Mininet: An instant Virtual Network on your Laptop

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work with Brandon Heller, Nikhil Handigol, Vimal Jeyakumar, and the Mininet Contributors
Talk Outline

Network Emulation
– Why it’s awesome

Challenges
– Scalability (demo)
– Ease of use (demo)
– Performance Accuracy (demo)

Interactive Demo
What is Network Emulation?

In this talk, *emulation* (running on an *emulator*) means running *unmodified* code *interactively* on *virtual hardware* on a *regular PC*, providing convenience and realism at low cost – with some limitations (e.g. speed, detail.)

This is in contrast to running on a *hardware testbed* (fast, accurate, expensive/shared) or a *simulator* (cheap, detailed, but perhaps slow and requiring code modifications.)
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Interactive Demo
Apps move seamlessly to/from hardware
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Interactive Demo
Creating a Network Emulator

Need to model hosts, switches, links, and (possibly) network controllers (for SDN/OpenFlow.)

Scalability challenge: we would like to model networks of interesting size with practical performance.

How to do it? Virtualization!
To start with, a Very Simple Network
Very Simple Network using Full System Virtualization

- VM Server
- Very Simple Network using Full System Virtualization
- ovs-vswitchd
- Linux Kernel
- openvswitch kernel module
- Host VM
- cupsd
- bash
- init
- eth0
- tap0
- 10.0.0.1
- Host VM
- cupsd
- bash
- init
- eth0
- tap1
- 10.0.0.2
- Host VM
- httpd
- bash
- eth0
- tap0
- 10.0.0.2
Very Simple Network using Lightweight Virtualization

Network Namespace 1
- firefox
- eth0
- veth1

Network Namespace 2
- httpd
- eth0
- veth2

Linux Kernel
- openvswitch kernel module

Server (or VM!)
Network Namespaces and Virtual Ethernet Pairs

Network Namespace 1
- Firefox
- eth0
- veth1

Network Namespace 2
- httpd
- eth0
- veth2

Root Namespace
- Software Switch

virtual Ethernet pairs
## Lightweight Virtualization in Linux

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<th>Network component or property</th>
<th>Modeling mechanism</th>
<th>Configuration command(s)</th>
</tr>
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<tr>
<td>Hosts</td>
<td>Processes in network namespaces</td>
<td>ip netns</td>
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<tr>
<td>Links</td>
<td>Virtual Ethernet pairs</td>
<td>ip link</td>
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<tr>
<td>Switches</td>
<td>Software switches (OVS)</td>
<td>ovs-vsctl</td>
</tr>
<tr>
<td>Controllers</td>
<td>Processes</td>
<td>controller</td>
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</table>
Demo

```bash
# mn --topo linear,100 --switch user --controller ref
```
Talk Outline

Network Emulation
  – Why it’s awesome
Challenges
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  – Ease of use (demo)
  – Performance Accuracy (demo)
Interactive Demo
Demo: basic network setup in Linux

```bash
sudo bash
# Create host namespaces
ip netns add h1
ip netns add h2
# Create switch
ovs-vsctl add-br s1
# Create links
ip link add h1-eth0 type veth peer name s1-eth1
ip link add h2-eth0 type veth peer name s1-eth2
ip link show
# Move host ports into namespaces
ip link set h1-eth0 netns h1
ip link set h2-eth0 netns h2
ip netns exec h1 ip link show
ip netns exec h2 ip link show
# Connect switch ports to OVS
ovs-vsctl add-port s1 s1-eth1
ovs-vsctl add-port s1 s1-eth2
ovs-vsctl show
# Set up OpenFlow controller
ovs-vsctl set-controller s1 tcp:127.0.0.1
ovs-controller ptcp: &
ovs-vsctl show
```

# Configure network
ip netns exec h1 ifconfig h1-eth0 10.1
ip netns exec h1 ifconfig lo up
ip netns exec h2 ifconfig h2-eth0 10.2
ip netns exec h1 ifconfig lo up
ifconfig s1-eth1 up
ifconfig s1-eth2 up
# Test network
ip netns exec h1 ping -c1 10.2
```
Wouldn’t it be great if...

We had a simple command-line tool and/or API that did this for us automatically?

It allowed us to easily create topologies of varying size, up to hundreds of nodes, and run tests on them?

It was already included in Ubuntu?
Basic network setup in Mininet (API)

```python
net = Mininet()

h1 = net.addHost( 'h1' )  # h1 is a Host() object
h2 = net.addHost( 'h2' )  # h2 is a Host()

s1 = net.addSwitch( 's1' )  # s1 is a Switch() object

ctrlr = net.addController( 'c0' )  # c0 is a Controller()

net.addLink( h1, s1 )  # creates a Link() object
net.addLink( h2, s1 )

net.start()

h2.cmd( 'python -m SimpleHTTPServer 80 &' )
sleep( 2 )

print h1.cmd( 'curl', h2.IP() )

CLI( net )

h2.cmd('kill %python')

net.stop()
```
mn command and Mininet CLI demo

# mn --test pingall

# mn --topo tree,depth=3,fanout=3 --link=tc,bw=10

mininet> xterm h1 h2
h1# wireshark &
h2# python -m SimpleHTTPServer 80
h1# firefox &
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Interactive Demo
# Performance modeling with Linux

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</tr>
<tr>
<td>Link performance</td>
<td>Traffic Control (and netem subsystem)</td>
<td>tc</td>
</tr>
<tr>
<td>CPU performance</td>
<td>CPU Control Groups (CFS bandwidth limits)</td>
<td>cg{create,set,delete, classify}</td>
</tr>
</tbody>
</table>
Demo: performance setup in Linux

# Limit link bandwidth and add delay
```
tc qdisc add dev s1-eth2 root handle 5: tbf rate 10Mbit burst 5k latency 12ms
```
```
tc qdisc add dev s1-eth2 parent 5:1 handle 10: netem delay 50ms
```
```
ip netns exec h1 ping -c4 10.2
ip netns exec h2 iperf -s & /dev/null &
ip netns exec h1 iperf -t 5 -c 10.2
```

# Limit CPU bandwidth
```
cgcreate -g cpu:/h1
```
```
cgset -r cpu.cfs_period_us=100000 /h1
cgset -r cpu.cfs_quota_us=20000 /h1
```
```
ip netns exec h1 bash -c "while true; do a=1;done" &
cgclassify -g cpu:/h1 $!
```

Diagram of network setup:
- **s1** (switch) connected to:
  - **h1** (host 1)
  - **h2** (host 2)

- **ctrl’er** node

- Link bandwidth limits:
  - 10 Mbps
  - 50 ms delay

- CPU bandwidth limits:
  - 20% for **h1**
  - 10.0.0.1 IP address

- 10.0.0.2 IP address for **h2**

- **20% of CPU** indicates CPU allocation for **h1**
Performance setup in Mininet

# Limit link bandwidth and add delay
net.addLink(h2, s1, cls=TCLink,
    bw=10, delay='50ms')

# Limit CPU bandwidth
net.addHost('h1', cls=CPULimitedHost, cpu=.2)
Accuracy = Matching hardware

Experiments on emulator should match results on hardware.

How to test? Micro/macrobenchmarks?

Better (and bigger) idea: Grad students!
reproducingnetworkresearch.wordpress.com
REPRODUCING NETWORK RESEARCH
network systems experiments made accessible, runnable, and reproducible

projects / about / contribute

Posts by CS244 Spring 2012 Students

- Exploring Outcast
- Multipath TCP over WiFi and 3G links
- TCP Dayton's Congestion Control with a Misbehaving Receiver
- Solving Bufferbloat - The CoDel Way
- Life's not fair, neither is TCP (.. under the following conditions)
- Fairness of Jellyfish vs. Fat-Tree
- DCell: A Scalable and Fault-Tolerant Network Structure for Data Centers
- Jellyfish vs. Fat Tree
- Choosing the Default Initial Congestion Window
- DCTCP and Queues
- DCell: A Scalable and Fault-Tolerant Network Structure for Data Centers
- Hedera
- Seeing RED
- Why Flow-Completion Time is the Right Metric for Congestion Control
- MPTCP Wireless Performance
- Increasing TCP's Initial Congestion Window
- HULL: High Bandwidth, Ultra Low Latency
- TCP Incast Collapse
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Interactive Demo
Demo: Connect to Mininet with your phone or laptop!

Interactive demo here in Gates 104:

1) connect to “mininet” wi–fi network
2) check your IP address if you like
3) go to www.mn
4) go to google.com or any other site
Demo Topology

Internet connectivity through Host OS

- **linux br**
- **dnsmasq**
- **www.mn**: 10.10.10.10
- **video.mn**: 10.10.10.11
- **h1**: 10.10.10.1
- **h2**: 10.10.10.2

**Switches**

- **Switch** (100 Mbps)
- **Switch** (5 Mbps)

**Network Devices**

- **d-link**
- **SSID: mininet**

**Network Configuration**

- MASQUERADE
  - `ip_forward=1`
- **NodeJS**
  - **h1**: www.mn 10.10.10.10
  - **h2**: video.mn 10.10.10.11

**Legacy Switch** (bridge mode)
class DemoTopo( Topo ):
    def __init__(self, inetIntf, wlanIntf, **opts):
        Topo.__init__(self, **opts)
        s1 = self.addSwitch( 's1' )
        s2 = self.addSwitch( 's2' )
        s3 = self.addSwitch( 's3' )
        # connect switches in a triangle
        self.addLink( s1, s2, cls=TCLink, bw=5, delay='1ms', max_queue_size=20 )
        self.addLink( s2, s3 )
        self.addLink( s1, s3, cls=TCLink, bw=100, delay='1ms', max_queue_size=20 )
        # add servers and connect to s2
        h1 = self.addHost( 'h1', ip='10.10.10.10/24', defaultRoute='via 10.10.10.1' )
        h2 = self.addHost( 'h2', ip='10.10.10.11/24', defaultRoute='via 10.10.10.1' )
        self.addLink( s2, h1 )
        self.addLink( s2, h2 )
        # add NAT and connect it to s1
        nat = self.addNode( 'nat', ip='10.10.10.1/24', cls=NAT,
            subnet=10.10.10.0/24, inetIntf=inetIntf, inNamespace=False )
        self.addLink( s1, nat )
        # add DHCP server and connect it to s3
        dhcp = self.addNode( 'dhcp', ip='10.10.10.2/24', cls=DHCPServer, defaultRoute='via 10.10.10.1' )
        self.addLink( s3, dhcp )
        # add the WiFi interface to s3
        self.addLink( s3, s3, cls=HWIntfLink, intfName1=wlanIntf, cls2=NoneIntf )
Enjoy Mininet!

mininet.org

docs.mininet.org

teaching.mininet.org

reproducingnetworkresearch.wordpress.com

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Interactive Demo
Backup Slides
Predictive Accuracy: *Network Invariants*

Idea: Emulator should not violate conditions that we know must be true.

For example, for non-empty switch queue, output data rate should be constant and packets should be evenly spaced.

If we can *specify and monitor invariants*, simulation is more likely to be accurate.

More info at: http://purl.stanford.edu/zk853sv3422
Demo: Reproducible experiments and a “Runnable” Paper

Reproducible Network Experiments using Container-Based Emulation
http://conferences.sigcomm.org/co-next/2012/e-proceedings/conext/p253.pdf
Mininet(.org)

- command line tool and interface (mn)
- simple Python API
- parametrized topologies
- link modeling and CPU limits
- scales to hundreds of nodes on a laptop
- free/open source – you can (and should) contribute code on GitHub
- mininet-discuss mailing list
- pre-made VM image (easy to run/share)
- included in Ubuntu!
Low-level API: Nodes and Links

```python
h1 = Host( 'h1' )
h2 = Host( 'h2' )
s1 = OVSSwitch( 's1', inNamespace=False )
c0 = Controller( 'c0', inNamespace=False )
Link( h1, s1 )
Link( h2, s1 )
h1.setIP( '10.1/8' )
h2.setIP( '10.2/8' )
c0.start()
s1.start( [ c0 ] )
print h1.cmd( 'ping -c1', h2.IP() )
s1.stop()
c0.stop()
```
Mid-level API: Network object

```python
net = Mininet()

h1 = net.addHost( 'h1' )
h2 = net.addHost( 'h2' )
s1 = net.addSwitch( 's1' )
c0 = net.addController( 'c0' )

net.addLink( h1, s1 )
net.addLink( h2, s1 )
net.start()

print h1.cmd( 'ping -c1', h2.IP() )
CLI( net )
net.stop()
```
High-level API: Topology templates

class SingleSwitchTopo( Topo ):
    "Single Switch Topology"
    def __init__( self, count=1, **params ):
        Topo.__init__( self, **params )
        hosts = [ self.addHost( 'h%d' % i )
                  for i in range( 1, count + 1 ) ]
        s1 = self.addSwitch( 's1' )
        for h in hosts:
            self.addLink( h, s1 )

    net = Mininet( topo=SingleSwitchTopo( 3 ) )
    net.start()  
    CLI( net )
    net.stop()

more examples and info available at docs.mininet.org
## Example Mininet use cases

<table>
<thead>
<tr>
<th>... for Teaching</th>
<th>organization(s)</th>
<th>link</th>
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</thead>
<tbody>
<tr>
<td><strong>Buffer Bloat</strong> (in–class lab)</td>
<td>Stanford (CS144)</td>
<td><a href="https://github.com/mininet/mininet/wiki/Bufferbloat">https://github.com/mininet/mininet/wiki/Bufferbloat</a></td>
</tr>
<tr>
<td><strong>MAC Overflow Attack</strong> (demo)</td>
<td>Stanford (CS144)</td>
<td><a href="https://github.com/mininet/mininet/wiki/Mac-address-table-overflow-attack">https://github.com/mininet/mininet/wiki/Mac-address-table-overflow-attack</a></td>
</tr>
<tr>
<td>Simple <strong>OpenFlow hub and firewall</strong> (and other course assignments)</td>
<td>Georgia Tech, Coursera (MOOC)</td>
<td></td>
</tr>
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</table>

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<tr>
<td><strong>ElasticTree</strong></td>
<td>Stanford, Berkeley</td>
<td><a href="http://dl.acm.org/citation.cfm?id=1855728">http://dl.acm.org/citation.cfm?id=1855728</a></td>
</tr>
<tr>
<td><strong>NetSight</strong></td>
<td>Stanford</td>
<td></td>
</tr>
<tr>
<td><strong>Reproducible Research Experiments</strong></td>
<td>Stanford (and hopefully everywhere!)</td>
<td><a href="http://reproducingnetworkresearch.wordpress.com">http://reproducingnetworkresearch.wordpress.com</a></td>
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<tr>
<td><strong>Floodlight</strong></td>
<td>Big Switch</td>
<td><a href="http://www.projectfloodlight.org/floodlight/">http://www.projectfloodlight.org/floodlight/</a></td>
</tr>
<tr>
<td><strong>??</strong></td>
<td>Insieme/Cisco</td>
<td><a href="http://www.insiemenetworks.com">http://www.insiemenetworks.com</a></td>
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</table>
Mininet usage and adoption

Students: use it at many universities (e.g. Stanford CS144, CS244), MOOCs

Researchers: have used it for many SDN projects (e.g. Beacon, Netsight, ONOS, …)

Teachers: use it for labs, demos and course projects – teaching.mininet.org

Companies: used by Big Switch, HP, Insieme, others (liberal BSD license so we don’t know)

IT services: used at Stanford for experimenting with SDN applications
Mininet usage: indirect numbers

Mininet.org

~133,000 visits since inception
October 2013: 16,000 visits

Pre-installed Virtual Machine Downloads

Mininet 2.0 – 217,134 (12/1/12 – 9/20/13)
Mininet 2.1 – 12,714 (9/20/13 – 11/3/13)

Github: 142 Forks (private copies of the source hosted on Github)

mininet-discuss Mailing List: ~180–250 messages/month, ~975 members

CiteSeerX: 31+ citations (and growing!)
Experiences running an Open Source software project

+ Increases impact, benefit, and visibility (for the project at least)

+-: code (and other) contributions

- A lot of work to go from research prototype to production (documentation, web site, tests, examples, build system, launchpad...)

- Large support overhead (mailing list is a self-filtering system)

- More public criticism (some inaccurate)

- Work appropriation ("HP Mininet")
Mininet Enhancements/Futures

Cluster Edition/Distributed Mininet:
Tunnels are easy! Work at ARCCN, U. Paderborn, ON. Lab enables large networks (ARCCN: 30,000 nodes?!) 

Time Dilation: Work at Stanford (Vimal J., Antonin Bas) decouples virtual time from real time, allowing “faster” simulations

GSoC 2013 projects: “Clone” a physical topology on Mininet; wireless link modeling integrating ns-3 model
Some related work

Container-based emulators: CORE, virtual Emulab, Trellis, Imunes, even ns-3 (in emulation mode)

VM-based emulators: DieCast

UML-based emulators: NetKit

Simulators: ns-3, OPNET

Testbeds: Emulab, GENI, PlanetLab, ORBIT