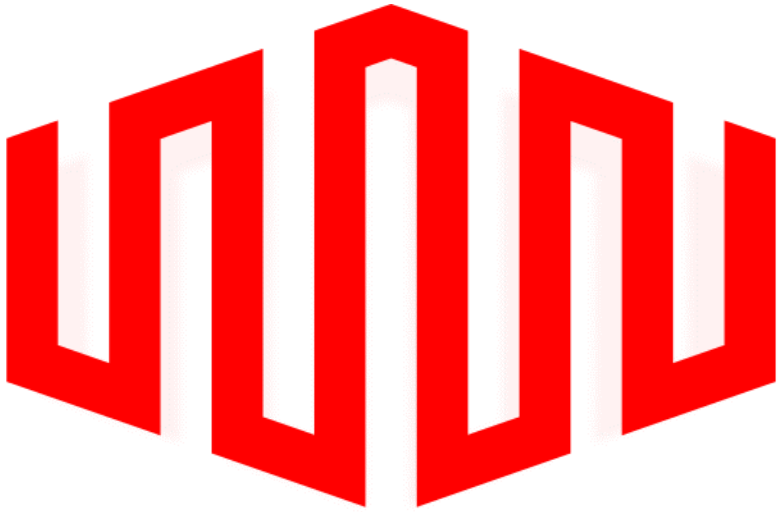

EQUINIX

SDN/NFV VNF Service Chaining

Spring Final Review (SFR)

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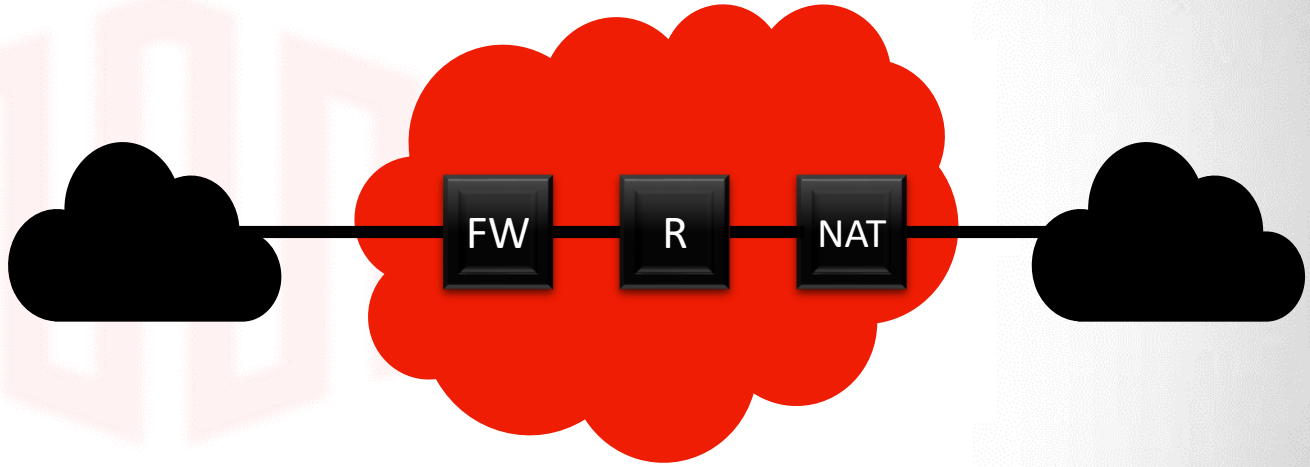
Agenda

1. Project Objectives
2. Design Description
3. Test Overview
4. Test Results
5. Systems Engineering
6. Project Management

Project Objectives

What is Service Chaining?

- Service chaining - set of network functions connected to support an application.
- SDN/NFV facilitates the ease of provisioning and reconfiguring the service chains.
- Building a service chain using SDN/NFV eliminates the need of acquiring network hardware.



Project Purpose

Field of application

Service Chaining using VNF facilitates dynamic network design. This has gained popularity specially in ISP's and data-centers for faster deployment of desired network functions.

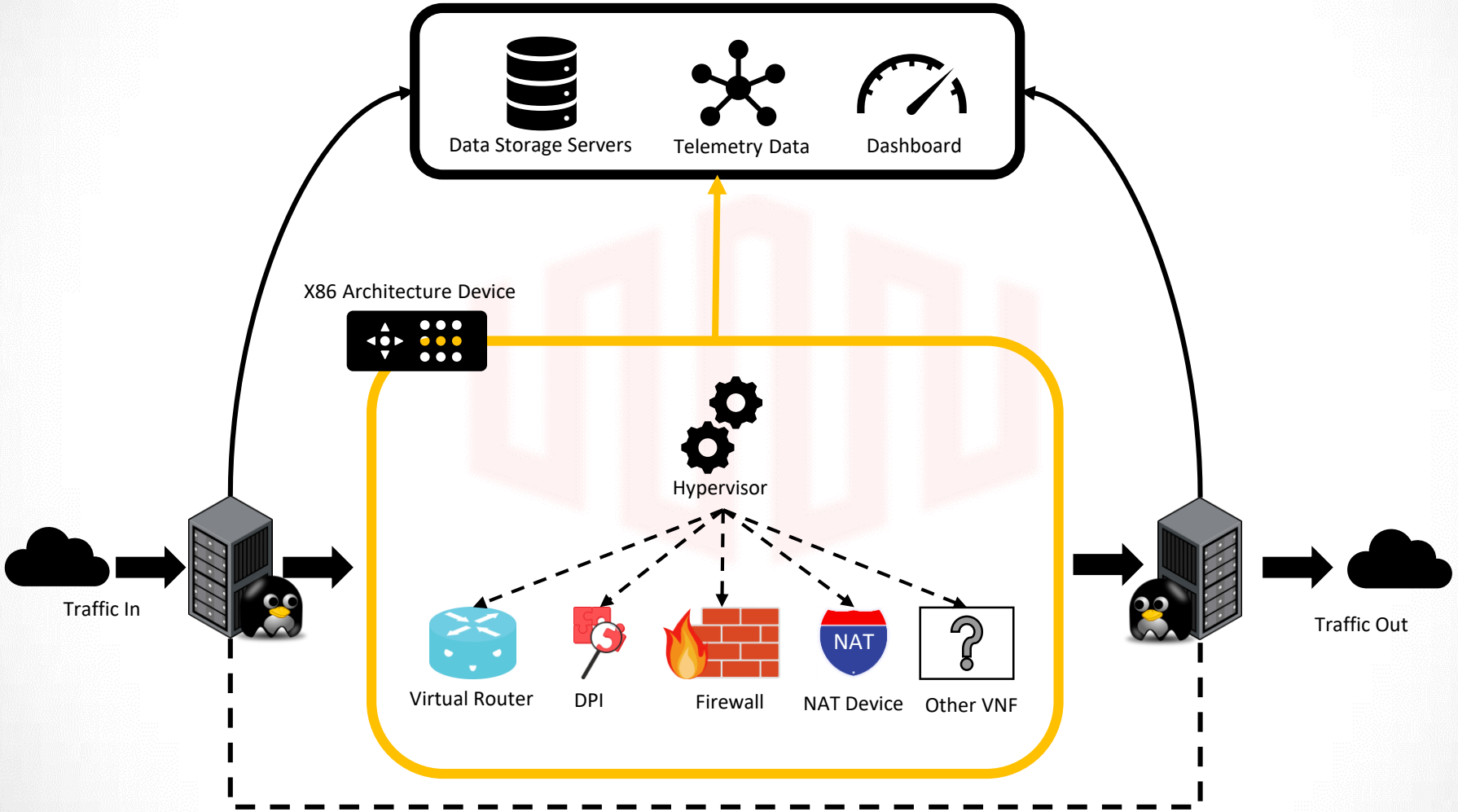
Problem

We did not come across any existing research study, that evaluates the performance characteristics of these chaining using multiple VNFs. Therefore, this project focuses on testing the operation of various service chains and quantifying the impact each VNF, and effectively the service chain has on the server resource utilization and network performance parameters.

Potential impact

The results of this project will help industry professionals predict the impact service chains have on the server and network resources before implementing them on industry-grade equipment.

Concept of Operations



Levels of success

Level 1: Infrastructure Setup

- Hardware Installation
- OpenStack and Monitoring Tools deployment
- Set up Iperf server and Iperf Client

Level 2: Test Environment Setup

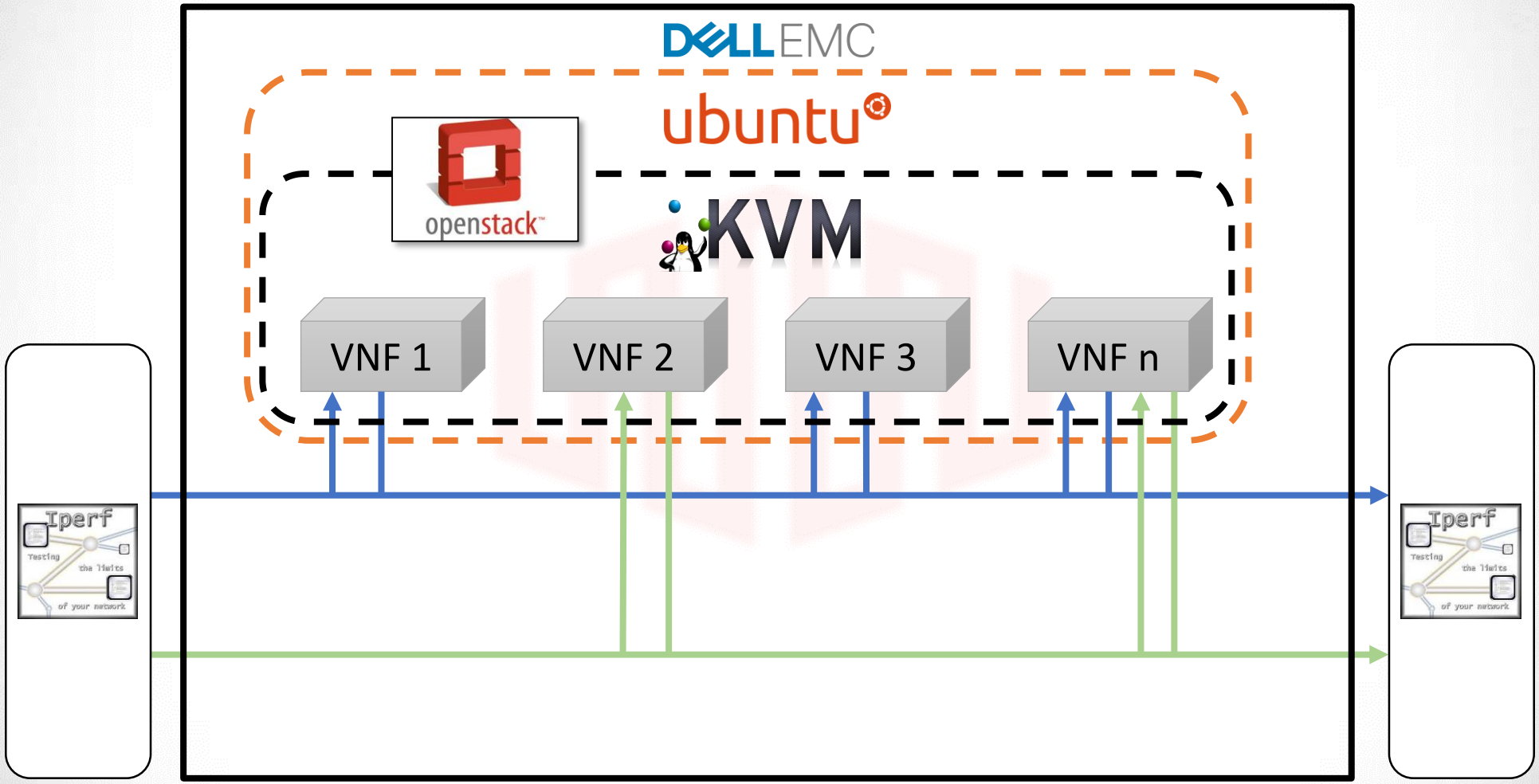
- Implement service chain
- Ensure traffic is passed through service chain

Level 3: Evaluation and Analysis

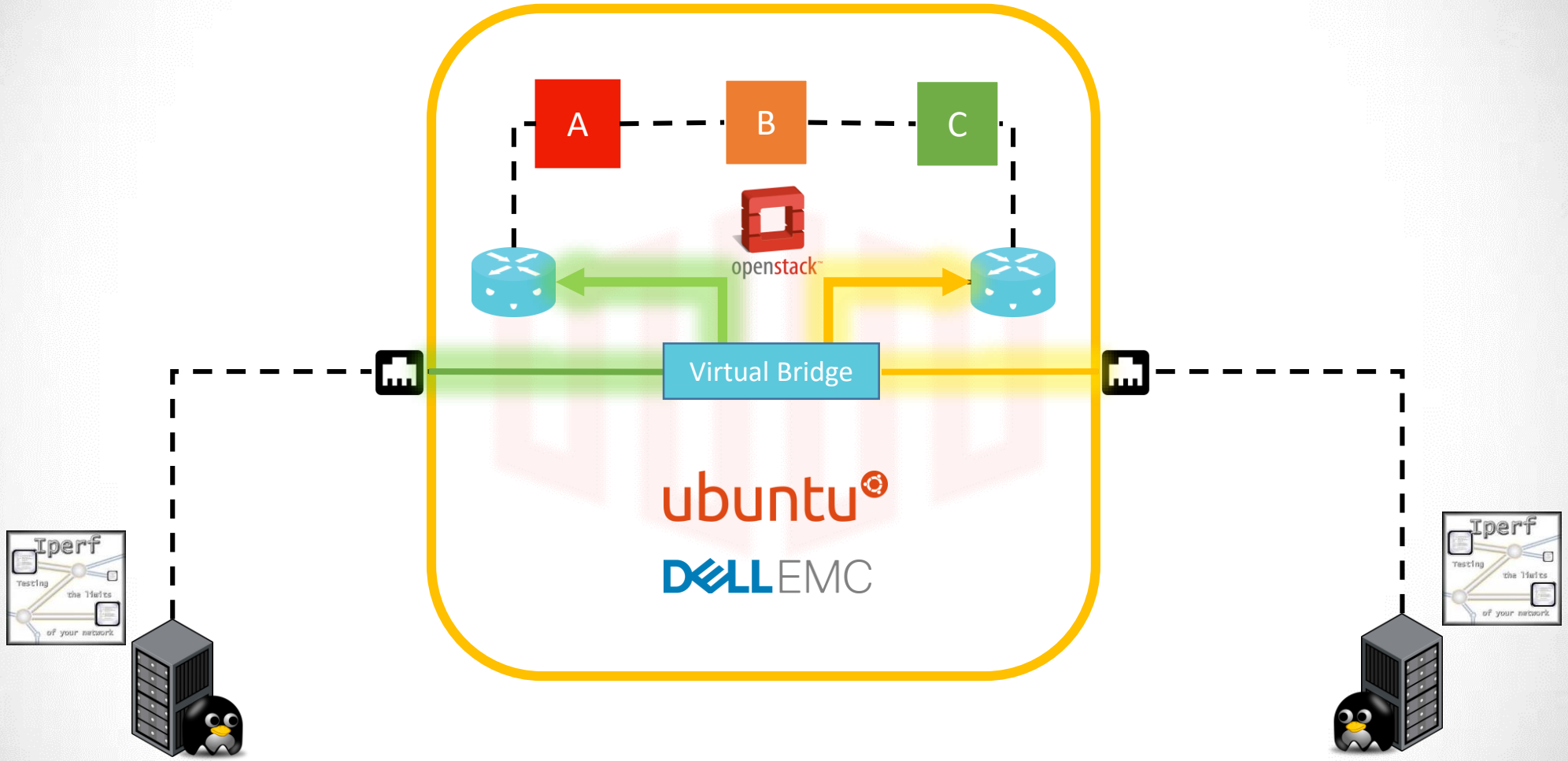
- Server and VNF metric collection
- Analyze the collected data

Design Description

Functional Block Diagram

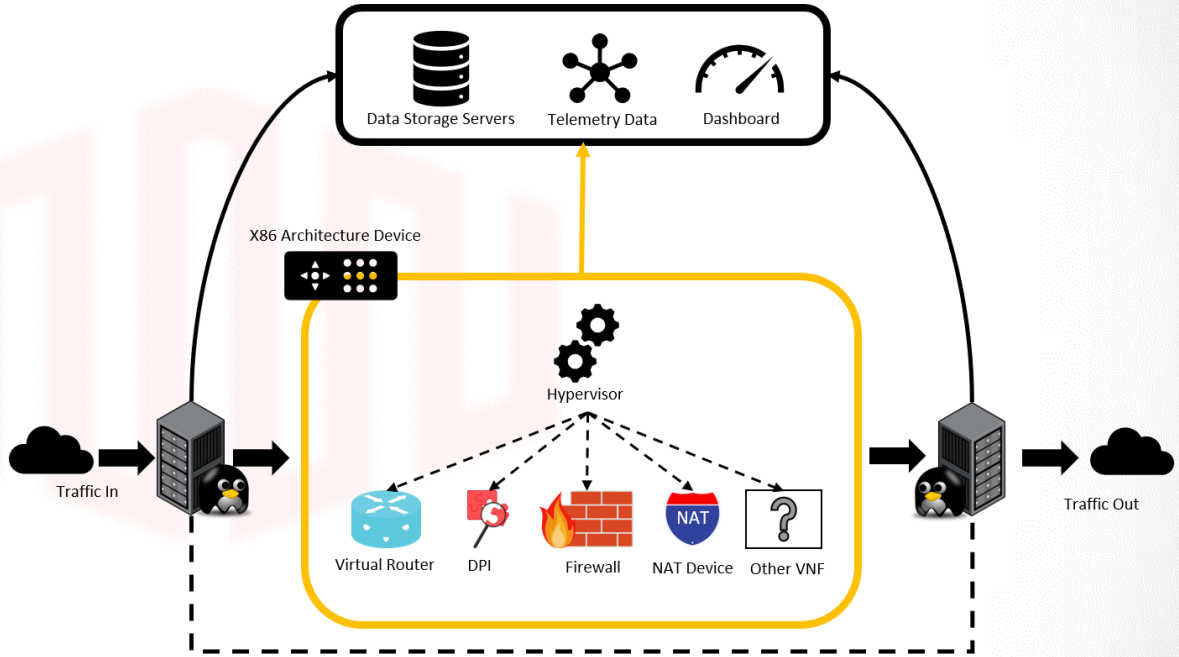


Project Implementation



Critical Project Elements

DES.1.1	• VNF Deployment
DES.1.2	• Use of OpenStack and KVM Hypervisor
DES.1.3	• x86 Architecture Device
DES.2.1	• Consistent test environment
DES.2.2	• Testing using traffic generator



Components

Type	Product	Features	Description
Hardware	Dell PowerEdge R430	Memory: 64 GB Networking: 4X1Gb Ethernet NICs CPU: Intel® Xeon® E5-2600 v4 family	Procured in Telecom Lab
Software	Ubuntu	Version: 16.04.6 LTS	Operating System
	OpenStack	Version: Stable/Rocky	Cloud Orchestrator
	Iperf	Version: 3.0.11	Traffic Generator
	Grafana	Version: 6.1.2	Monitoring Tool
VNF	Juniper - vSRX 1G	Firewall	License provided by Equinix
	Cisco - CSR 1G	Router	License provided by Equinix
	VYOS	Router/NAT	Open source

Test Overview

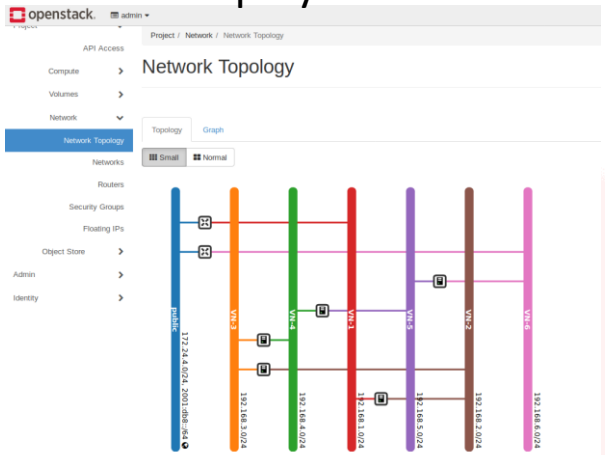
Infrastructure Setup

Level 1: Infrastructure Setup

Python Script for testing server deployment and parameters

```
==============UBUNTU DETAILS==============
The Ubuntu release on the server is: 16.04.

==============CPU INFORMATION==============
The CPU Architecture: x86_64
The CPU modes available on the server: 32-bit, 64-bit
Number of CPU cores in the server: 12
Processor actual speed: 1371.812 MHz
Processor maximum speed: 1600.0000 MHz
Processor minimum speed: 1200.0000 MHz

==============CURRENT SERVER TIME==============
22:28:10 MST

==============CPU STATISTICS==============
Server CPU is 81% idle.

==============MEMORY USAGE==============
Total memory available: 62G
Used memory: 16G
Free memory: 44G

==============DISK SPACE==============
Details of disk /dev/sda1:
Total size: 458G
Available space: 393G

==============INTERFACE DETAILS==============
Details of the interface eno1:
IP Address: 172.16.218.10 255.255.0.0

Details of the interface eno3:
IP Address: 1.1.1.100 255.255.255.0

Details of the interface eno4:
IP Address: 2.2.2.100 255.255.255.0

==============IPERF SERVER AND CLIENT REACHABILITY==============
iPerf Client at 1.1.1.1 is reachable.
iPerf Server at 2.2.2.2 is reachable.

==============OPENSTACK OPERATION CONFIRMATION==============
Images in OpenStack using the command 'openstack image list':
+--------------------------------------+-------------------------+--------+
| ID                                   | Name                    | Status |
+--------------------------------------+-------------------------+--------+
| 38660642-882e-4828-bf8d-101823098873 | cirros-0.3.5-x86_64-disk | active |
| 4b3ad6e3-61ed-4a64-b313-7c28202aed2e | csr_image               | active |
| 02f23e98-a123-4575-bb0e-795698d1e579 | vsrx_juniper            | active |
+--------------------------------------+-------------------------+--------+
```

OpenStack and Monitoring Tool deployment



Iperf Server and Client communication

```
t9eqx@t9eqx: ~
File  Edit  View  Search  Terminal  Help
Connecting to host 2.2.2.2, port 5201
[  4] local 1.1.1.1 port 48018 connected to 2.2.2.2 port 5201
[ ID] Interval           Transfer     Bandwidth       Retr  Cwnd
[  4]   0.00-1.00   sec  69.4 MBytes   582 Mbits/sec   40   1.43 MBytes
[  4]   1.00-2.00   sec  71.2 MBytes   598 Mbits/sec   20   1.10 MBytes
[  4]   2.00-3.00   sec  70.0 MBytes   587 Mbits/sec    0   1.18 MBytes
[  4]   3.00-4.00   sec  55.0 MBytes   461 Mbits/sec    0   1.24 MBytes
[  4]   4.00-5.00   sec  72.5 MBytes   608 Mbits/sec    0   1.28 MBytes
[  4]   5.00-6.00   sec  78.8 MBytes   661 Mbits/sec    0   1.30 MBytes
[  4]   6.00-7.00   sec  83.8 MBytes   703 Mbits/sec    0   1.32 MBytes
[  4]   7.00-8.00   sec  85.0 MBytes   713 Mbits/sec    0   1.32 MBytes
[  4]   8.00-9.00   sec  67.5 MBytes   566 Mbits/sec   42    971 KBytes
[  4]   9.00-10.00  sec  77.5 MBytes   650 Mbits/sec    0   1.07 MBytes
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  4]   0.00-10.00  sec   731 MBytes   613 Mbits/sec  102             sender
[  4]   0.00-10.00  sec   728 MBytes   611 Mbits/sec                  receiver

iperf Done.
t9eqx@t9eqx:~$
```

```
t9eqx@t9eqx_iperf2: ~
File  Edit  View  Search  Terminal  Help
Accepted connection from 1.1.1.1, port 48016
[  5] local 2.2.2.2 port 5201 connected to 1.1.1.1 port 48018
[ ID] Interval           Transfer     Bandwidth
[  5]   0.00-1.00   sec  63.9 MBytes   536 Mbits/sec
[  5]   1.00-2.00   sec  71.8 MBytes   602 Mbits/sec
[  5]   2.00-3.00   sec  69.9 MBytes   586 Mbits/sec
[  5]   3.00-4.00   sec  55.6 MBytes   467 Mbits/sec
[  5]   4.00-5.00   sec  71.8 MBytes   602 Mbits/sec
[  5]   5.00-6.00   sec  77.7 MBytes   651 Mbits/sec
[  5]   6.00-7.00   sec  84.0 MBytes   704 Mbits/sec
[  5]   7.00-8.00   sec  85.4 MBytes   717 Mbits/sec
[  5]   8.00-9.00   sec  68.6 MBytes   575 Mbits/sec
[  5]   9.00-10.00  sec  76.6 MBytes   643 Mbits/sec
[  5]  10.00-10.04  sec  2.82 MBytes   642 Mbits/sec
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Retr
[  5]   0.00-10.04  sec   731 MBytes   611 Mbits/sec  102             sender
[  5]   0.00-10.04  sec   728 MBytes   609 Mbits/sec                  receiver
-----------------------------------------------------------
Server listening on 5201
-----------------------------------------------------------
```

Service Chain Combinations

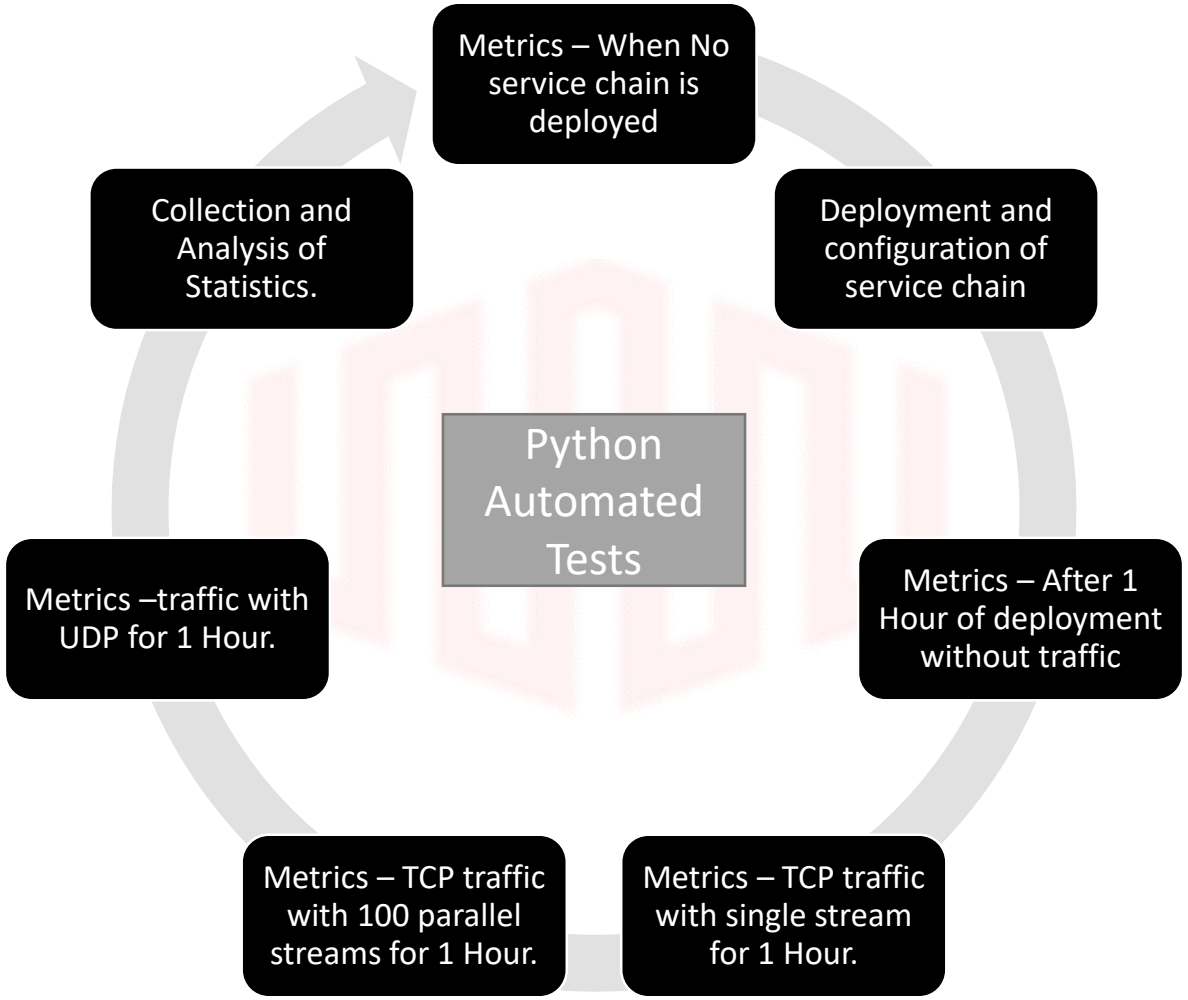
Level 2: Test Environment Setup

Test Cases
1. NAT
2. Router
3. Firewall
4. Router – NAT
5. Firewall – NAT
6. Router – Router
7. Firewall – Router
8. Firewall – Router – NAT
9. Router – Router – Router
10. Router – Router – Router – Router
11. Router – Router – Router – Router – Router

Functionality	Image
NAT	VYOS
Router	Cisco CSR 1000v
Firewall	Juniper VSRX

Test Procedure

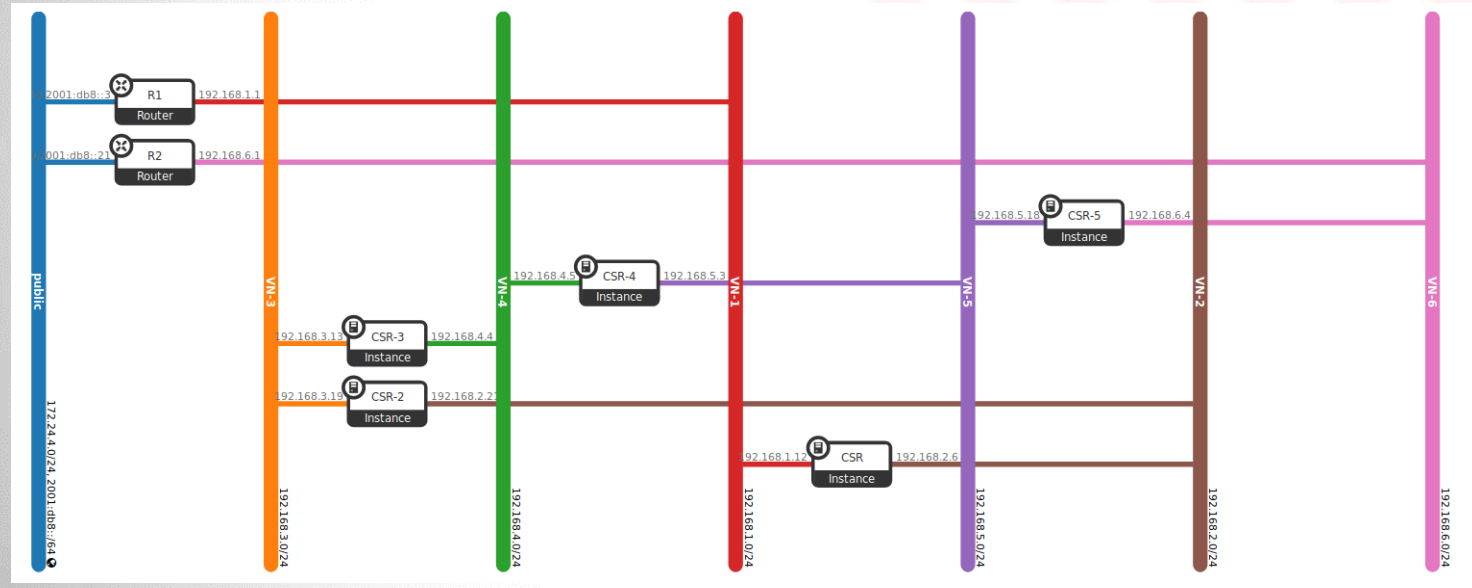
Level 2: Test Environment Setup



Test Procedure

Level 2: Test Environment Setup

Iperf Client → OpenStack R1 → Service Chain → OpenStack R2 → Iperf Server




```
t9eqx@t9eqx:~$ traceroute 2.2.2.2
traceroute to 2.2.2.2 (2.2.2.2), 64 hops max
  1   1.1.1.100  0.258ms  0.138ms  0.153ms
  2   172.24.4.13  0.649ms  0.189ms  0.147ms
  3   192.168.1.12  1.604ms  0.761ms  0.617ms
  4   192.168.2.21  6.006ms  1.207ms  1.062ms
  5   192.168.3.13  4.049ms  1.162ms  2.017ms
  6   192.168.4.5  3.990ms  3.659ms  2.754ms
  7   192.168.5.18  2.806ms  5.526ms  2.304ms
  8   192.168.6.1  2.469ms  3.003ms  2.260ms
  9   1.1.1.100  1.180ms  4.468ms  1.762ms
 10   2.2.2.2  7.040ms  4.613ms  5.954ms
```

Collection of Key Metrics

Level 3: Evaluation and Analysis

Server

- CPU Utilization (%)
- Memory Utilization (%)
- CPU Load 1 m(%)
- CPU Load 5 m(%)

Service Chain

- Latency
- TCP Throughput
- TCP Stream Throughput
- UDP Datagram Loss (%)

VNF

- CPU Utilization (%)
- Disk Usage (Bytses)
- Disk Allocation (Bytes)
- Disk Size (GB)
- Disk Capacity (GB)
- VCPUs (Count)
- Memory (MB)
- Ephemeral Size (GB)

TRR Objectives

Test	Objective	Checklist
Test Infrastructure Setup	Verify working of hardware infrastructure.	✓
Implement Service Chain	Ensure deployment of Service Chain in OpenStack.	✓
Metric Collection	Check Integrity of Metric Collection.	✓
Reproducibility	Confirm reproducibility of the test cases.	✓

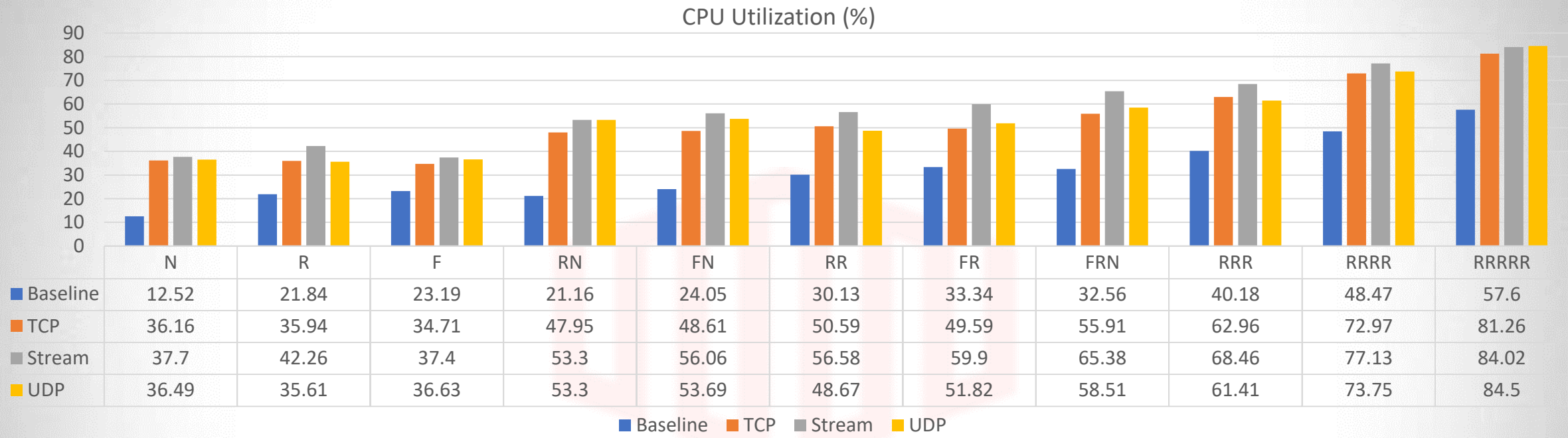
Test Results

Introduction

Element	Description
CPU Utilization (%)	• It is the percentage of CPU core used. • The value can be above 100% depending on number of cores. • Maximum CPU Utilization = 100 * Number of Cores (12) = 1200%
Memory Utilization (%)	• Total RAM consumed during the period of testing. • Current server is equipped with 64GB of RAM.
Latency	• Round Trip Time between Iperf Client and Server.
Throughput	• Amount of data passed between the Iperf Client and Server.

Abbreviation	Element
F	Firewall – Juniper VSRX
R	Router – Cisco CSR 1000v
N	NAT – VYOS

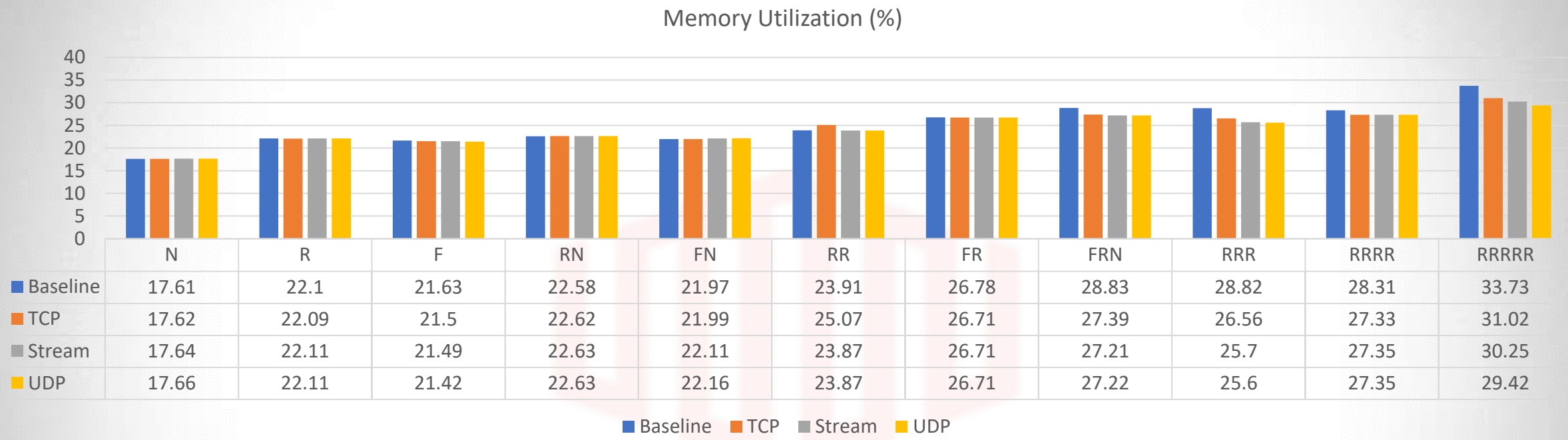
Server – CPU Utilization



	N	R	F	RN	FN	RR	FR	FRN	RRR	RRRR	RRRRR
Baseline	12.52	21.84	23.19	21.16	24.05	30.13	33.34	32.56	40.18	48.47	57.6
TCP	36.16	35.94	34.71	47.95	48.61	50.59	49.59	55.91	62.96	72.97	81.26
Stream	37.7	42.26	37.4	53.3	56.06	56.58	59.9	65.38	68.46	77.13	84.02
UDP	36.49	35.61	36.63	53.3	53.69	48.67	51.82	58.51	61.41	73.75	84.5

- Each additional VNF (except NAT) increases CPU utilization percentage of the server by 8-12 in value without traffic.
- Out of all the traffic types, parallel streams consumes highest CPU on the server, followed by UDP, and finally TCP.
- VYOS (NAT) has negligible CPU utilization when it is deployed and no traffic passes through it, followed by CSR (Router) and VSRX (Firewall).
- The rate of increase in CPU utilization decreases with addition of each router when traffic is passed through it.

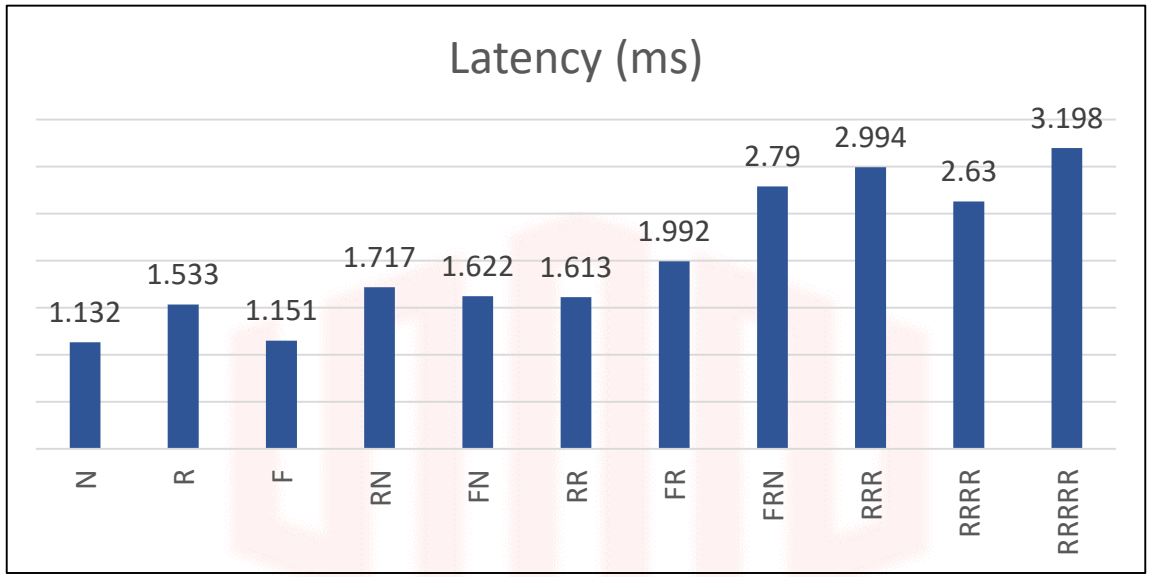
Server – Memory Utilization



	N	R	F	RN	FN	RR	FR	FRN	RRR	RRRR	RRRRR
Baseline	17.61	22.1	21.63	22.58	21.97	23.91	26.78	28.83	28.82	28.31	33.73
TCP	17.62	22.09	21.5	22.62	21.99	25.07	26.71	27.39	26.56	27.33	31.02
Stream	17.64	22.11	21.49	22.63	22.11	23.87	26.71	27.21	25.7	27.35	30.25
UDP	17.66	22.11	21.42	22.63	22.16	23.87	26.71	27.22	25.6	27.35	29.42

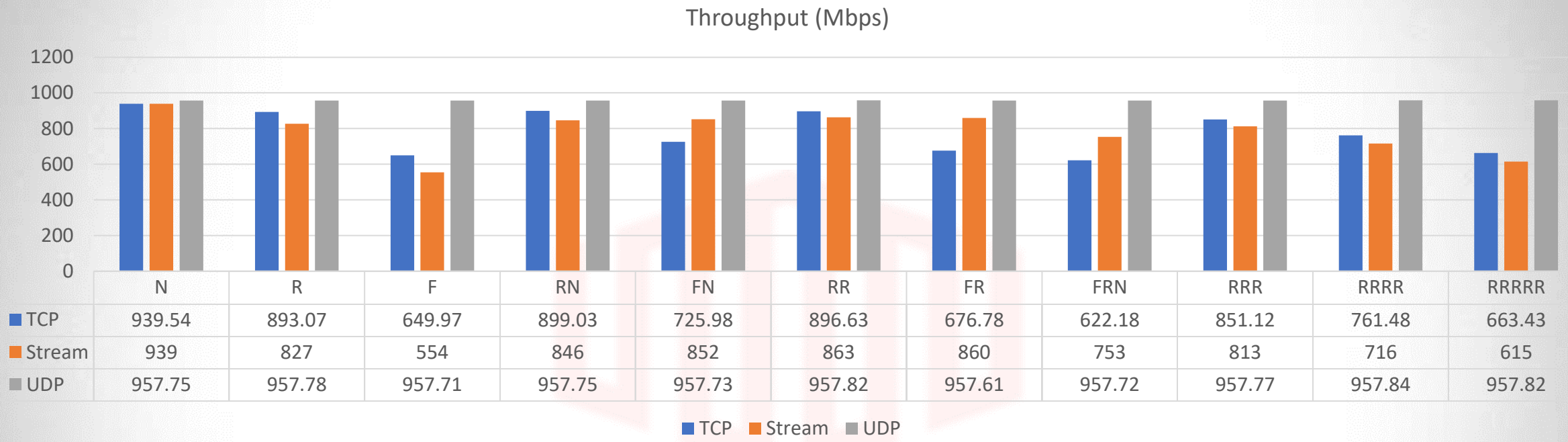
- Memory Utilization (RAM) increases with increase in the number of VNFs with no discernible pattern when no traffic is passed through the service chain.
- Passing traffic through the service chain has no effect on Memory Utilization (RAM) of the server and is unaffected by different traffic types.

Latency Through Service Chain



- Without any VNF Deployed the latency across server was marked as **0.499 ms.**
- Latency increases with increase in number of VNFs.
- No direct relation observed between the type of VNF added and latency.

Throughput

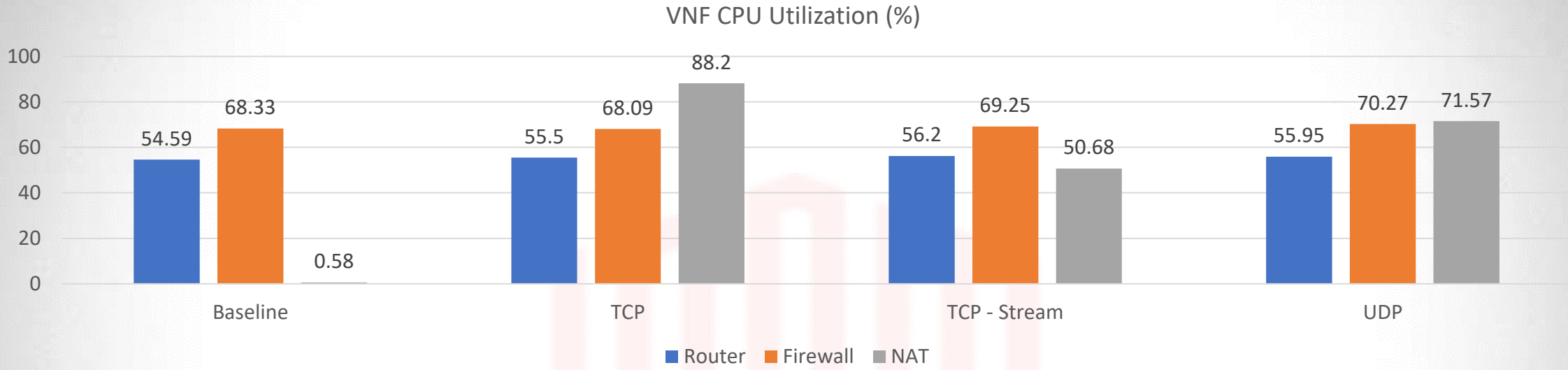


	N	R	F	RN	FN	RR	FR	FRN	RRR	RRRR	RRRRR
TCP	939.54	893.07	649.97	899.03	725.98	896.63	676.78	622.18	851.12	761.48	663.43
Stream	939	827	554	846	852	863	860	753	813	716	615
UDP	957.75	957.78	957.71	957.75	957.73	957.82	957.61	957.72	957.77	957.84	957.82

*TCP Stream indicates 100 parallel TCP connections between iPerf client and server. Average throughput per stream has been normalized (multiplied by 100) for comparison purposes.

- Overall throughput for all traffic types (except UDP) decreases with increase in the number of VNF.
- Highest throughput is obtained for UDP traffic followed by TCP and finally TCP stream.
- Throughput loss observed is highest in Firewall, followed by Router and NAT.

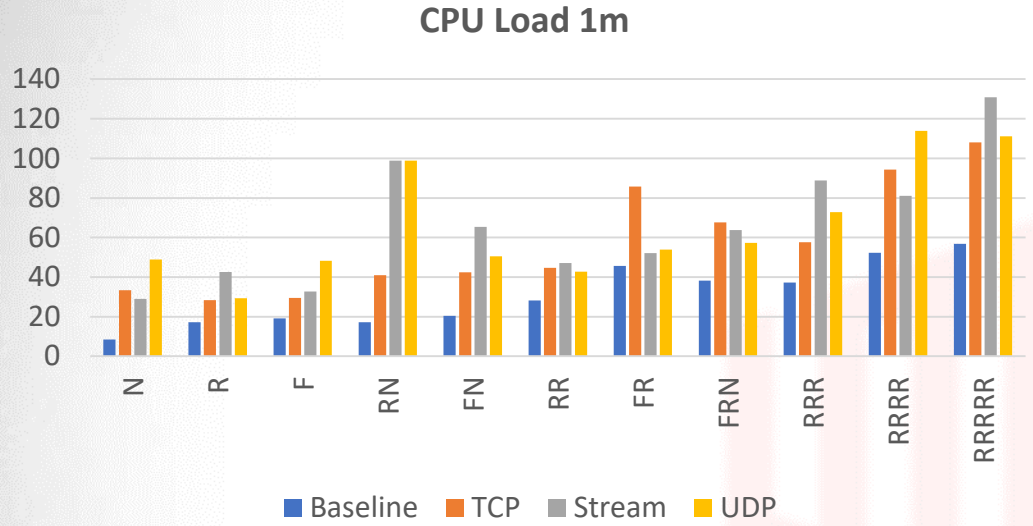
VNF CPU Utilization

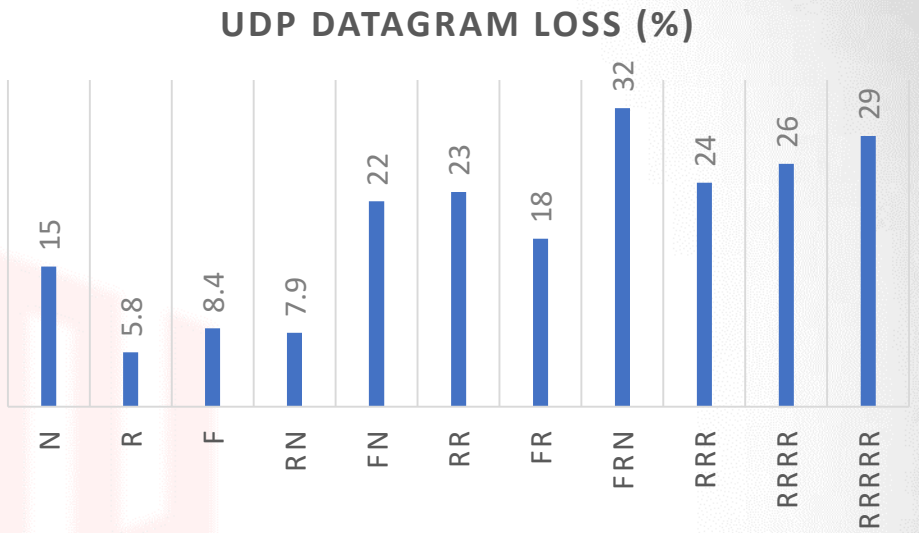


VNF Statistics:

- Juniper VSRX (Firewall) consumes highest CPU amongst all other VNFs (67 at baseline). With addition of new VNF, increase in CPU utilization is minimal.
- Cisco CSR 1000v (Router) CPU utilization percentage remains constant (55) at baseline and even when traffic passes through the chain.
- VYOS (NAT) CPU utilization increases drastically (reaching 80%) when it is the only one in the service chain. When combined with other VNFs, the NAT VNF CPU utilization percentage ranges from 25-40.

Uncertainties in Test Results





- CPU Load:
  - We saw aberration in presence of traffic in CPU Load with different service chains.
  - There was no relation to the number of VNF deployed and the varying CPU load.
- UDP Datagram Loss:
  - No Conclusion could be drawn from UDP Datagram Loss obtained for each service chain.
  - Since UDP is unreliable we could not relate to the test environment and the Loss percentage received.

System Engineering

Approach

Tool	Intent	Benefits in later stages of the Project
PDD	Scoped the project and identified critical project elements and levels of success.	Gave us clear insights on the critical factors that need more attention while designing the test environment.
CDD	Examined key design options for Traffic generators and Hypervisors. Chose iPerf and KVM respectively using sound rationale developed considering key parameters.	Project element analysis and comparison, this helped us in giving more in-depth knowledge of the products capabilities and limitations.
CDR	Identified Project Risks and their mitigation. Chalked out a work plan and primary testing scenarios.	Helped us design the timeline and fix work schedule to ensure completion of the project on time.
Post-CDR	Installed OpenStack, Monitoring tool for provisioning service chains.	Gave us a early start in environment setup phase, giving ample time in testing and inference.
Pre-TRR	Set up testing environment to direct testing traffic into the service chain. Configure polling of data for individual VNFs and server parameters.	Understand environment variables and factors influencing test results. Laid out plan to mitigate issues.
Post-TRR	Execute automated tests for various service chain combinations. Consolidate extracted data and analyze it to gain insights into operations.	Increased efficiency of testing via automation and insured consistency in testing - reducing variables.

Learnings

Issues encountered

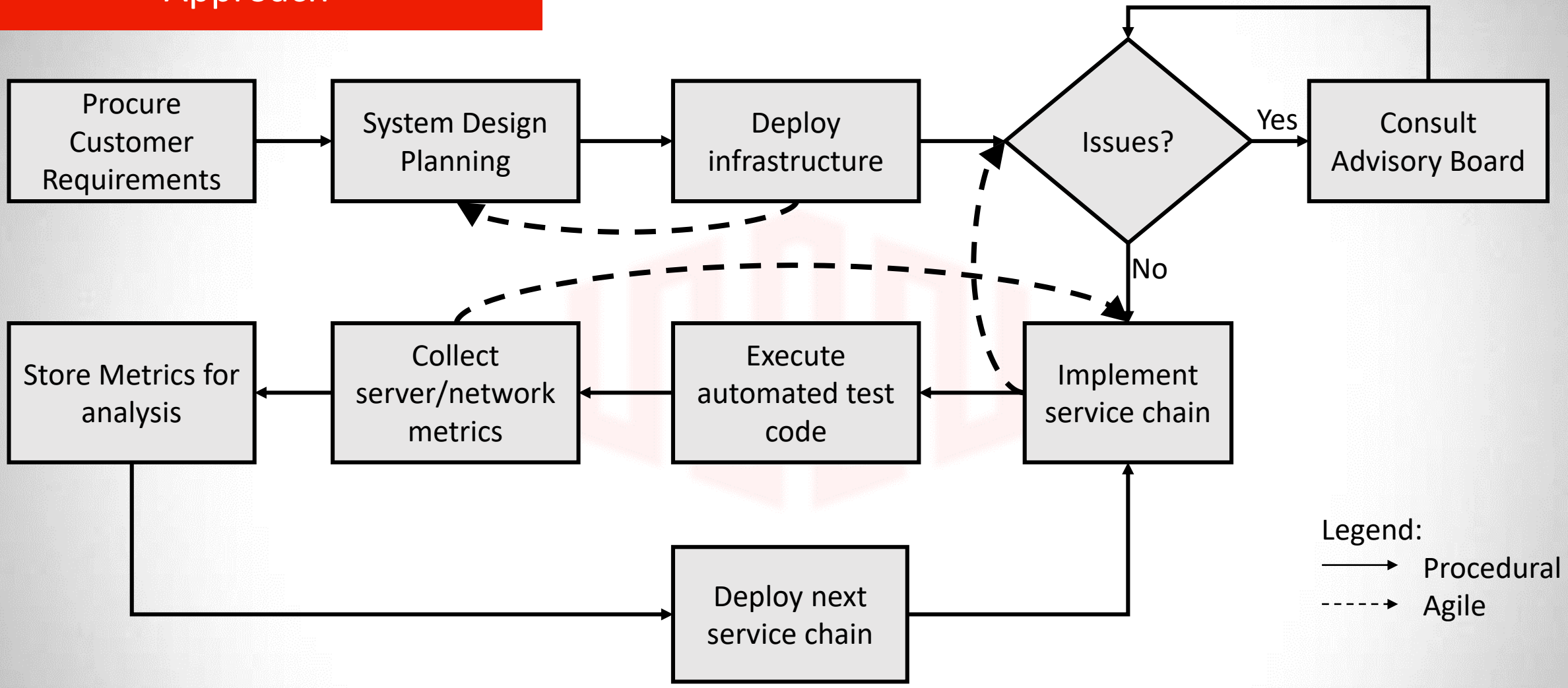
- OpenStack installation delayed due to unstable master branch. Had to use stable/rocky instead.
- Poor documentation for open source software (OpenStack and Gnocchi).
- Knowledge gap with respect to vendor specific functionalities such as Juniper VSRX/Cisco CSR.
- Issues in directing traffic in and out of the service chain.

Lessons learned

- Understand customer requirements completely before proceeding towards implementation.
- Opportunity to get familiar with cloud orchestration tool OpenStack.
- Implement simple designs to make the system work.
- Keep trying various solutions till one works.
- Allocate some time towards the end as buffer in case unforeseen complications occur.

Project Management

Approach


Procure Customer Requirements
System Design Planning
Deploy infrastructure
Issues?
Yes
Consult Advisory Board
No
Implement service chain
Execute automated test code
Collect server/network metrics
Store Metrics for analysis
Deploy next service chain
Legend:
Procedural
Agile

Learnings

Successes

- The team was able to adapt to frequent changes in online repositories and come up with alternatives to achieve high-level goals.
- Use of agile methodology helped the team achieve incremental goals while accommodating customer requirements.
- Effective documentation allowed tasks to be taken over among members smoothly.

Lessons learned

- Breaking down big problems into multiple smaller ones helps focus on one problem at a time.
- Use of Kanban board to assign tasks to team members is important to keep up the pace of the project.
- Scope out components of the project early on. This helps to prepare for alternative solutions in case of failure.

Estimated Industry Cost

Component	Value
Number of Engineers	4
Number of Weeks	30
Hours/Week/Engineer	20
Cost/Hour ($)	40
Total labor cost	$96,000
Total cost with overhead rate (200%)	$192,000

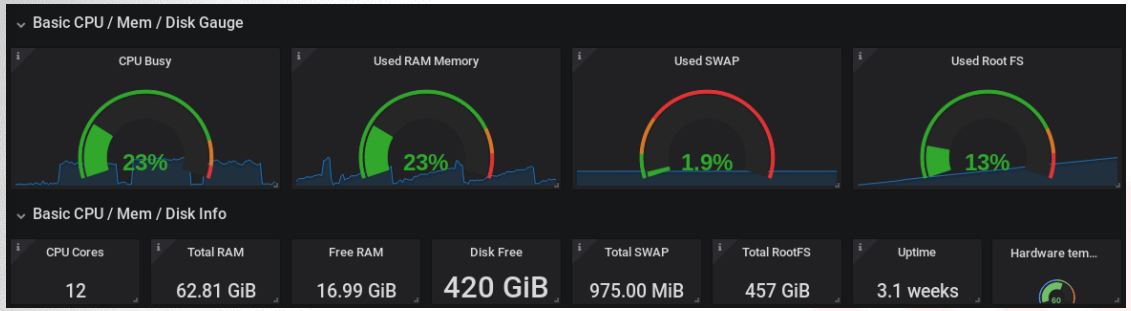
FIN/ACK?

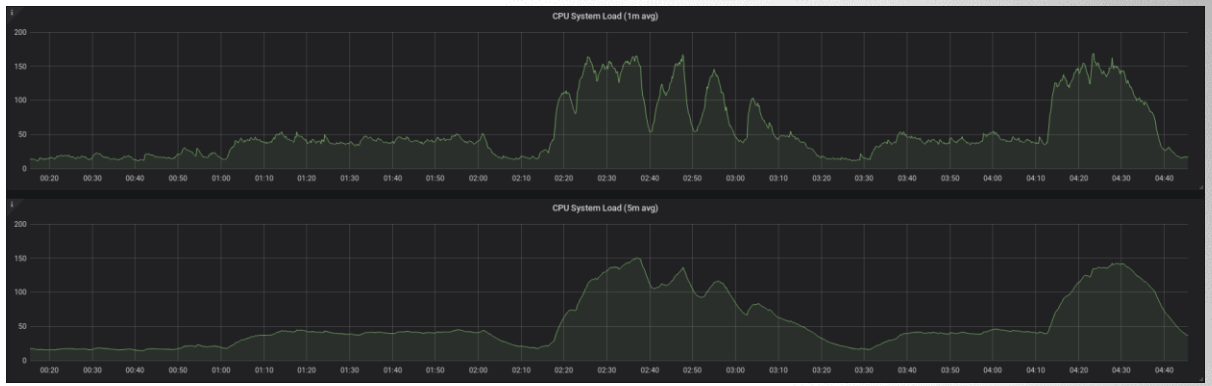
Firewall Router NAT Output

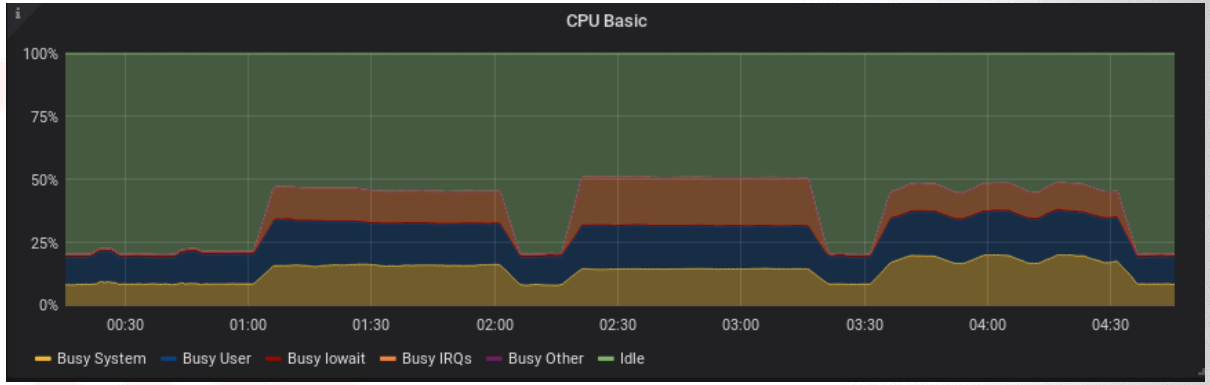
Output Performance																					
Test Case Number	Service Chain	Traffic Type		Server				VNF	Firewall Juniper VSRX				Router Cisco CSR				VyOS NAT				Notes
			Parameters	Max	Min	Avg	Delta	Parameters	Max	Min	Avg	Delta	Max	Min	Avg	Delta	Max	Min	Avg	Delta	
0	Baseline statistics (Before service chain deployment)	N/A	CPU Utilization (%)	20.9	9.68	11.24	N/A														
			Memory Utilization (%)	16.29	16.14	16.22	N/A														
			CPU Load 1 m (%)	22.5	1.08	7.32	N/A														
			CPU Load 5m (%)	12.33	3.58	6.94	N/A														
1	Baseline statistics (After deployment of service chain)	N/A	CPU Utilization (%)	51.48	28.22	32.56	21.32	CPU Utilization (%)	67.64	67.29	67.49	N/A	54.47	54.37	54.43	N/A	1.07	0.05	0.14	N/A	
			Memory Utilization (%)	29.21	28.68	28.83	12.61	Disk Usage (Bytses)	410648576.00	401080320.00	405924942.77	N/A	55443456.00	55443456.00	55443456.00	N/A	262784.00	262784.00	262784.00	N/A	
			CPU Load 1 m (%)	117.17	21.92	38.15	30.83	Disk Allocation (Bytes)	410591232				55386112				204800				
			CPU Load 5m (%)	82.25	26.58	38.20	31.26	Disk Size (GB)	40				40				40				
			Latency (ms)	5.66	2.04	2.79	N/A	Disk Capacity (GB)	42949672960				42949672960				42949672960				
								VCPUs (number)	2				2				2				
								Memory (MB)	4096				4096				4096				
								Ephemeral Size (GB)	0				0				0				
2	TCP Traffic Stream: 1	TCP	CPU Utilization (%)	70.87	35.03	55.91	23.35	CPU Utilization (%)	70.50	67.56	70.04	2.55	54.92	54.47	54.76	0.33	27.94	0.06	24.90	24.76	
			Memory Utilization (%)	28.58	27.17	27.39	-1.44	Disk Usage (Bytses)	422707200.00	413138944.00	417882742.15	11957799.38	55443456.00	55443456.00	55443456.00	0.00	262784.00	262784.00	262784.00	0.00	
			CPU Load 1 m(%)	154.83	30.08	67.71	29.56														
			CPU Load 5 m(%)	117.42	29.83	65.68	27.48														
			Throughput (Mb)	860.00	0.00	622.18	N/A														
3	TCP Traffic Stream: 100	TCP	CPU Utilization (%)	78.20	32.63	65.38	32.82	CPU Utilization (%)	73.95	67.80	72.91	5.42	56.12	54.45	55.53	1.10	32.69	0.11	29.24	29.10	
			Memory Utilization (%)	27.28	27.15	27.21	-1.62	Disk Usage (Bytses)	434896896.00	425197568.00	429971613.54	24046670.77	55443456.00	55443456.00	55443456.00	0.00	262784.00	262784.00	262784.00	0.00	For TCP Stream - Avergage BW is per stream.
			CPU Load 1 m(%)	120.33	30.33	63.68	25.53														
			CPU Load 5 m(%)	84.25	34.33	61.69	23.49														
			Throughput (Mb)	58.30	0.00	7.53	N/A														
4	UDP Traffic Stream: 1	UDP	CPU Utilization (%)	76.53	34.22	58.51	25.95	CPU Utilization (%)	73.95	67.62	72.45	4.96	55.45	54.43	55.20	0.77	31.17	0.06	27.20	27.06	
			Memory Utilization (%)	27.32	27.17	27.22	-1.61	Disk Usage (Bytses)	447021056.00	437256192.00	442110897.23	36185954.46	55443456.00	55443456.00	55443456.00	0.00	262784.00	262784.00	262784.00	0.00	
			CPU Load 1 m(%)	104.08	46.00	57.28	19.13														UDP Datagram Loss: 32%
			CPU Load 5 m(%)	83.92	52.17	58.80	20.60														
			Throughput (Mb)	959.00	863.00	957.72	N/A														
			UDP Datagram Loss (%)				32														
Start Time:	09 April 2019 00:43:40																				
End Time:	09 April 2019 05:29:08																				
Server:	172.16.218.20																				

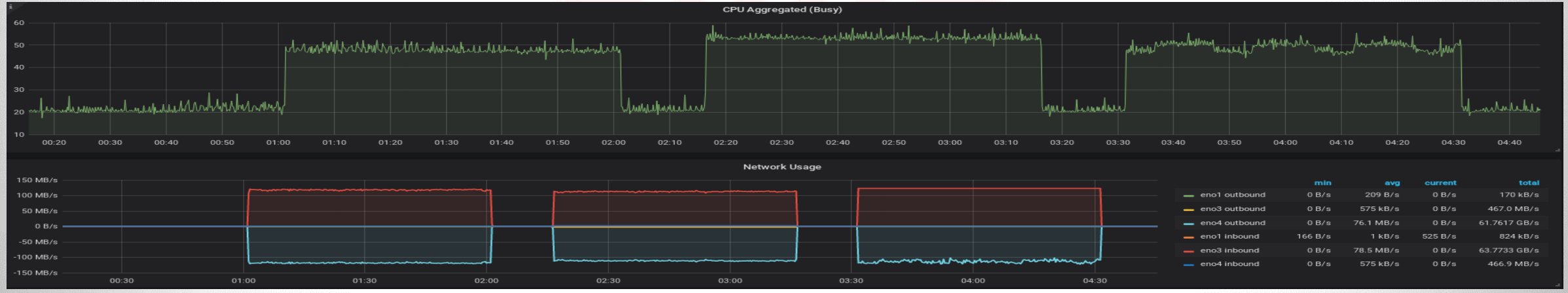
Appendix

Firewall Router NAT Graphs









Appendix

Resource Allocations

Element	Value
Server	
Operating System	Ubuntu 16.0.4 LTS
CPU	X86_64
Number of Cores	12
Processor Speed	1600 MHz
Total Memory (RAM)	64GB
Disk Space	512 GB
Interfaces	Fast Ethernet
Each VNF	
Disk Allocation	204800 Bytes
Disk Size	40 GB
VCPUs	2
Memory (RAM)	4096 Mb
Ephemeral Disk	0 Gb