Privacy Enhancing Technologies (PETs) Testbed

REPHRAIN
Protecting citizens online

THE UNIVERSITY of EDINBURGH
informatics

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Overview

- Background
- Use Cases
- Design Considerations
- Current Implementation
- Demonstration
- Privacy Analysis
- Future Work
- Conclusion

Use Cases

Diversity of Users

Research

CS, HCI, STS, Funders,

→ Publication, Evaluation, Teaching

Policy

Standardization, Law Enforcement, Civil Servants

→ Regulatory Content/ Enforcement, Sharing datasets

Public Users

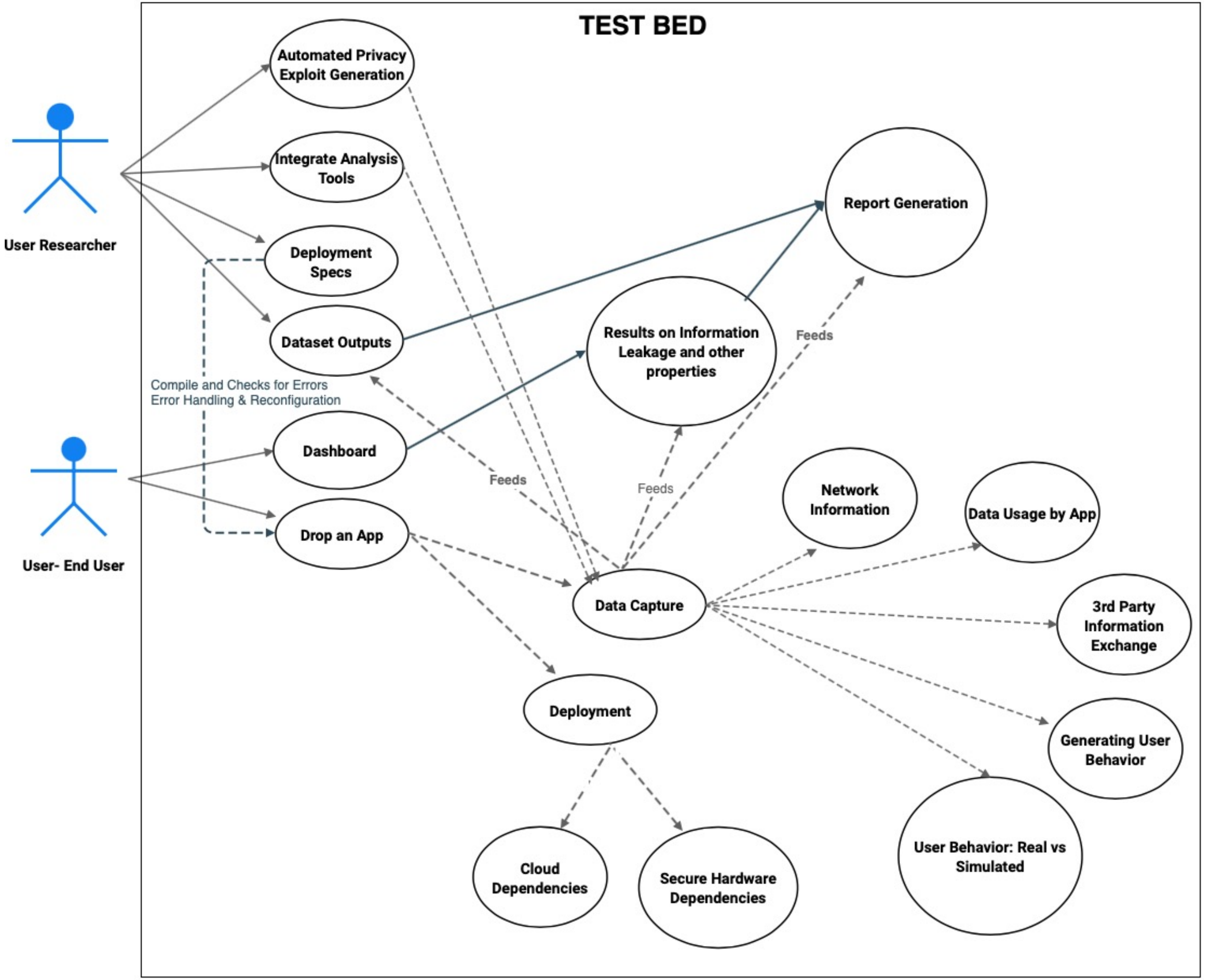
Journalists, Special Abilities, Charities,

→ Citizen Watch

Industry

Developers, Managers

→ Regulatory Evaluation, Independent Evaluation, Use Datasets


TEST BED
User Researcher
User- End User
Automated Privacy Exploit Generation
Integrate Analysis Tools
Deployment Specs
Dataset Outputs
Compile and Checks for Errors
Error Handling & Reconfiguration
Dashboard
Drop an App
Report Generation
Results on Information Leakage and other properties
Feeds
Feeds
Feeds
Network Information
Data Usage by App
3rd Party Information Exchange
Generating User Behavior
User Behavior: Real vs Simulated
Data Capture
Deployment
Cloud Dependencies
Secure Hardware Dependencies

Use Case 1

- Developer Alpha produces an app using multiple third party libraries
- Wants to see if libraries are collecting unnecessary data from users
- Testbed launches multiple instances of Android and IoS devices with app installed
  - Testbed can simulate user interaction with app
- Testbed collects all network traffic from apps to internet, presents report to Alpha
  - Traffic contents, destinations etc
- Testbed can map collected data to a privacy-evaluation framework (e.g. Privacy by Design, LINDDUN)
- Testbed can apply automated analysis (e.g. Exodus, LibRadar)

https://www.linddun.org

Use Case 2

- Developer Beta develops a privacy preserving P2P file sharing application
- Wants to measure resilience against attacks such as Sybil or partitioning
- Launches large number of instances in P2P topology
- Makes subset of instances “malicious” to perform the attack
- Performs attacks, and measures impact on privacy and performance

Use Case 3

- Privacy Engineer Gamma wants to learn about and test modern PETs, e.g. homomorphic encryption, secure multi-party computation and differential privacy
- Testbed used to run and evaluate these technologies before use in final product
  - Can launch instances and simulate “users”

Current Test Case – End to End Encrypted Messengers

- What information is leaked from end to end encrypted messengers?
  - E.g. Signal, Whatsapp, Telegram
- Run clients in testbed, capture traffic, look for information leakage
  - Metadata
  - Inferable data

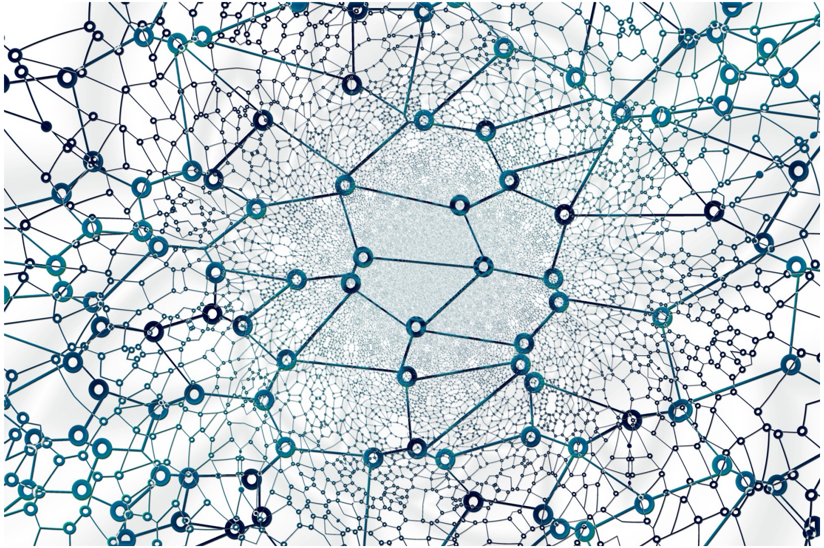
Testbed Design Considerations

Key Functionalities

- Deployment
- Orchestration
- Data Logging

Deployment

- Testbed should allow for easy deployment of services and hosts
  - Potentially thousands
- Support for both traditional hosts, as well as emulated smartphone OSs
- Testbed should provide a virtual network
  - Use of SDN for orchestration

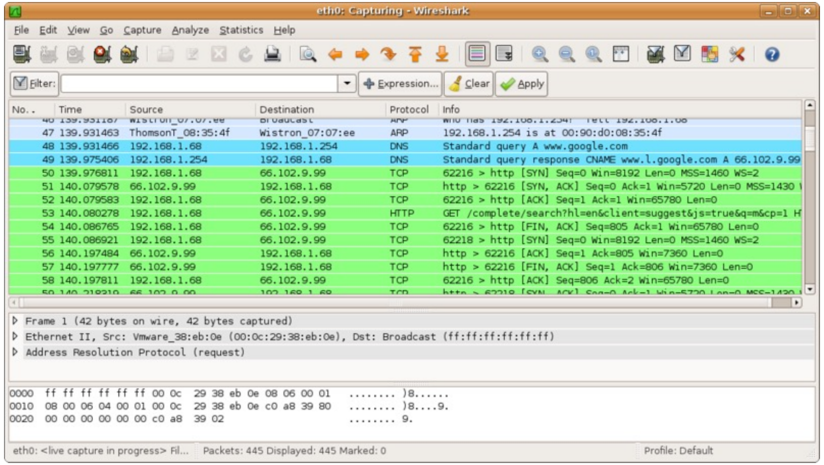


Orchestration

- Testbed should allow for automated control of applications
- Simulated user interaction, simulated sensor values
- Replaying of network traffic captures

Data Logging

- Testbed should capture sufficient data for analysis
- Potential sources:
  - Network captures
  - Memory captures
  - Screen captures



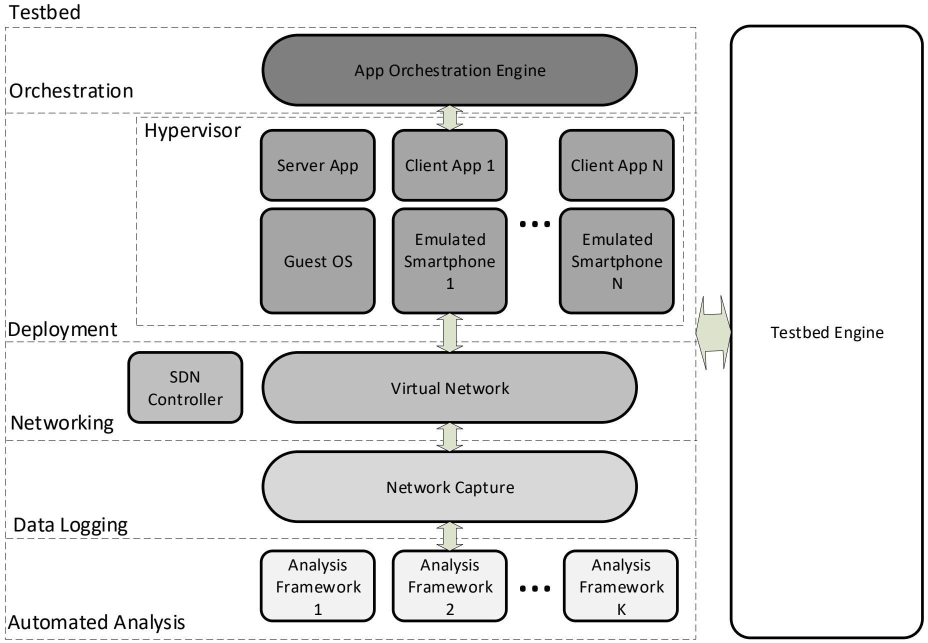
Further Design Elements

- Application Agnostic
  - Testbed should support multiple application types and architectures
- Extensibility
  - Testbed should be scalable.
  - Multiple instances of testbed should be joinable to increase virtualisation capability
- Automated Analysis
  - Testbed should have automated privacy analysis tools to be easily applied to use cases with minimal knowledge
- Modularity
  - New features (such as new analysis tool) can be added to testbed with ease

Testbed Implementation

Overview

- Testbed consists of tool, kvm-compose, which manages deployment, networking and orchestration



Virtualisation

- Virtualisation is provided using KVM
- Can deploy OS from disk image, or build as required
- Android applications emulated using Google's Android Virtual Device (AVD)
  - Deployed inside Ubuntu Desktop VM
- Virtualisation managed by kvm-compose tool

kvm-compose

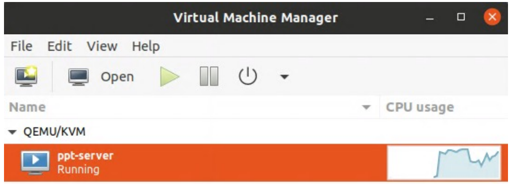
- kvm-compose is a CLI tool Jacob developed (and expended by team) for Linux using Rust (and the libvirt library) that takes in a custom configuration file format describing a test environment, and can create or destroy it (with up/down subcommands).

kvm-compose.yaml

```yaml
machines:
  - name: server
    memory_mb: 4096
    cpus: 2
    disk:
      existing_disk:
        path: ./server-disk.img
        driver_type: qcow2
    interfaces:
      - bridge: br0

bridges:
  - name: br0
```

$ kvm-compose up

→



- This is the first step of automating a testbed:
- From a simple configuration file kvm-compose will deal with the conversion to a relatively complex libvirt domain configuration XMLs (for KVM), and create the virtual machines.
- It will also create and connect the virtual machines up to a virtual network

Cloud-init, Scripting, Context etc.

- cloud-init is used to automatically initialize new virtual machines (disk creation and software installation). The NoCloud datasource option uses a clever system of attaching a specifically formatted virtual disk, and passing flags via the SMBIOS serial number of the VM.
- What happens now?

kvm-compose.yaml

```yaml
machines:
  - name: server
    disk:
      cloud_image:
        name: ubuntu_18_04
        expand_gigabytes: 20
    interfaces:
      - bridge: br0
    run_script: ./first_boot_script.sh
    context: ./context_folder

ssh_public_key: ssh-rsa AAAAB3NzaC1yc2EAAAADAQABAAACAQC
```

- The Ubuntu cloud image will be downloaded (once and then cached), copied, and expanded with 20G free space.
- At boot the machine will auto configure its hostname to match the machine name in the configuration file.
- Our SSH public key will be injected into the instance, allowing remote access.
- Files in the context folder will be copied in at /etc/nocloud/context.
- An arbitrary run_script will be run once on the first boot.

Networking – Software Defined Networking

- Networking is provided using OpenvSwitch (OVS)
- OVS bridges can easily be linked up to an SDN controller (such as Floodlight), enabling more advanced network management.

```
bridges:
  - name: br0
    connect_external_interfaces: [eth0]
    enable_dhcp_client: true
    controller: tcp:127.0.0.1:6653
    protocol: OpenFlow13
```

Floodlight Dashboard Topology Switches Hosts Live updates

Switch 00:00:00:15:5d:0a:8f:17 /127.0.0.1:33980

Connected Since 28/04/2021, 11:42:14
Nicira, Inc.
Open vSwitch
2.13.1
S/N: None
OpenFlow Version: OF_13

Ports (4)

#	Link Status	TX Bytes	RX Bytes	TX Pkts	RX Pkts	Dropped	Errors
local (dp3t-br0)	UP	0	0	0	0	0	0
1 (eth0)	UP 1 Gbps FDX	0	0	0	0	0	0
2 (vnet0)	UP 10 Mbps FDX	0	0	0	0	0	0
3 (vnet1)	UP 10 Mbps FDX	0	0	0	0	0	0

Flows (73)

Cookie	Table	Priority	Match	Apply Actions	Write Actions	Clear Actions	Goto Group	Goto Meter	Write Metadata	Experimenter	Packets	Bytes	Age (s)	Timeout (s)
9007199254740992	0x0	1	in_port=1 eth_dst=00:15:5d:0a:8f:17 eth_src=c2:84:b4:74:d6:e4 eth_type=0x0x800 ip_proto=0x6 ipv4_src=34.107.221.82 ipv4_dst=10.3.10.146 tcp_src=80 tcp_dst=55810	actions:output=local	---	---	---	---	---	---	2	572	7	5

Networking - Management

- Linux bridge acts as DHCP and DNS server for clients, and as gateway for internet access
- Also provides NAT service for external connections
- At least one of the OVS bridges must be connected to Linux bridge
- Clients connect to OVS bridges, Linux bridge assigns IP addresses and runs internal DNS
- Internal routing managed by SDN controller, external traffic routed to linux bridge and external interface

Orchestration

- Need to be able to configure and control applications automatically
- Cloudinit can handle configuration and installation
- For interaction with command line applications, can use SSH
- For automated interaction with AVD devices, can use ADB functionality
  - Send screen presses
  - Send text
  - Can be recorded and replayed, or programmatically generated

Data Capture

- Tcpdump can be run on OVS bridges
  - A mirror port is configured and used for capture
- Can capture on individual bridges to capture at different points on the network
- If using external services, can capture on Linux Bridge to collect all traffic from testbed to outside
  - Does feature noise from background host machine and VM traffic

Demonstration

Demonstration Overview

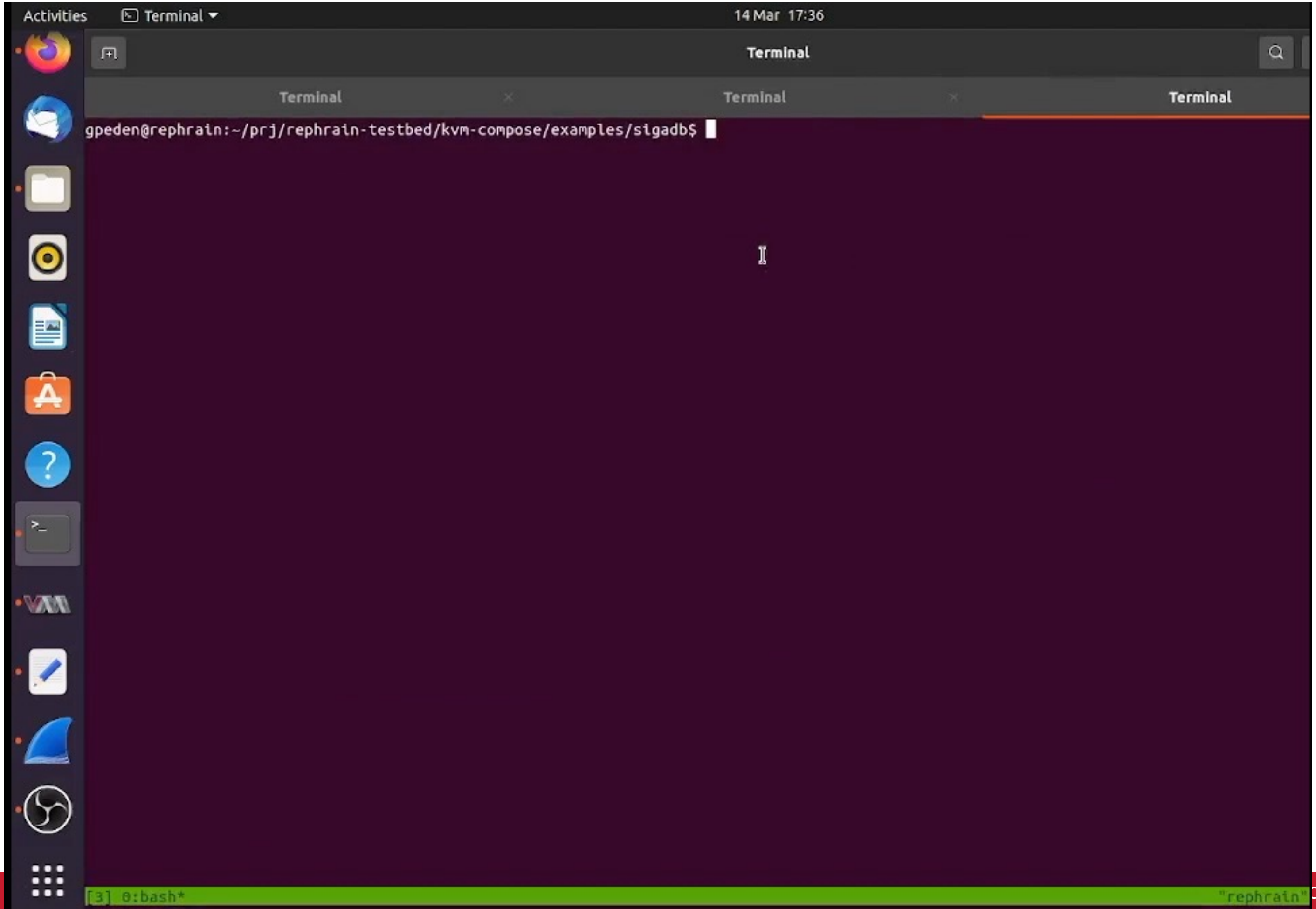
- We will launch an deployment of the Signal end-to-end encrypted messaging application
- We will run 2 Android Signal clients on emulators, communicating with the real-world Signal servers
  - We can also run the 3rd party Signal-CLI client with our own server
- Clients will register numbers manually
- Clients will communicate automatically
- Testbed is running on a Dell Workstation
  - 2x Intel Xeon 4110 CPU (8 core 2.1 GHz), 125Gb RAM.

Demonstration – Virtual Machines

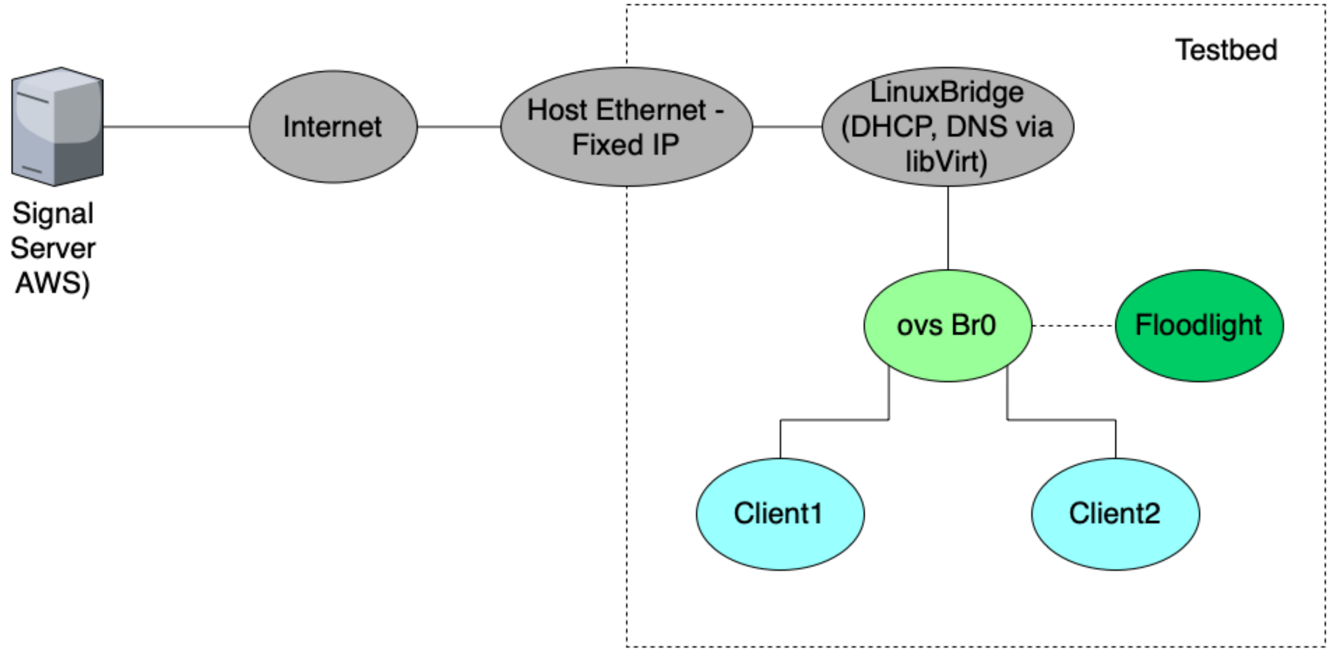
- We launch two instances of an Ubuntu VM running ADB to create 2 Signal Clients

```yaml
machines:

  - name: client1
    cpus: 2
    memory_mb: 6144
    extended_graphics_support: true
    disk:
       existing_disk:
         path: /home/gpeden/prj/rephrain-testbed/demo/ubuntu20.04-1.qcow2
         driver_type: qcow2
         device_type: disk
         readonly: false
    interfaces:
      - bridge: br0
    run_script: ./run.sh
    context: ./emulator/

  - name: client2
    cpus: 2
    memory_mb: 6144
    extended_graphics_support: true
    disk:
      existing_disk:
        path: /home/gpeden/prj/rephrain-testbed/demo/ubuntu20.04-1.qcow2
        driver_type: qcow2
        device_type: disk
        readonly: false
    interfaces:
      - bridge: br0
    run_script: ./run.sh
    context: ./emulator/

bridges:
  - name: br0
    controller: tcp:127.0.0.1:6653
    protocol: OpenFlow13

external_bridge: br0

ssh_public_key: ___
password_ssh_enabled: true
```

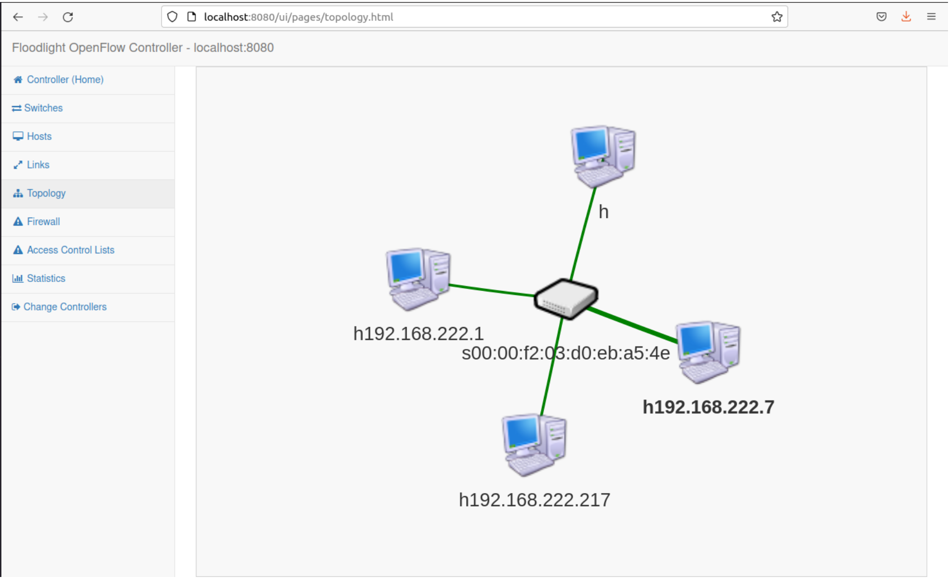
Compose Up

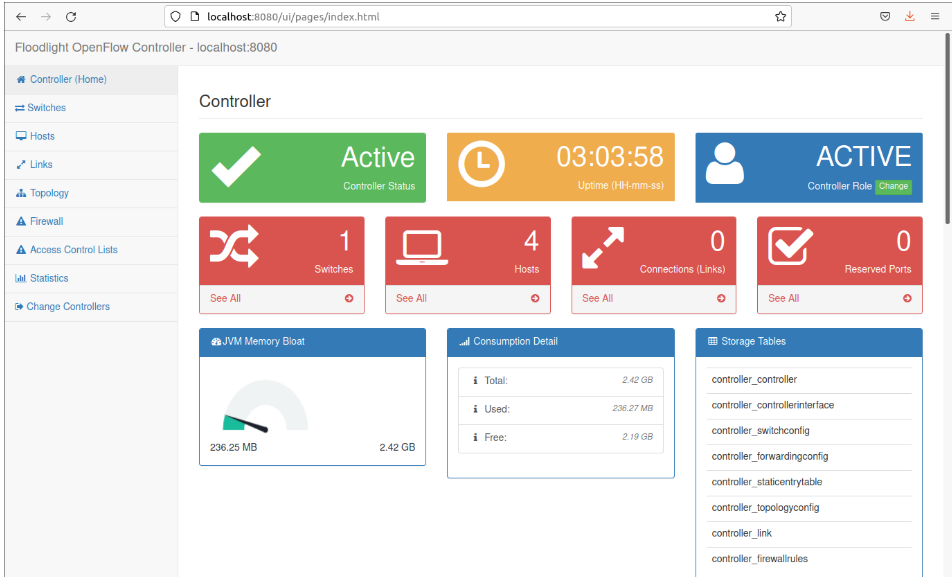

Activities
Terminal
14 Mar 17:36
Terminal
Terminal
Terminal
Terminal
gpeden@rephrain:~/prj/rephrain-testbed/kvm-compose/examples/sigadb$
[3] 0:bash*
"rephrain"

Demonstration - Network

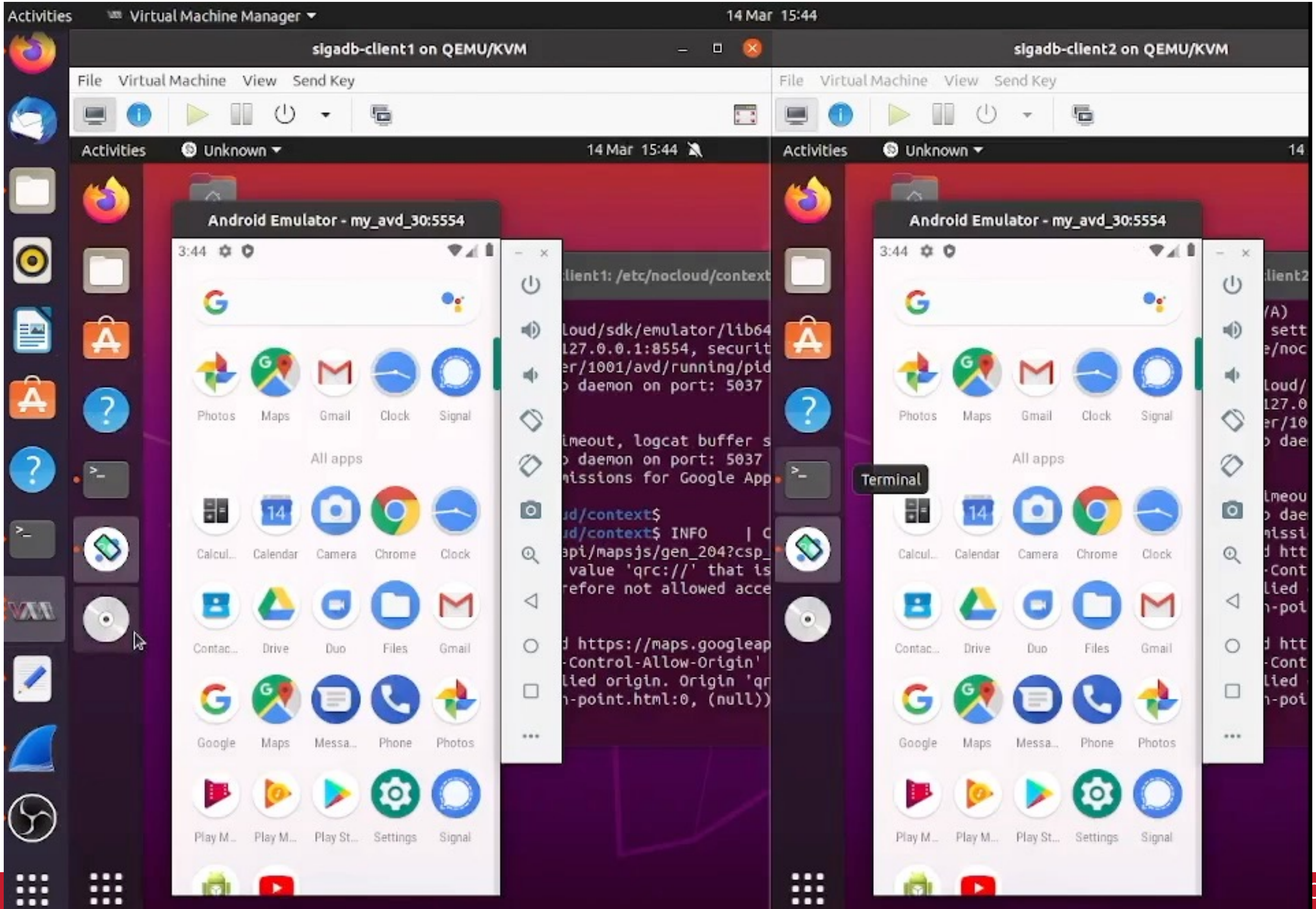


Floodlight SDN





Signal Registration

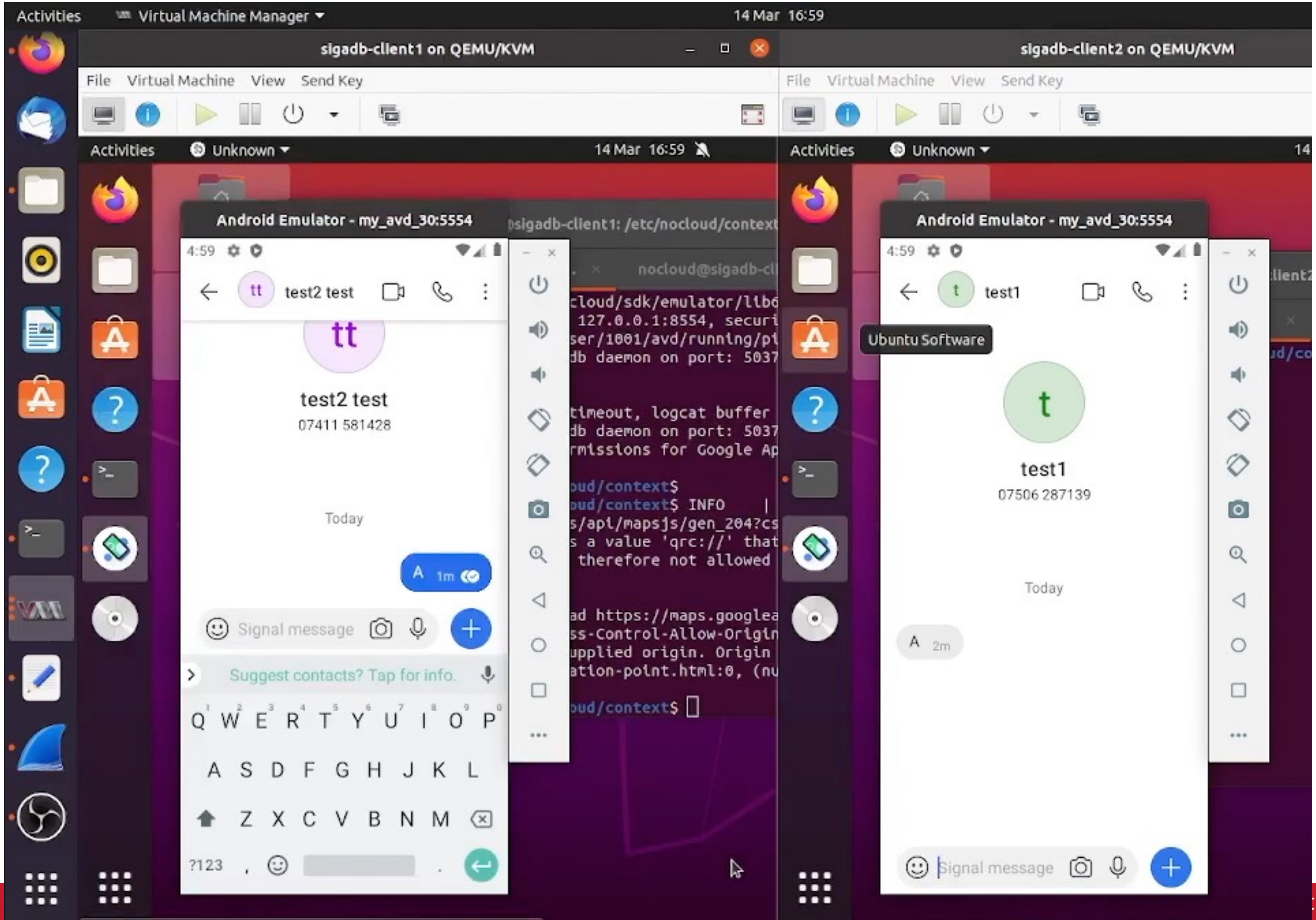


Orchestration

- Clients automatically send messages to each other
  - Includes simulated picture messages controlled by finger clicks
- Launched by bash script, messages sent using ADB functions
  - Automated text entry, no user interaction required

```bash
#!/bin/bash

send_image(){
  echo "Sending an image"
  adb exec-out input tap 195 379
  sleep 1
  adb exec-out input tap 161 495
  sleep 1
  adb exec-out input tap 291 597
  sleep 1
}

send_text() {
  echo "Sending text $1"
  adb exec-out input text "$1"
  sleep 1
  adb exec-out input tap 284 380
  sleep 1
}

click_on_keyboard(){
  adb exec-out input tap 126 611
}

while :
do
  click_on_keyboard
  send_text "hello"
  send_image

done
```

Client Messaging (Automated)



Demo – Data Capture

- Traffic is captured on OVS bridge
- Saved to PCAP
  - One capture during registration
  - One during messaging
- Used for privacy analysis

Privacy Analysis

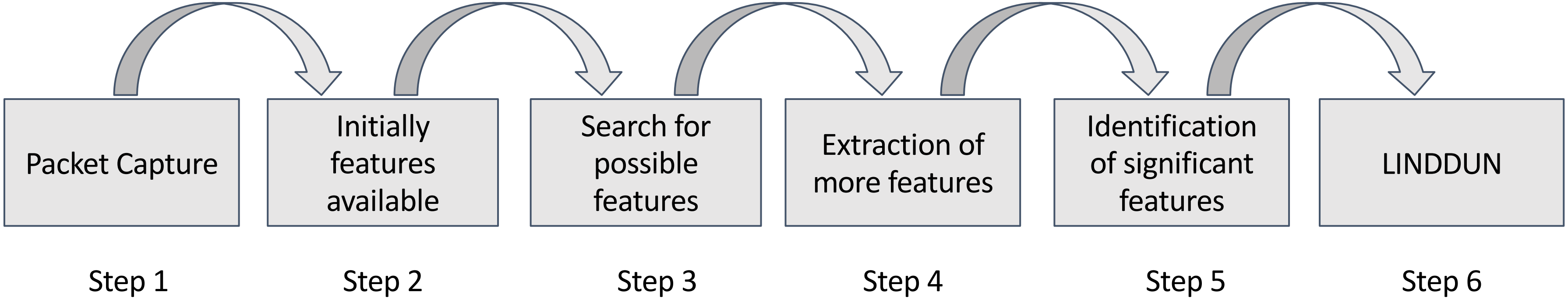
Overview

- The information a passive adversary observing the network can learn.
  - Can they link communicating entities?
  - The hosts that has access to network information and information they can reveal.
- The information an active adversary can get –
  - For example, deanonymizing the sender and the recipient
- Information captured by third party APIs
- The efficacy of shareable datasets
  - Compliance with adequate anonymization
- Systematically analyse privacy behaviour of client-server application
  - Integrate with privacy threat elicitation frameworks the information visible to passive and active adversary
  - Evolve a risk/threat scenario

Extracted features

- Source IP Address
- Destination IP Address
- Source Port
- Destination Port
- Domain Name
- IP Protocol Specifier
- Length of packet
- Traffic Class - QoS

How we performed the analysis?

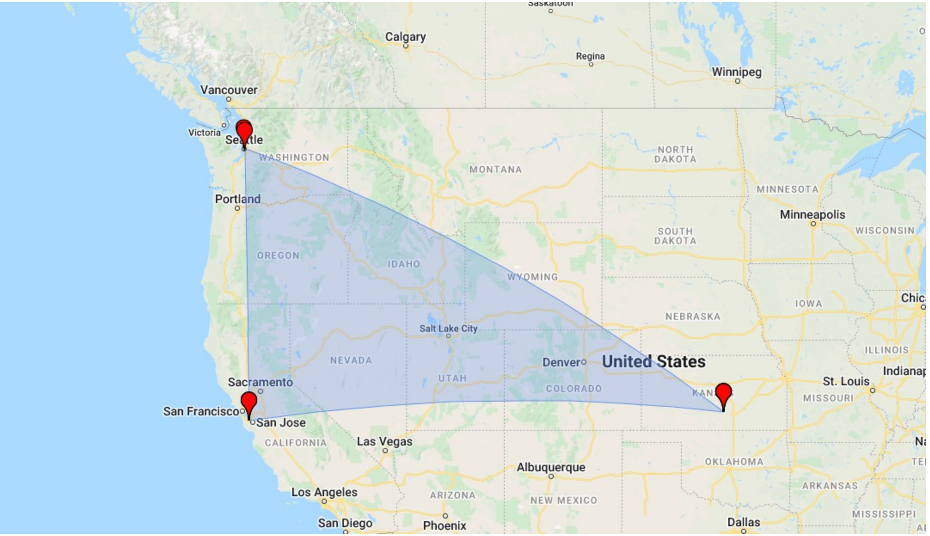


Sample Results – Signal Message Exchange

13.248.212.111,'ac88393aca5853df7.awsglobalaccelerator.com',United States
142.250.178.10,'lhr48s27-in-f10.1e100.net',United States
142.250.180.4,'lhr25s32-in-f4.1e100.net',United States
142.250.200.10,'lhr48s29-in-f10.1e100.net',United States
142.250.200.35,'lhr48s30-in-f3.1e100.net',United States
142.250.200.42,'lhr48s30-in-f10.1e100.net',United States
192.168.222.1,'ip-192-168-222-1.eu-west-2.compute.internal',Not found
192.168.222.217,'ip-192-168-222-217.eu-west-2.compute.internal',Not found
192.168.222.7,'ip-192-168-222-7.eu-west-2.compute.internal',Not found
216.58.212.202,'ams16s21-in-f10.1e100.net',United States
216.58.212.206,'ams16s21-in-f14.1e100.net',United States
35.232.111.17,'17.111.232.35.bc.googleusercontent.com',United States
76.223.92.165,'ac88393aca5853df7.awsglobalaccelerator.com',United States

DST-IPs, Name & Location

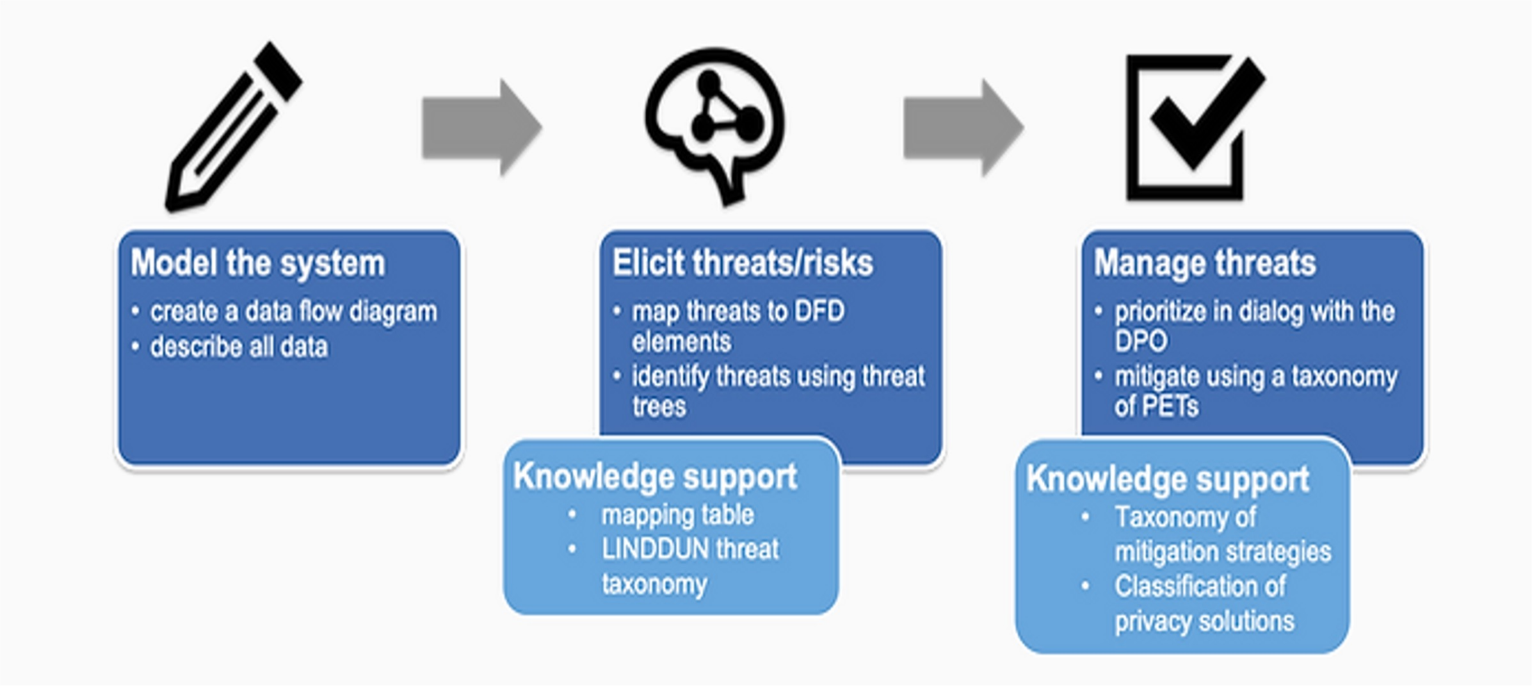
Location on Map



Signal Client Registration

13.224.218.48,‘server-13-224-218-48.lhr61.r.cloudfront.net’,United States
13.248.212.111,‘ac88393aca5853df7.awsglobalaccelerator.com’,United States
142.250.178.19,‘lhr48s27-in-f19.1e100.net’,United States
142.250.178.2,‘lhr48s27-in-f2.1e100.net’,United States
142.250.179.227,‘lhr25s31-in-f3.1e100.net’,United States
142.250.179.234,‘lhr25s31-in-f10.1e100.net’,United States
142.250.180.10,‘lhr25s32-in-f10.1e100.net’,United States
142.250.180.4,‘lhr25s32-in-f4.1e100.net’,United States
142.250.200.10,‘lhr48s29-in-f10.1e100.net’,United States
142.250.200.35,‘lhr48s30-in-f3.1e100.net’,United States
142.250.200.42,‘lhr48s30-in-f10.1e100.net’,United States
142.250.200.46,‘lhr48s30-in-f14.1e100.net’,United States
142.251.5.188,‘wg-in-f188.1e100.net’,United States
172.217.16.234,‘mad08s04-in-f10.1e100.net’,United States
172.217.169.10,‘lhr25s26-in-f10.1e100.net’,United States
172.217.169.74,‘lhr48s09-in-f10.1e100.net’,United States
192.168.222.1,‘ip-192-168-222-1.eu-west-2.compute.internal’,Not found
192.168.222.217,‘ip-192-168-222-217.eu-west-2.compute.internal’,Not found
192.168.222.7,‘ip-192-168-222-7.eu-west-2.compute.internal’,Not found
216.58.212.206,‘ams16s21-in-f206.1e100.net’,United States
216.58.213.10,‘lhr25s25-in-f10.1e100.net’,United States
34.122.121.32,‘32.121.122.34.bc.googleusercontent.com’,United States
35.232.111.17,‘17.111.232.35.bc.googleusercontent.com’,United States
76.223.92.165,‘ac88393aca5853df7.awsglobalaccelerator.com’,United States

What is LINDDUN?



Reference: https://www.linddun.org/linddun

LINDDUN Threat Categories

Linkability
An adversary is able to link two items of interest without knowing the identity of the data subject(s) involved.

Identifiability
An adversary is able to identify a data subject from a set of data subjects through an item of interest.

Non-repudiation
The data subject is unable to deny a claim (e.g., having performed an action, or sent a request).

Detectability
An adversary is able to distinguish whether an item of interest about a data subject exists or not, regardless of being able to read the contents itself.

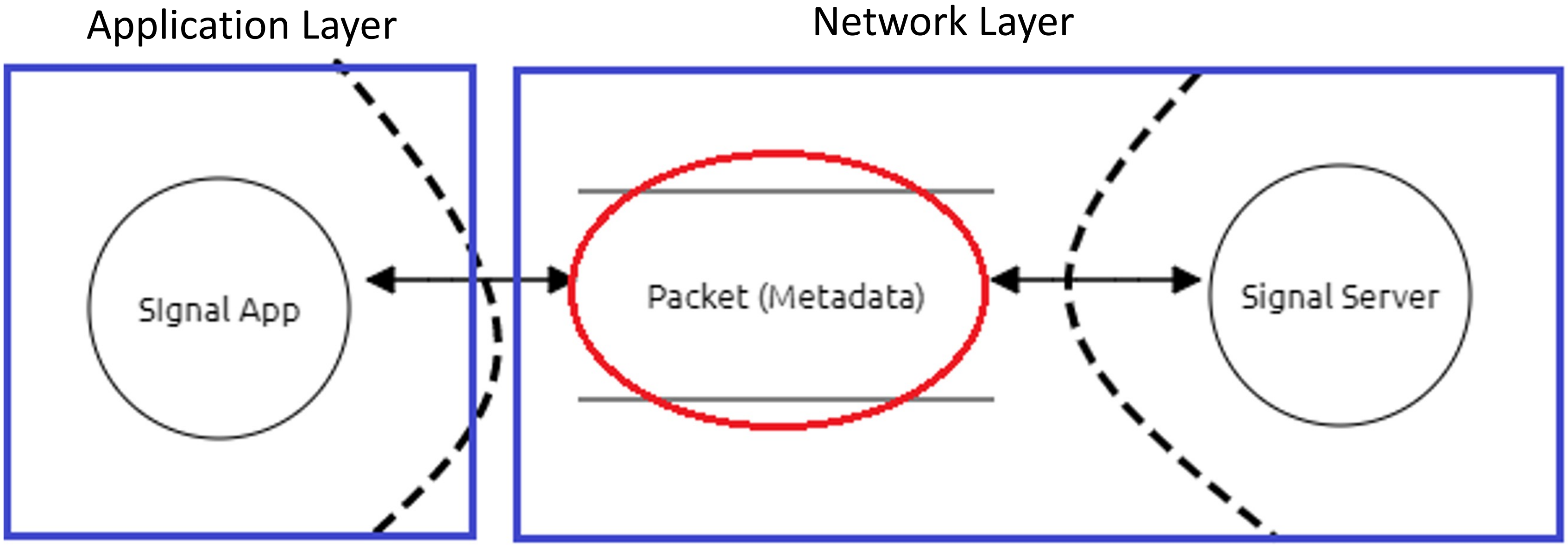
Disclosure of information
An adversary is able to learn the content of an item of interest about a data subject.

Unawareness
The data subject is unaware of the collection, processing, storage, or sharing activities (and corresponding purposes) of the data subject's personal data.

Non-compliance
The processing, storage, or handling of personal data is not compliant with legislation, regulation, and/or policy.

Reference: https://www.linddun.org/linddun

Step 6 - LINDDUN



Step 6 - LINDDUN

Metadata	L	I	N	D	D	U	N
Src IP Add.	x	x	x	x	x	x	
Dst. IP Add.	x	x	x	x	x	x	
Src. Port	x	x	x	x	x	x	
Dst. Port	x	x	x	x	x	x	
Domain Name	x	x	x	x	x	x	x
IP Protocol Specifier	x	x	x	x	x	x	x
QoS			x	x			

LINDDUN - Examples and Implications

Metadata	L	I	N	D	D	U	N
Src IP Add.	x	x	x	x	x	x	
Dst. IP Add.	x	x	x	x	x	x	
Src. Port	x	x	x	x	x	x	
Dst. Port	x	x	x	x	x	x	
Domain Name	x	x	x	x	x	x	x
IP Protocol Specifier	x	x	x	x	x	x	x
QoS			x	x			

Future Work

Future Work – Implementation

- Improved scalability
  - Deployable across multiple machines
- Greater degree of automated interaction
- Further improvements to deployment mechanisms
  - E.g. snapshots
- Implement further data sources for analysis

Future Work – Privacy Analysis

- Pruning the capture information.
- Explore the extent to which we can automate the analysis with LINDDUN
- Incorporate data taxonomy with threat taxonomy.

Publications

- "A Privacy Testbed for IT Professionals: Use Cases and Design Considerations" J. Gardiner, M. Tahaei, J. Halsey, T. Elahi, A Rashid; 7th Workshop on Security Information Workers (WSIW 2021) (Extended Abstract)
- "Building a Privacy Testbed: Use Cases and Design Considerations" J. Gardiner, P. D. Chowdhury, J. Halsey, M. Tahaei, T. Elahi and A. Rashid; 4th International Workshop on SECurity and Privacy Requirements Engineering (SECPRE 2021) (Short Paper)

Thank You!

Questions?

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