A Comprehensive Framework For DDoS Resiliency in the Cloud

Mohammad Noureddine

PERFORM Group

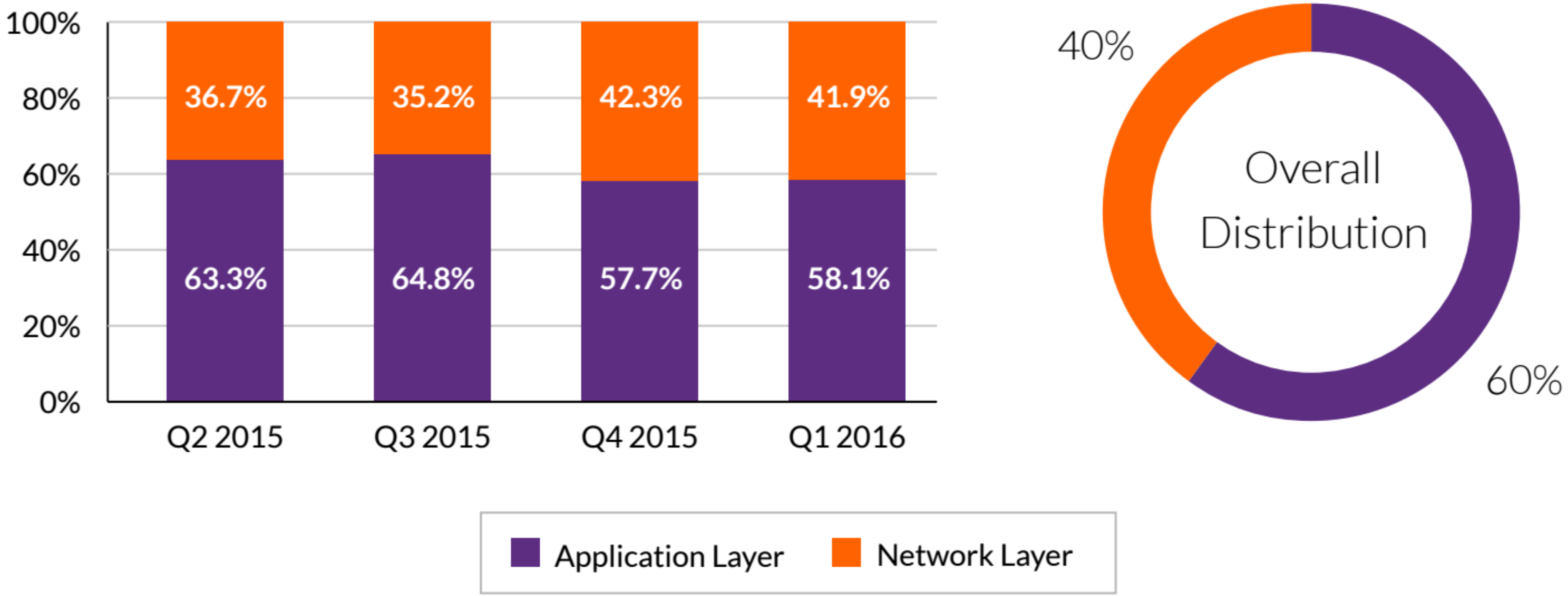
UIUC

Introduction

- DDoS attacks are becoming very effective
- Easy to launch attacks
  - DDoS as a Service
  - $38 for one hour/month attack subscription service
- *"Subleasing"* botnets containing millions of hosts
  - User machines, mobile devices, IoT devices, etc.
- Largest recorded DDoS assault at 650 Gbps

Motivation

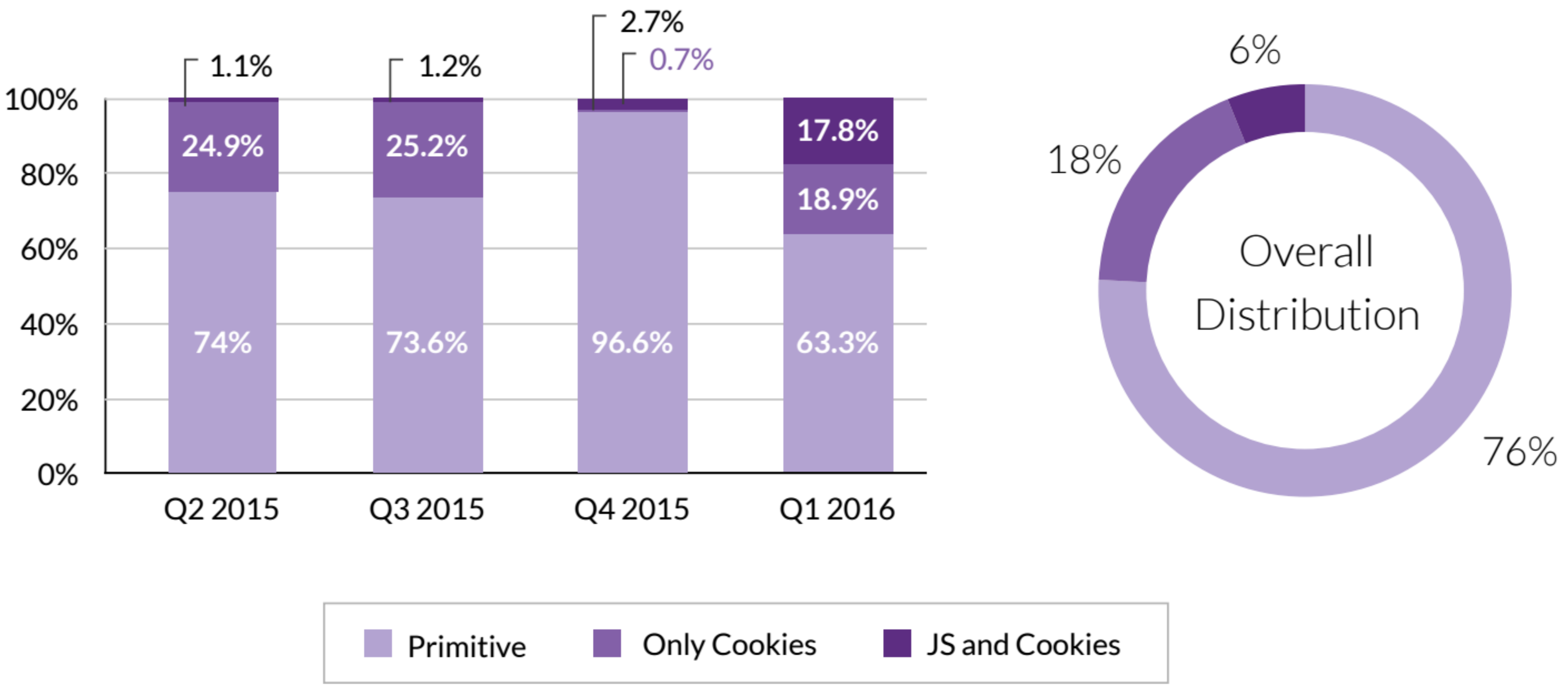
- DDoS is far from being solved



Imperva DDoS Threat Landscape Report 2015-2016

Attack Capabilities

- Majority of botnets are still primitive



The Cloud

- Cloud adoption rates are increasing
  - Cloud providers making it easier
- Provides flexibility and elasticity
  - Efficient use of ever-increasing capacity
- Lucrative targets for DDoS attacks
- Does profit drive security?
  - Telemetry infrastructure unexploited

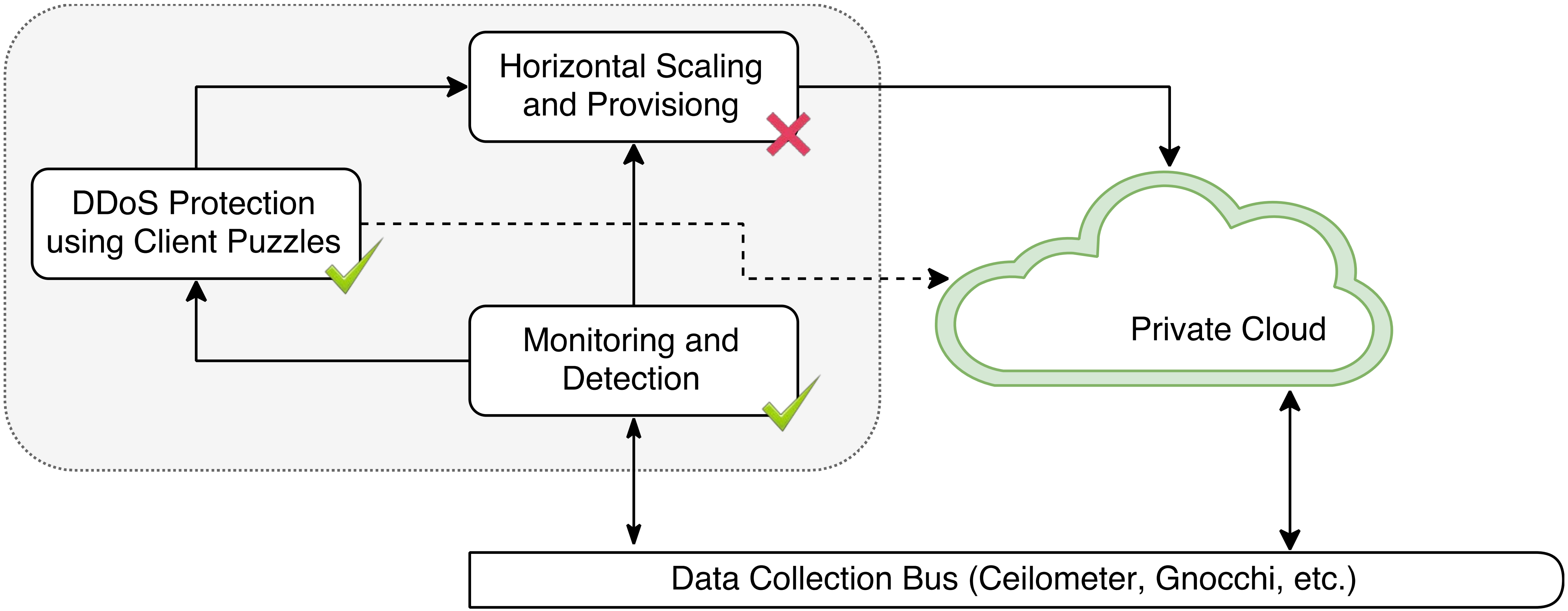
Traditional Approaches

- Often very intrusive
  - Capabilities require changes to core routers
- Require cooperation between ISPs
  - Unlikely to happen without enforcement
- Require expensive classification of hosts
  - IP traceback is expensive and easily fooled
- Very few make use of the cloud
  - The ones that are often proprietary

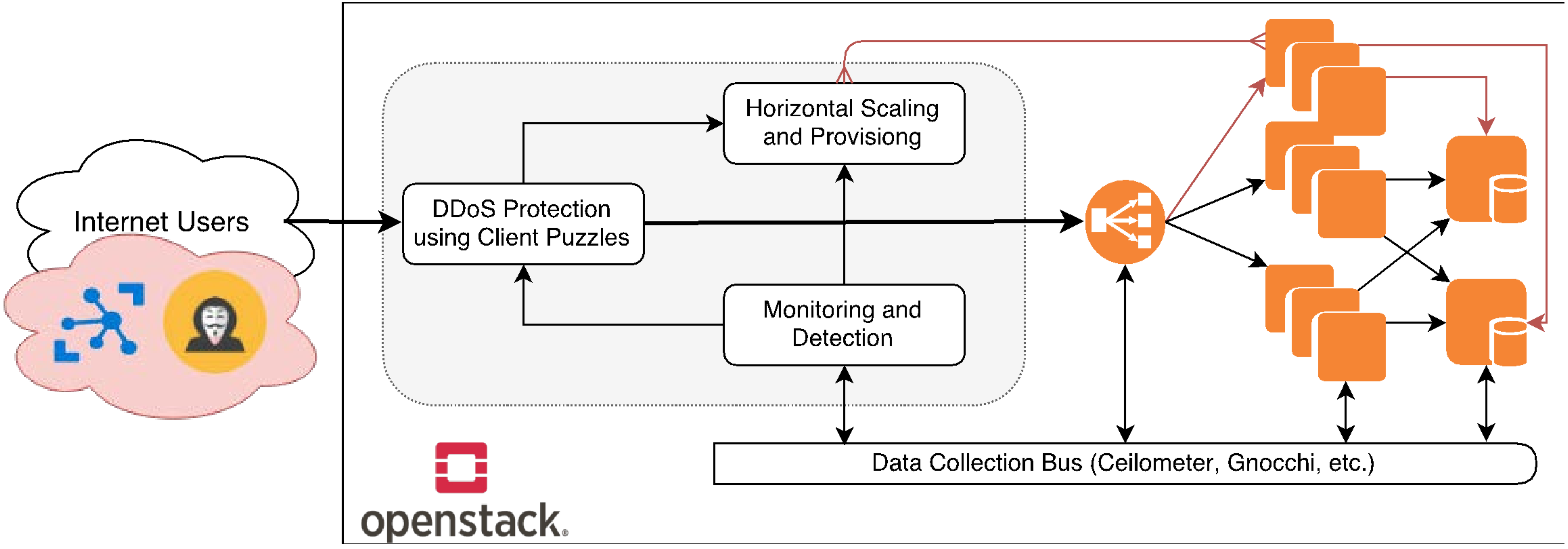
Requirements

- We need to detect DDoS attacks
  - Distinguish between high load and DDoS
- We need to effectively respond to attacks
  - Trigger protection mechanism
  - Maintain operation
- We need to scale up horizontally if possible
  - High availability, Content Delivery Networks (CDN)

Approach


Horizontal Scaling and Provisiong
DDoS Protection using Client Puzzles
Monitoring and Detection
Private Cloud
Data Collection Bus (Ceilometer, Gnocchi, etc.)

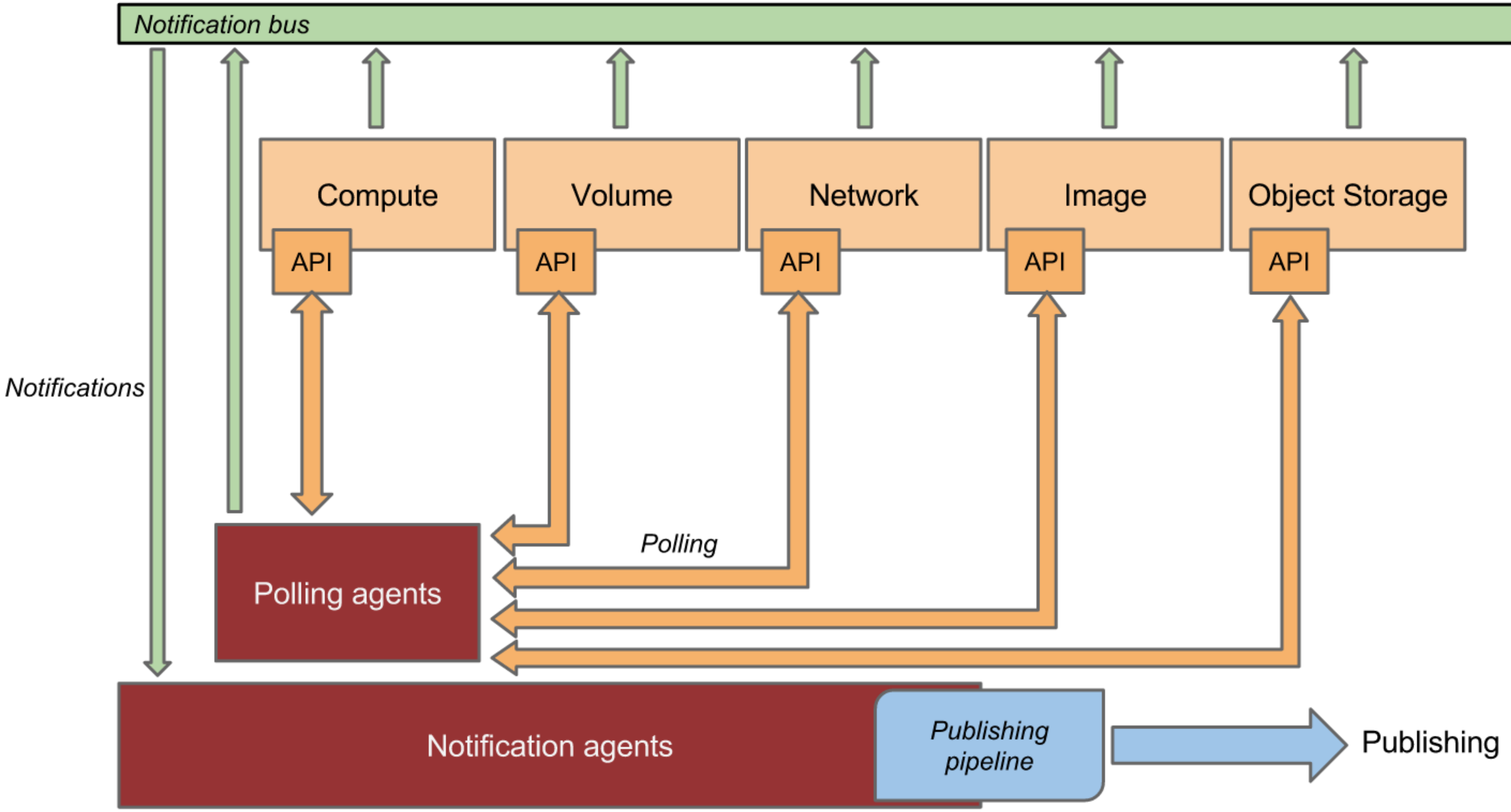
System Model



Data Collection

- Openstack, EC2, Azure provide strong telemetry infrastructure
  - Make use of it for security monitoring
- Openstack ceilometer
  - Complemented with Gnocchi for current and future versions
  - Time series database as a service

Ceilometer



Notification bus
Compute
Volume
Network
Image
Object Storage
API
API
API
API
API
Notifications
Polling
Polling agents
Notification agents
Publishing pipeline
Publishing

Change Point Detection

- Statistical detection of abrupt changes in normal behavior
- Traditionally, observe
  - $\Delta_t = \{SYNReq_t \ - SYNRep_t\}, t = 0,1,2, \ldots$
  - Focuses only on network information
  - Myopic to performance of server instances

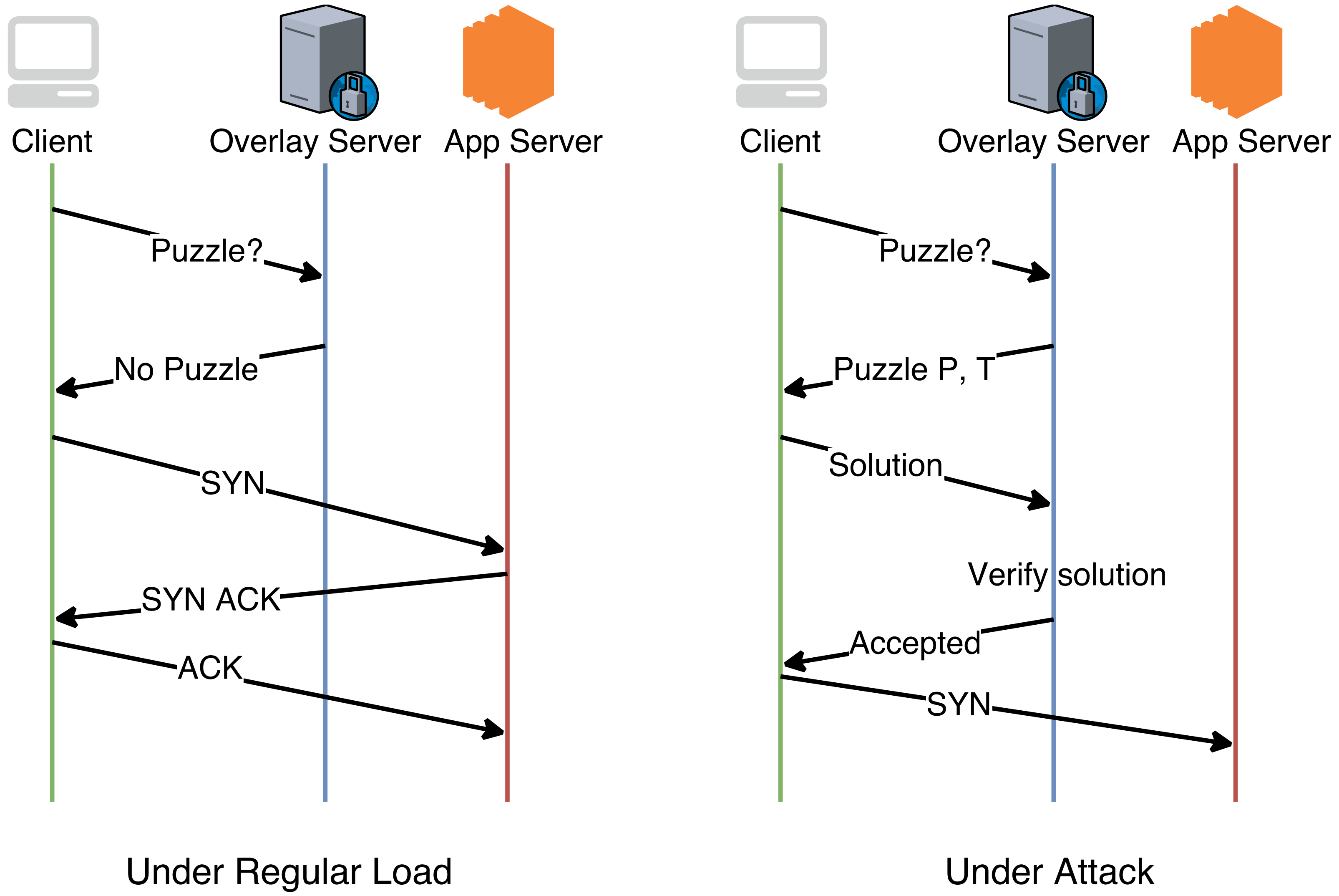
In Our Approach

- Ceilometer data collection
  - Disk usage, CPU utilization, Memory utilization, Network utilization
  - [Apache logs]
- Define new sample vector
  - $\overrightarrow{\boldsymbol{\Delta}_{\mathbf{t}}} = \{disk_t, cpu_t, mem_t, req_t, rep_t\}^T$
  - Provides richer definition of normal behavior
  - Covers larger space of attacks

Client Puzzles

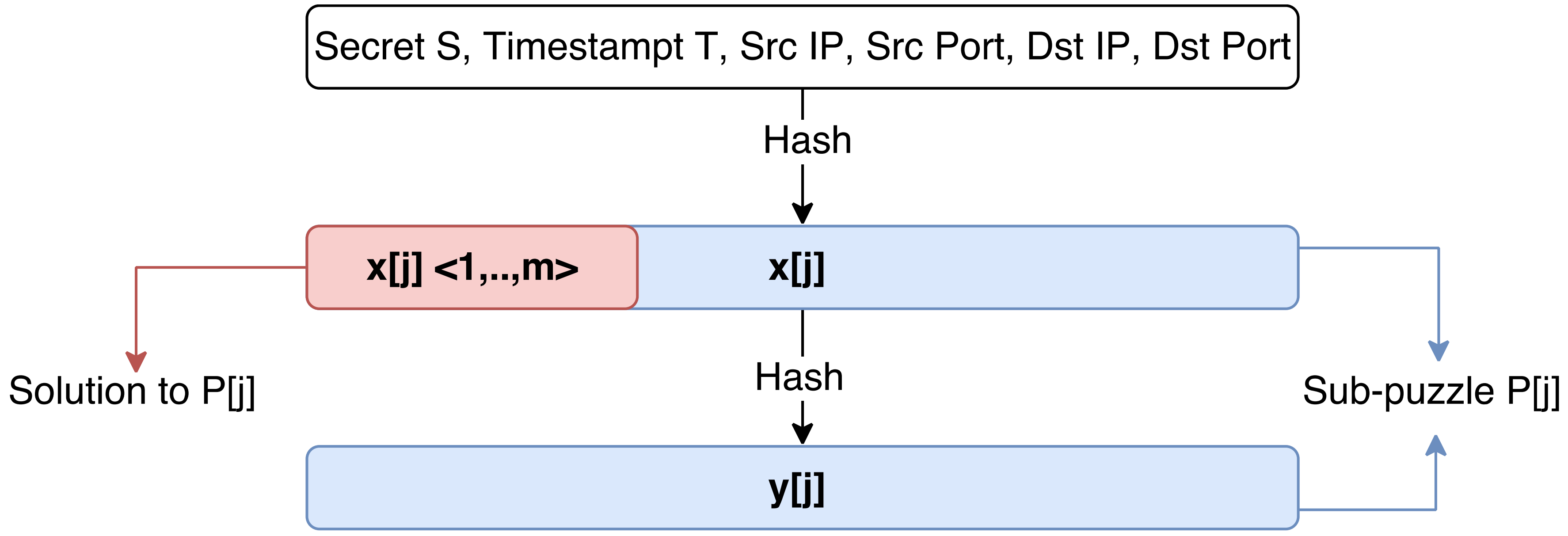
- Efficient stateless proof of work
  - Receive service only after appropriate "*payment*"
- No puzzle solution required under regular load
- Non intrusive, no infrastructure change required
- Puzzle mechanism initiated upon attack detection
  - Use historical data to select puzzle complexity
  - Mechanism/Incentive design problem

Puzzle Protocol



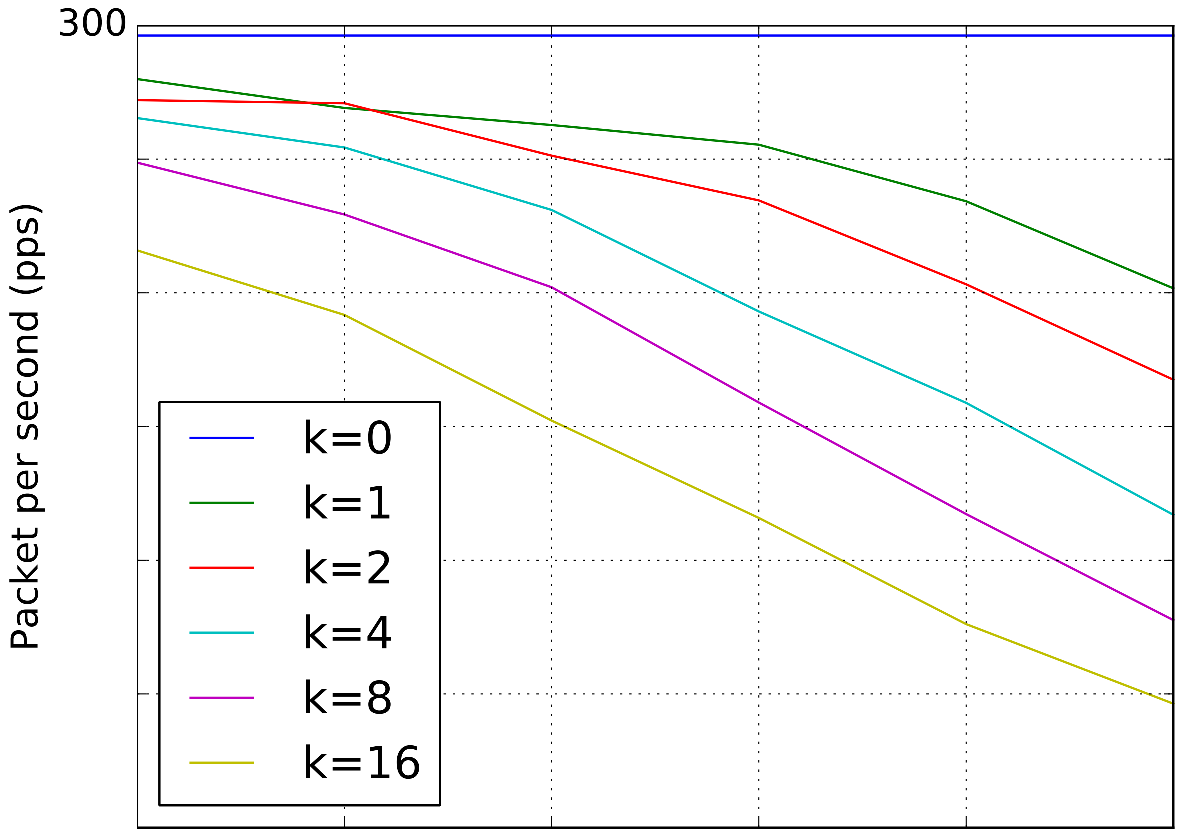
Puzzle Construction

- Each puzzle is compose of k sub-puzzles
  - Each sub-puzzle of length m bits
- Solve by brute force



Effectiveness

- Stateless mechanism to filter clients
- Serious rate limiting on the client side
- More complexity comes at lower cost for server



Limitations

- Can be DDoS’ed
  - More efficient ways to generate and check puzzles
  - White/Black listing clients based on history
  - Still better than SYN flood attacks
- How to pick k and m
  - Currently fixed for all users
  - Increased for everyone when attack intensifies
  - Mechanism/Incentive design problem

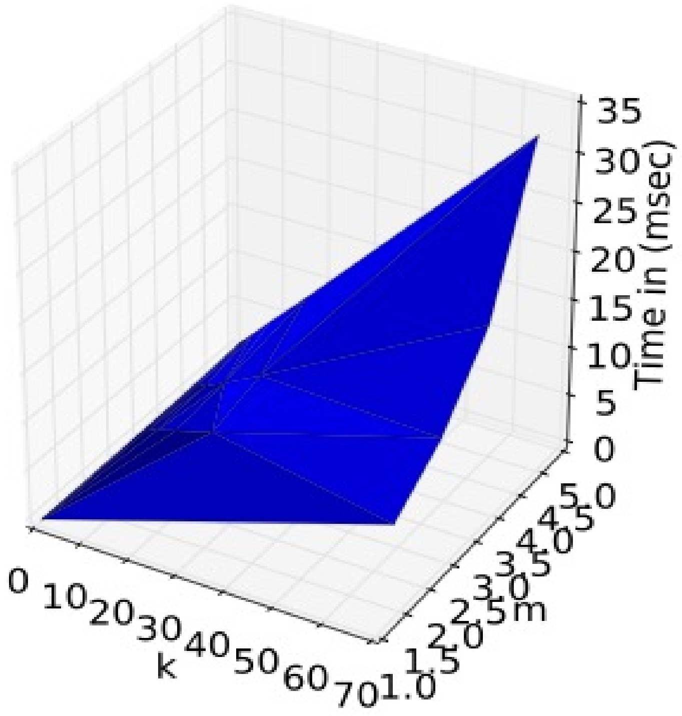
Choosing k and m

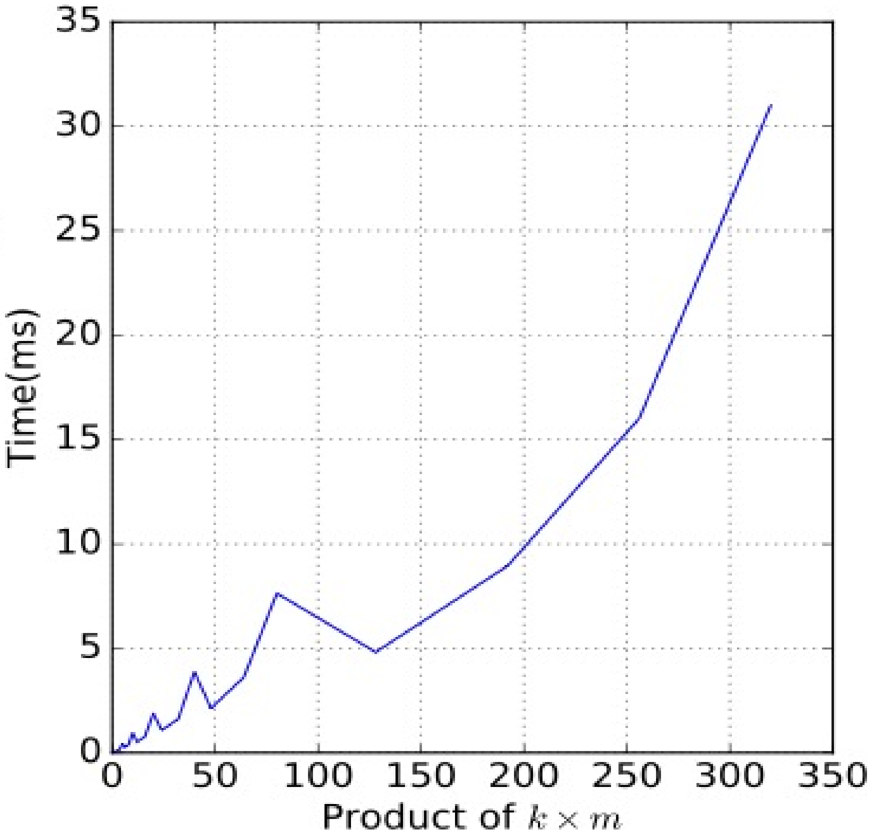
- Provide service for those who actually want it
- Motivation from network pricing
- x_i: Request rate for client i
- Define utility for each client

$$U_i(x_i, x_{-i}) = \log(1 + x_i) - \boxed{PuzzleCost_i} - \boxed{ServiceDelay}$$

Time to Solve a Puzzle

- Expected number of hashes to solve a puzzle is $k \times 2^{\{m-1\}}$





Service Delay

- Model application service as an M/M/c queue
  - c is the number of server replicas
- Rate of arrivals $\lambda = \frac{\sum_i x_i}{N}$, N being the number of flows
- Service rate μ is estimate from *ab* and other stress testing tools
- Analytical solution for expected wait time W
  - Function of $\rho = \frac{\lambda}{c\mu}$

Service Time Estimate

```
This is ApacheBench, Version 2.3 <$Revision: 1706008 $>
Copyright 1996 Adam Twiss, Zeus Technology Ltd, http://www.zeustech.net/
Licensed to The Apache Software Foundation, http://www.apache.org/

Benchmarking 34.210.20.7 (be patient)


Server Software:        nginx/1.12.0
Server Hostname:        34.210.20.7
Server Port:            80

Document Path:          /
Document Length:        52757 bytes

Concurrency Level:      100
Time taken for tests:   44.630 seconds
Complete requests:      500
Failed requests:        0
Total transferred:      26532500 bytes
HTML transferred:       26378500 bytes
Requests per second:    11.20 [#/sec] (mean)
Time per request:       8926.041 [ms] (mean)
Time per request:       89.260 [ms] (mean, across all concurrent requests)
Transfer rate:          580.56 [Kbytes/sec] received

Connection Times (ms)
```

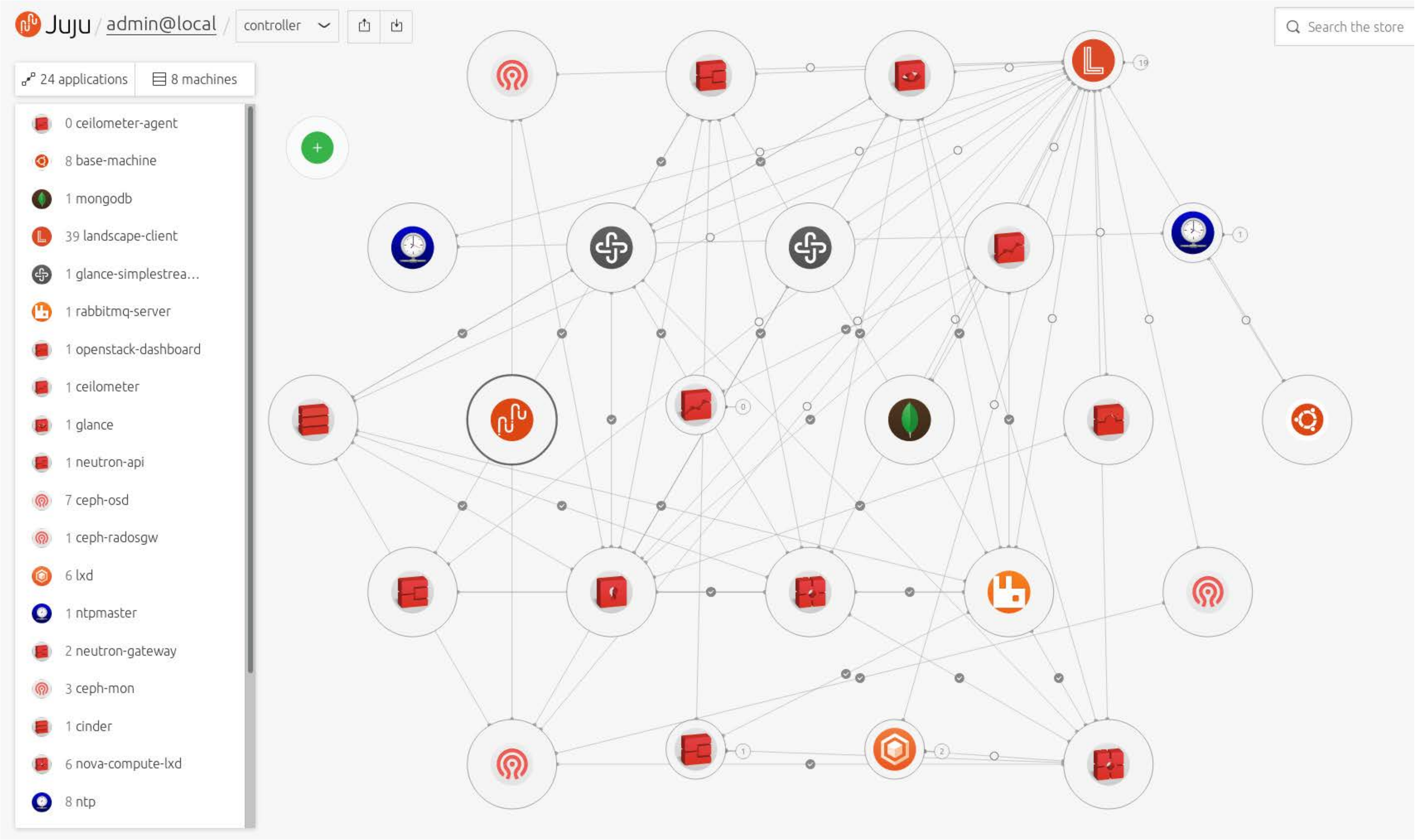
Stackelberg Game (Mechanism Design)

- $U_i(x_i, x_{-i}) = \log(1 + x_i) - k_i 2^{\{m_i - 1\}} x_i - W$
- W is a function of x_i and x_{-i}
- Solve for equilibrium rates x_i^*
  - $U_i(x_i^*, x_{-i}^*) \geq U_i(x_i, x_{-i}^*) \quad \forall x_i, \forall i$
- The cloud's design problem is to find k_i^* and m_i^*
  - $\underset{p_i, k_i \in \mathbb{N}}{\operatorname{argmax}} \sum_i \log(1 + x_i^*) - \sum_i (m_i \times k_i) x_i^*$

Horizontal Scaling Ideas

- Adding more replicas naively
- Give networking and compute budgets
  - Solve optimization problem
- Think in terms of the queueing model
  - Scale up to keep $\rho < 1$

OpenStack Deployment



Infrastructure and Applications

- Deployment composed of 4 servers and 6 commodity machines
- Running Wordpress server replicas with MySQL backend
- NginX load balancer

Steps for Evaluation

- Evaluate change point detection mechanism
- Simulations to evaluate puzzle difficulty selection
- Comprehensive evaluation
  - Simulate normal and heavy load using stress testing tools
  - Simulate attack using botnet simulator

Major Challenge

- We have tried multiple deployment tools
  - Each claim to be the “Chuck Norris” of deployment
- Lack of documentation for troubleshooting deployment errors
- Biggest success with Ubuntu Autopilot so far

Conclusion

- Comprehensive design for resilient applications in a private cloud
- Uses telemetry infrastructure for monitoring
- Uses client puzzles for DDoS protection under attack
- Provides horizontal scaling to guarantee performance