Case Studies in Experiment Design on a minimega Based Network Emulation Testbed

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DARPA Searchlight Program

- Enterprises need better tools to (1) understand network activity, and (2) manage quality of service
- TA1: Network traffic analysis
  - What does a network look like? What is the topology, what are the paths, etc.
  - What protocols, and more specifically, what applications are on the network?
  - What are the network's performance characteristics?
- TA2: Network resource management
  - Manage QoS between multiple applications of different priorities
  - Communicates with a TA1 to understand network behavior and state

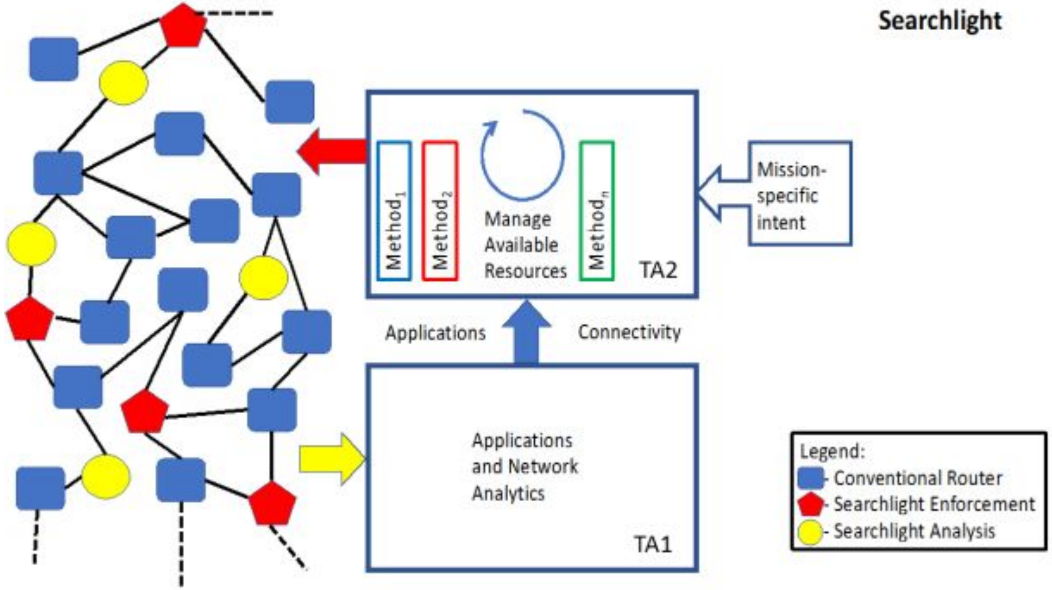


Figure 2: Searchlight Technical Area 1 and Technical Area 2

Source: https://sam.gov/api/prod/opps/v3/opportunities/resources/files/c48c47baaa1db4b26a023b3426d838ba/download?&status=archived&token=

Test and Evaluation Challenges

- Our objective: systematically evaluate TA1 and TA2 technologies on a variety of representative network conditions and applications
- TA1 evaluation challenges:
    - Evaluate classification accuracy of different applications on the network
        - Many combinations of applications make its job harder
    - Evaluate many different network topologies and network resource configurations
    - Understand impact of VPNs/tunnels on TA1 capabilities
- TA2 evaluation challenges:
    - Deploy high fidelity networks capable of supporting custom layer-2 forwarding applications
        - Virtual Openflow switches, DPDK applications, etc

minimega

Sandia National Laboratories

minimega

https://tip.minimega.org

- Virtualization based network emulation tool from Sandia National Laboratories
- Define and launch VM-based networks through Qemu/KVM
- Layer-2 network virtualized with VLAN-based software bridge (OpenvSwitch), with VXLAN tunnels for emulating networks that span physical nodes
- Orchestrate runtime behavior through a custom command-and-control system

Our experience with minimega

Features we liked and made use of:

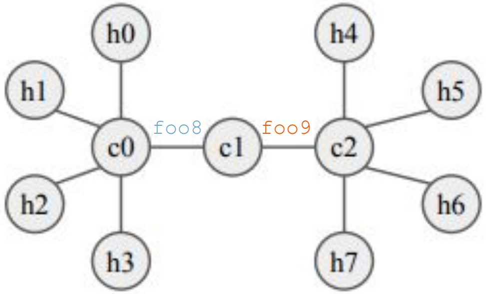
- High resource utilization
  - We were somewhat resource limited on our physical testbed (DeterLAB) at the time
- Zero configuration for DHCP/DNS
- `minirouter` and its centralized routing interface
  - We used a combination of static and OSPF based routing
- Management of images through Qemu snapshots

Challenges we encountered:

- Topology modeling
- Configuration and deployment of traffic

Our experimental needs required us to run several hundreds of experiments with a mixture of different topologies and application traffic mixes

Topology Modeling




```
for i in $(seq 0 7); do
    vm config net foo$i
    vm config h$i
done
vm config net foo0,foo1,foo2,foo3,foo8
vm start c0
vm config net foo4,foo5,foo6,foo7,foo9
vm start c2
vm config net foo8,foo9
vm start c1
```

- Maintaining lists of VLAN tags can get cumbersome, particularly as topologies grow in size and complexity
- Users of other network emulation testbeds (e.g., Emulab) are often familiar with link-centric specification methods
  - Specify links with endpoints, instead of nodes with network interface cards

Topology Modeling

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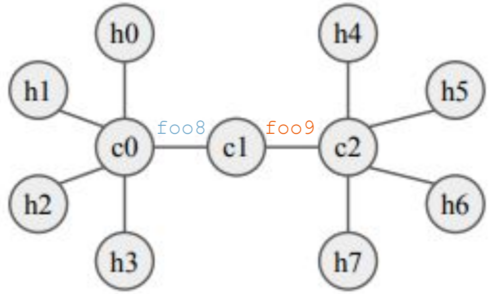


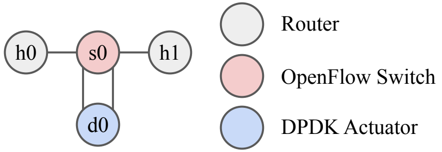
Alternative Network Model

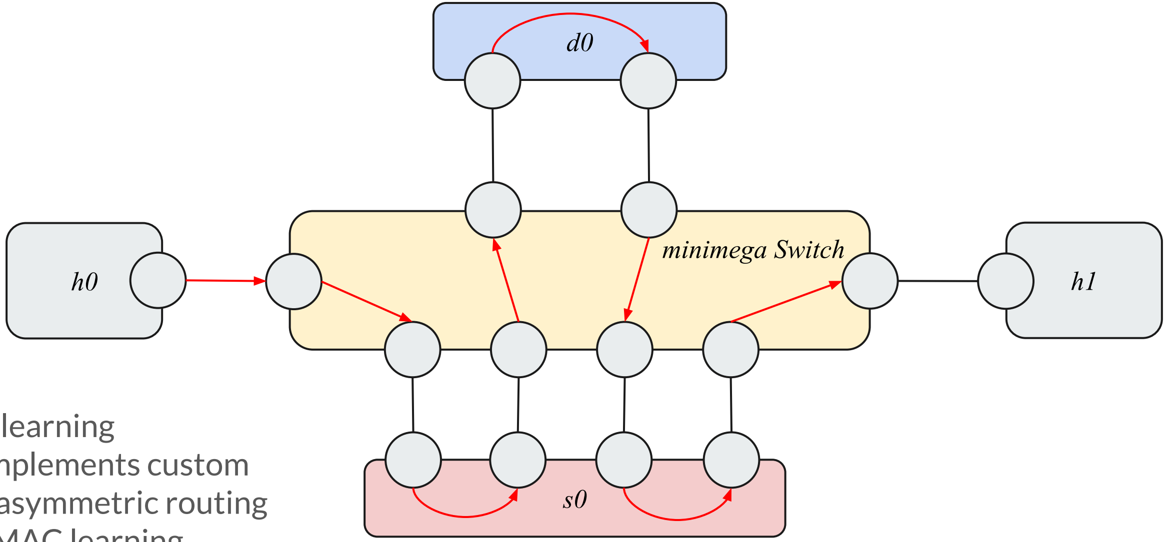
```
for i in $(seq 0 3); do
    connect_vms h$i c0
done

for i in $(seq 4 7); do
    connect_vms h$i c2
done

connect_vms c0 c1
connect_vms c2 c1
```

Topology Modeling: VM-to-VM Links





- Minimega switches use source MAC address learning
- This causes problems when guest software implements custom layer-2 forwarding mechanisms or performs asymmetric routing
- We developed VM-to-VM links that remove MAC learning
- More details in the paper

Traffic Modeling

- Minimega has limited traffic generation support through the `protonuke` traffic generator
- Deployment of traffic is done by developing shell scripts which minimega issues to each unique traffic generating end-host
- Challenges:
  - We found ourselves generating redundant shell scripts with significant overlap for things like managing process lifecycles and copying support bundles
  - Lack of traffic realism
- 3 contributions:
  - Development of a set of new traffic applications that extend minimega's native `protonuke` support.
  - Development of a common JSON-based structural abstraction that encodes application configuration
  - Compiler which automates the construction of shell scripts commands

Traffic Modeling: Video Streaming Example

```
{
    "video-streaming" : {
        "h0" : [{
            "target" : "h2",
            "params" : {
                "client" : {
                    "resolution" : "720",
                    "protocol" : "hls"
                },
                "server" : {}
            }
        }]
    }
}
```

Traffic Modeling: Video Streaming Example

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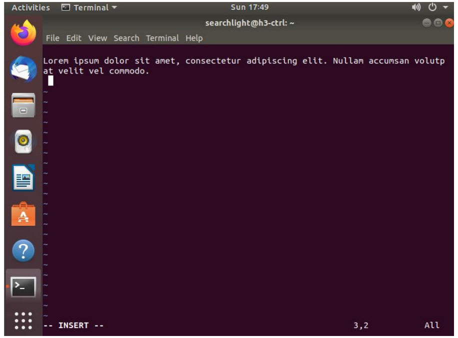
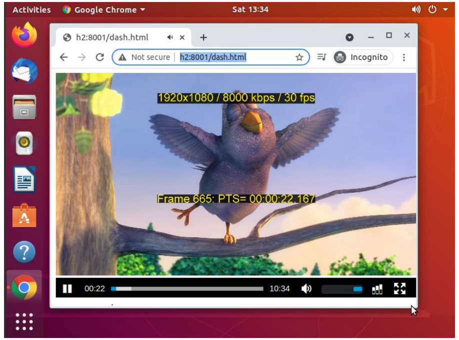
                    "protocol" : "hls"
                },
                "server" : {}
            }
        }]
    }
}
```

```
cc exec bash -c "rm -rf /tmp/miniccc/files/miniccc_files//video-streaming/"
cc send miniccc_files/protonuke
clear cc filter
cc filter name=h2
cc send miniccc_files/video-streaming/www.tar.gz
cc send miniccc_files/video-streaming/extract-www-tar.sh
cc exec bash -c
"/tmp/miniccc/files/miniccc_files/video-streaming/extract-www-tar.sh"
cc background /root/www-video/run.sh
clear cc filter
cc filter name=h0
cc send miniccc_files/video-streaming/client-watch-video.tar.gz
cc send miniccc_files/video-streaming/extract-client-watch-video-tar.sh
cc exec bash -c
"/tmp/miniccc/files/miniccc_files/video-streaming/extract-client-watch-video-tar.sh"
cc background sudo -u searchlight /home/searchlight/client-watch-video/run.sh
--server h2:8001 --resolution 720 --protocol hls --time 3
```

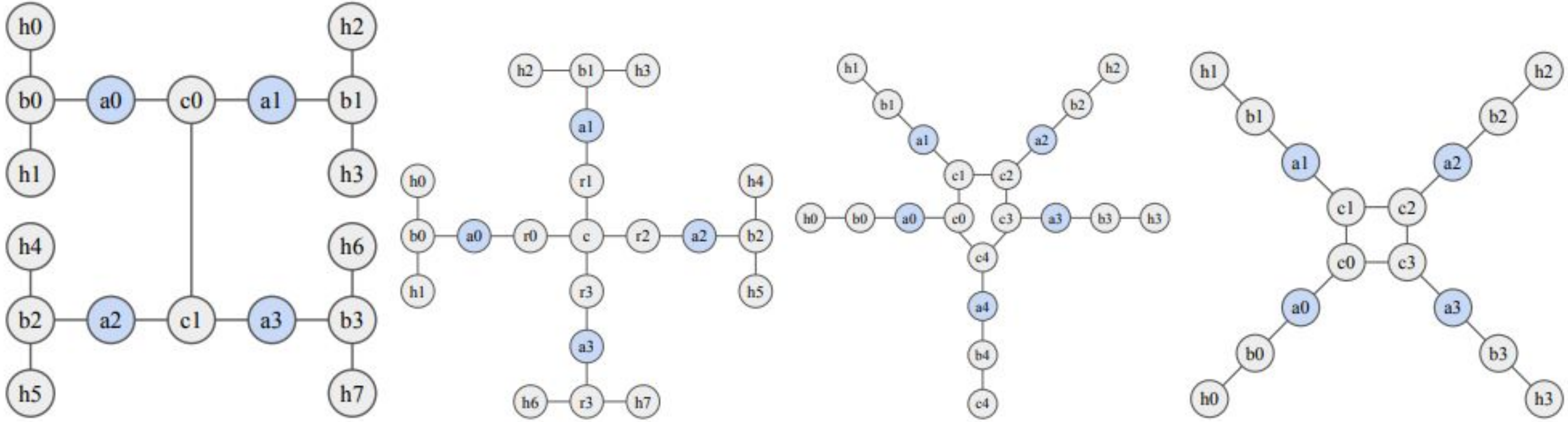
Traffic Types





- Several types supported natively by protonuke
  - File transfer with many protocol variants (SCP, HTTP(s), FTP(s))
  - IRC
  - Email (SMTP)
  - Web Browsing
- Additional types developed by our team
  - SSH text editing
  - Video Streaming
    - HLS, DASH, and HTML5 based options supported
- Compilation
  - Our scripts compile a single JSON based traffic representation into a set of scripts for each client or server endpoint in the topology
  - Removes the need to develop a large collection of `miniccc` scripts

Case Study: Distributed Topology Discovery



(a) Double dumbbell **(b) Star** **(c) 5-node loop** **(d) 4-node loop**

Objective: evaluate how well the system could measure the topological characteristics

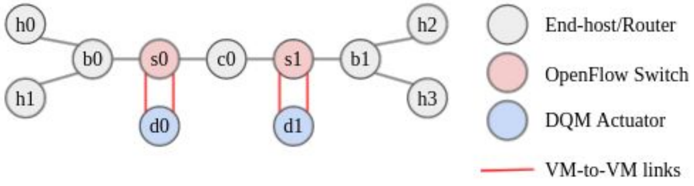
- Connectivity, routing (asymmetry + multipath), link criteria (delay/bandwidth/loss)

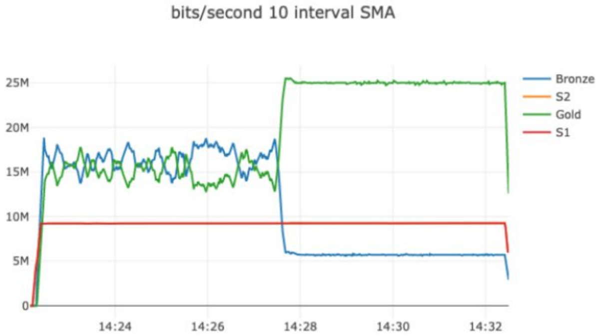
Case Study: Real-Time Traffic Classification

Objective: evaluate the system's ability to infer the set of applications on the network

- We developed a large collection of unique subsets of applications and determined classification accuracy
- Over 500 individual experiments using 26 different combinations of applications
- Structured, centralized interface to define traffic was instrumental in automating these experiments

Case Study: Distributed Traffic Engineering





- Objective: evaluate how well the system could achieve a target QoS specification (bandwidth for each application)
- Required VM-to-VM links due to the use of OpenFlow switches in the topology that could generate MAC address migration from the perspective of the minimega OVS switch

Takeaways and Conclusion

- Minimega is a useful, mature tool
  - Zero configuration DHCP/DNS
  - Centralized router configuration
  - VM lifecycles management
  - Image management
- We extended it to make it easier to run a lot of experiments that vary in subtle ways
  - Link centric models instead of VM centric in the minimega API
  - VM-to-VM links to address MAC learning problems
  - Centralized and automated traffic generation routines
- Models developed to run the experiments in the paper will soon be available online: https://mergetb.org/projects/searchlight
- Thanks to the minimega community for a great testbed tool

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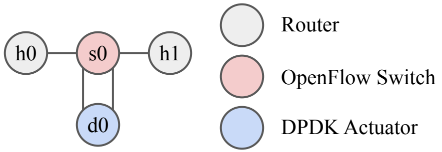
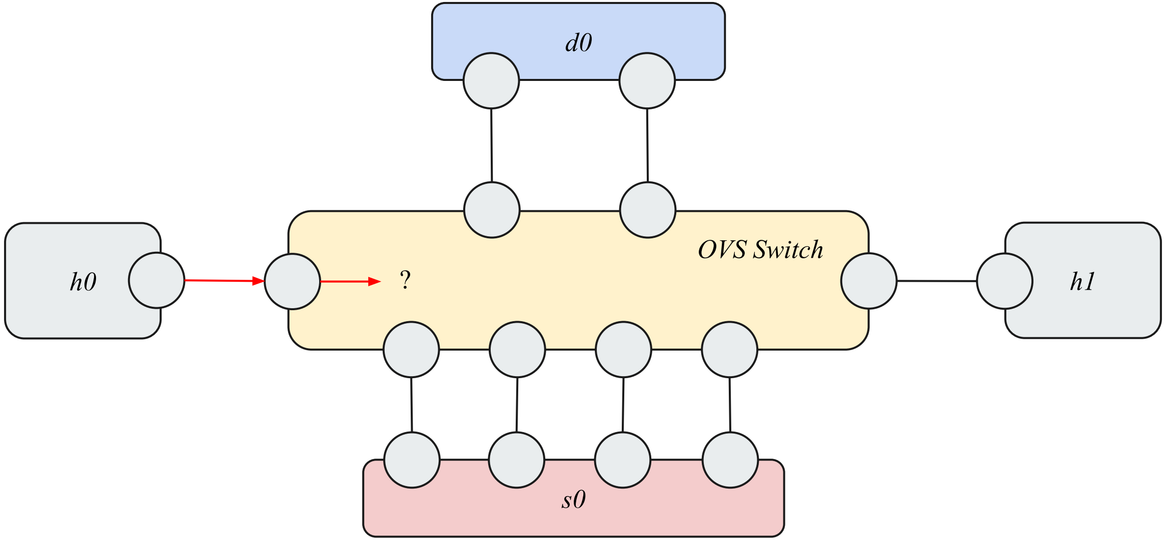
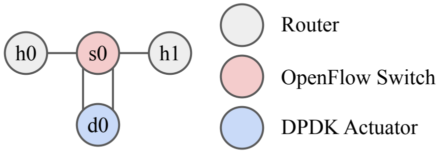
Backup Slides

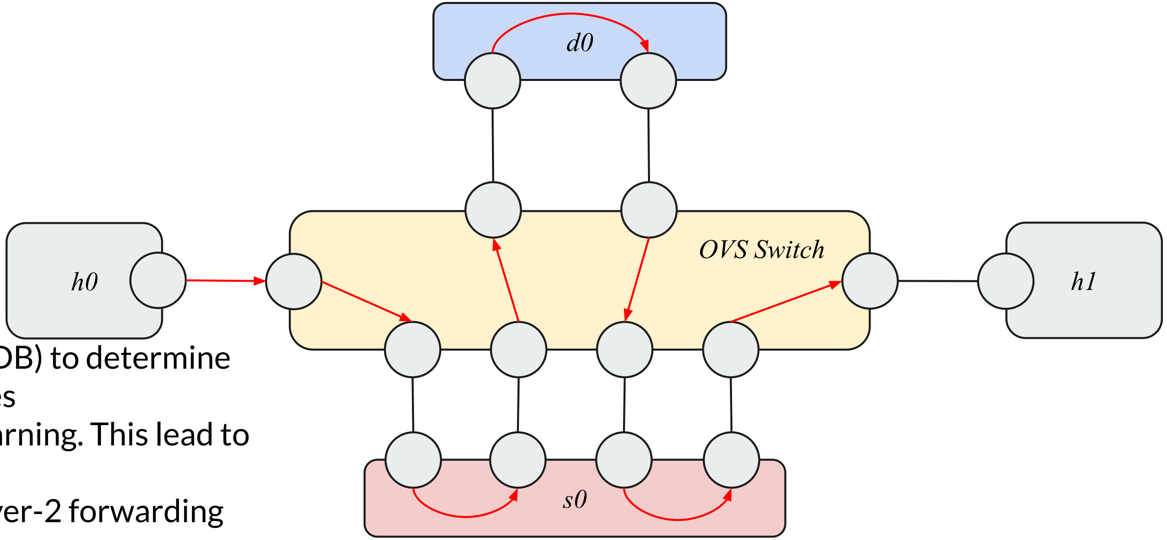
Topology Modeling: VM-to-VM Links





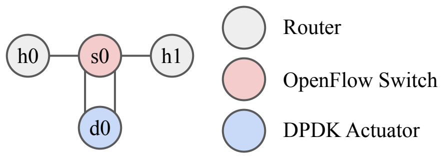
Topology Modeling: VM-to-VM Links

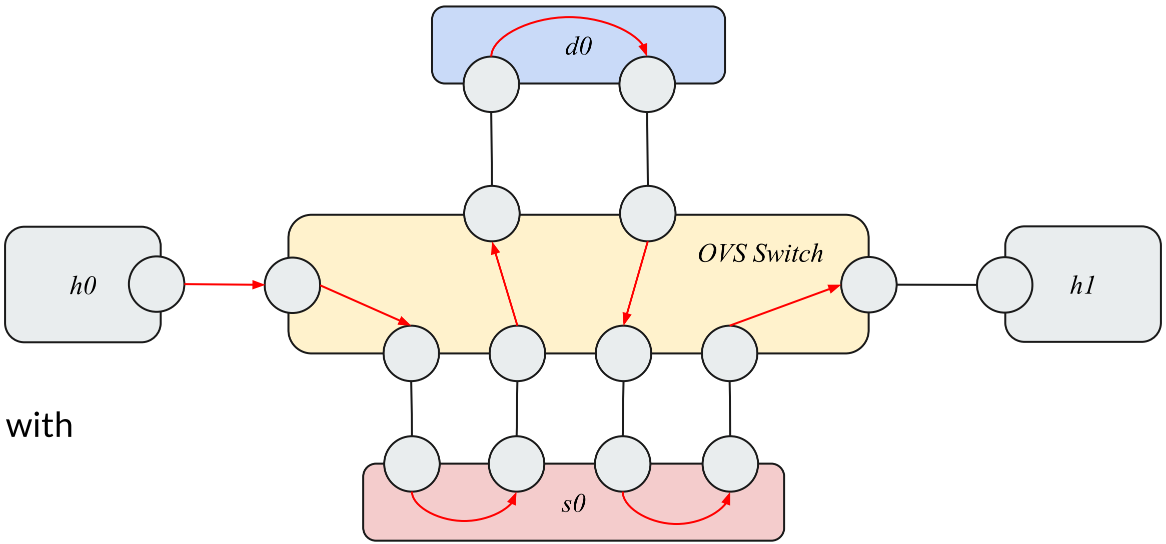




- Switch uses a switch forwarding database (FDB) to determine how to forward packets between TAP devices
- FDB is constructed through MAC address learning. This lead to at least two issues for us when:
    - Guest switches implement custom layer-2 forwarding mechanisms
    - Guest routers construct asymmetric routes
- MAC learning based forwarding becomes problematic, leading to excessive BUM traffic broadcast and/or packet loss

Topology Modeling: VM-to-VM Links





Solution: program minimega switch FDB with known device endpoints; e.g.:

```
connect_vms s0 d0
mark_v2v s0 d0
```

Removes MAC learning from FDB construction