use Cases

Implement algorithm in programmable networks

~150 stu./yr.

Networking virtual devices with Raspberry Pi

~40 stu./yr.

Implement network configuration such as NAT

~80 stu./yr.

Collaborate to achieve routing

~30 stu./yr.

Self-learners verify basic knowledge

~100 stu./yr.

Even several research works

E.g. a work using Klonet has been published in RTSS 2022

Use Cases

Implement algorithm in programmable networks

~150 stu./yr.

Project Ⅰ: Playing with algorithms (§6.1)

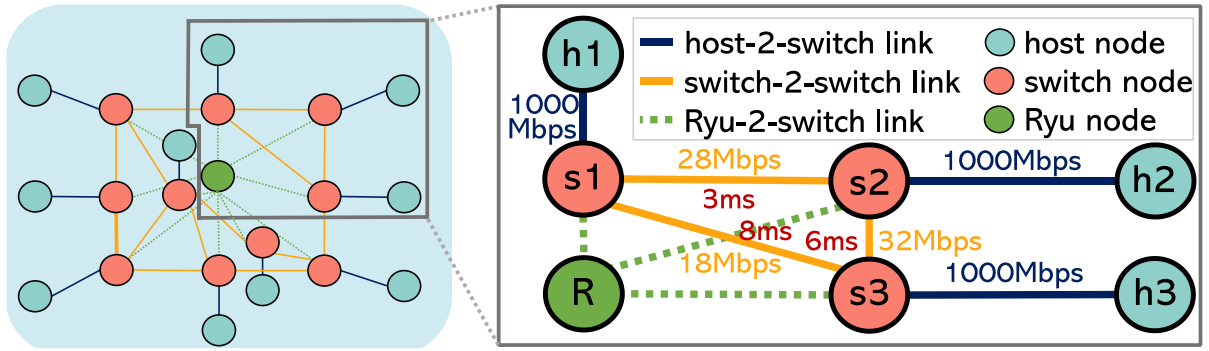
Collaborate to achieve routing

~30 stu./yr.

Project Ⅱ: Intra-domain Routing (§6.2)

Use Cases -- Project Ⅰ: Playing with algorithms

- Help students gain practical experience with algorithm performance in a programmable network

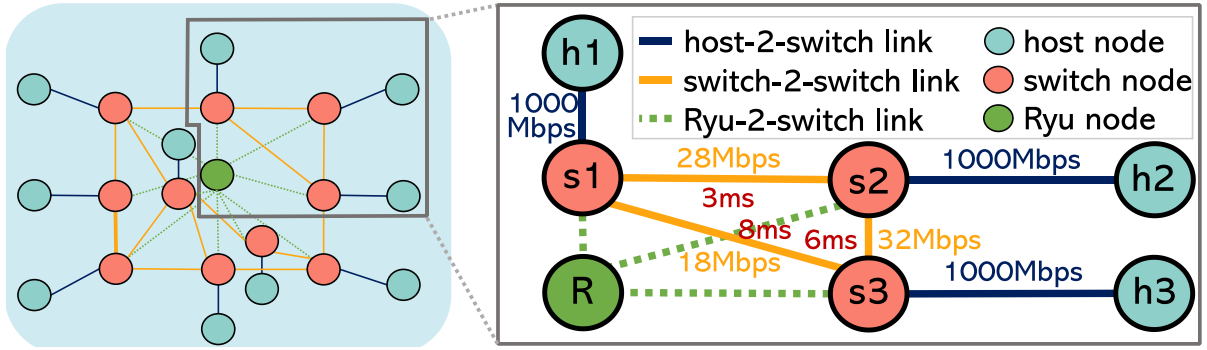


- **Learning outcomes**
  - Understand how OpenFlow works
  - Write algorithms in OpenFlow controllers
  - Identify the performance of algorithms

Challenges:

1. How to focus on learning SDN networks rather than building them?
2. How to quickly replay experiments for self-improvement or tutor assessment?
3. How to interact with the network, control it, and observe its performance?

Use Cases -- Project Ⅰ: Playing with algorithms



Challenges:

1. *How to focus on learning SDN networks rather than building them?*
2. *How to quickly replay experiments for self-improvement or tutor assessment?*
3. *How to interact with the network, control it, and observe its performance?*

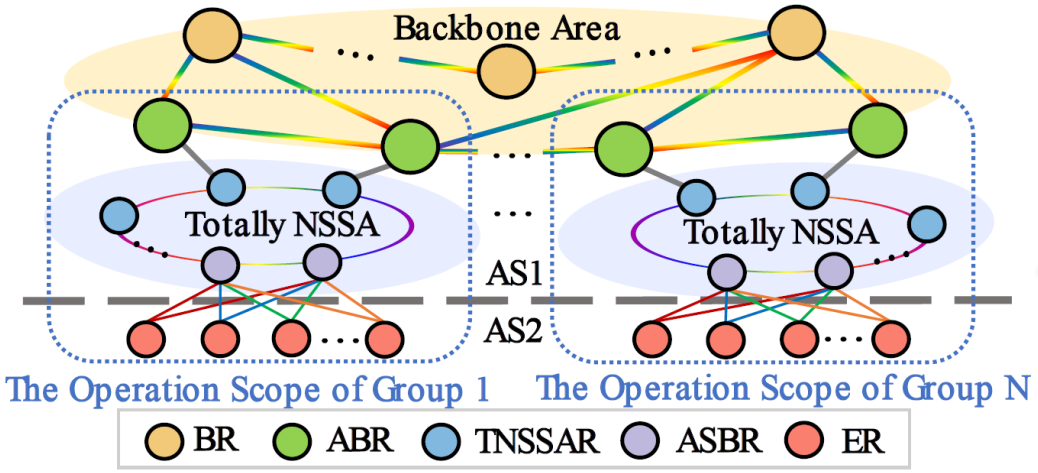
■ **Using Klonet's**

- **Image repository:** tutors can design new experiments quickly (*Address challenge 1*)
- **Scene repository:** students can start and refine experiments easily, TAs can correct and grade experiments easily (*Address challenge 1, 2*)
- **Web terminal, SSH connection:** students can program networks, control networks, and interact with networks easily (*Address challenge 3*)

Klonet holds great usability for both tutors and students

Use Cases -- Project Ⅱ: Intra-domain Routing

- **Help students gain a hands-on experiment that involves realistic network operations**

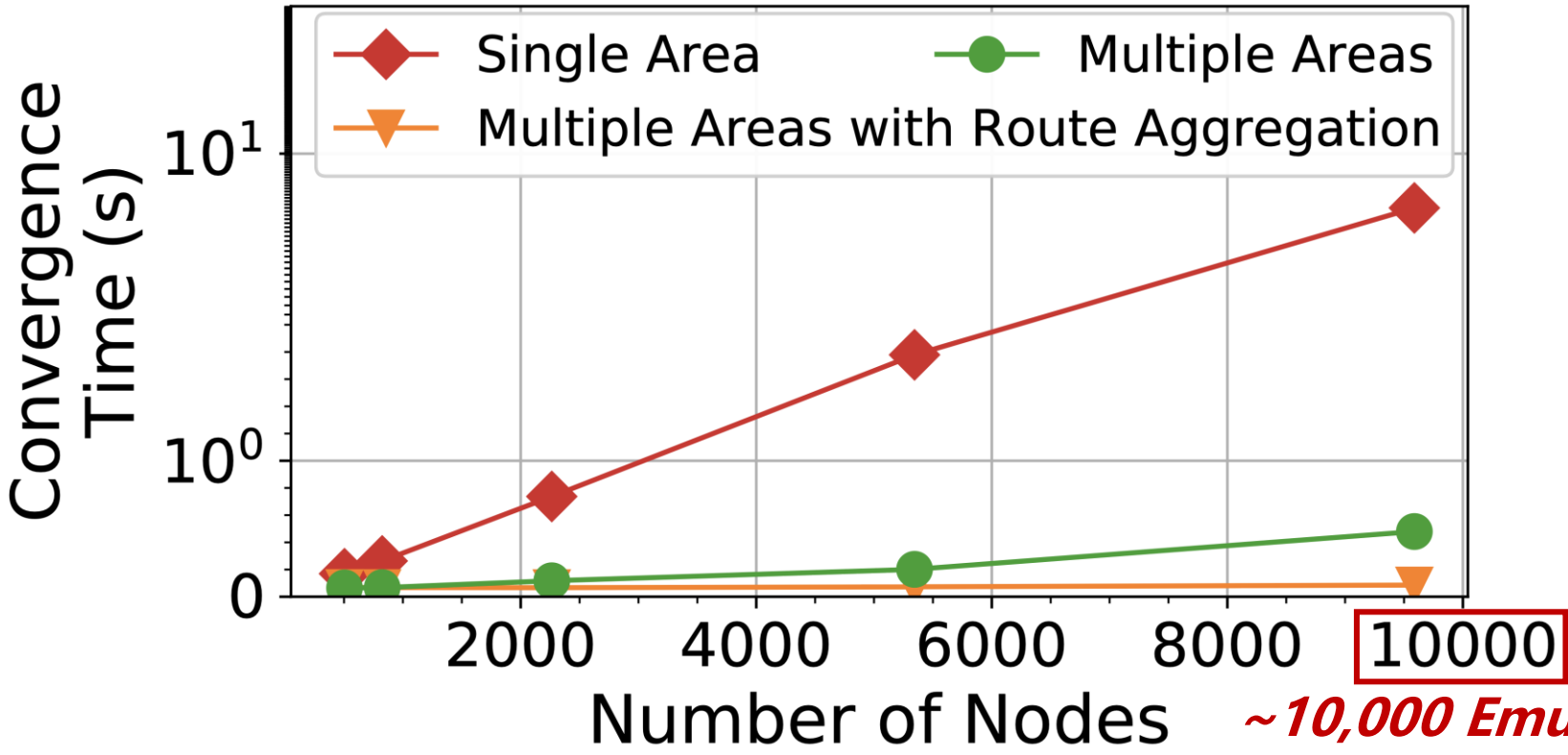


Challenges:

1. Massive scale as if in an enterprise network (up to ~10,000 routers)
2. Configure as if in an enterprise network
3. Observe as if in an enterprise network

- **Learning outcomes**
  - Build and operate enterprise network
  - Have a deeper understanding of OSPF and splitting areas
  - Observe and learn the benefits of route aggregation

Use Cases -- Project Ⅱ: Intra-domain Routing



~10,000 Emulated Routers

Klonet's virtual networks can scale to a very large size while maintaining the network's configurability and observability

Conclusion

- We present **Klonet**, an **easy-to-use** and **scalable** platform for computer networks **education**
- Klonet has been in development for **4 years** and in operation for **2 years**
- Klonet has been adopted in **3 universities** and **4 courses**, serving more than **800 students**
- **We call for more attention to be invested in computer networks education, for the future of our community!**

Thank You!

✉ **yuhf@uestc.edu.cn**

✉ Or if you have a WeChat account:

Welcome to contact us for discussion or cooperation!