PERFORMANCE TEST REPORT

STACS Blockchain Performance
On Premise Deployment
with
Dell Hardware

Preface

The STACS Blockchain has deployed and tested in an on-premise, Production environment on 5 bare metal Dell servers with a pre-optimized baseline steady-state performance of 4,527 Transactions Per Second (TPS).

The STACS Blockchain was also able to maintain such TPS during a stress test with over 40 million transactions in the blockchain state.

We also achieved all key objectives in various scenarios that we set out for our test, and are delighted to report that in all Production test cases and pessimistic scenarios, the STACS Blockchain was still able to achieve a minimum of 4,100 Transactions Per Second and is ready for any Production workloads even without further optimization.

We are grateful to Dell Technologies for partnering us in this stress test.

You can find below the full technical report

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1 Executive Summary

- The report outlines the performance test results and observations for STACS blockchain performance testing and it concludes as completed
- The following test were conducted to quantify the behavior of STACS Blockchain under the following scenarios:
    - Cycle 1: Baseline Test
    - Cycle 2: Stress Test 1x
    - Cycle 3: Stress Test 1x with Blockchain Data Erased
    - Cycle 4: Availability Test (Baseline Test with Node Offline)

- The performance test concludes the following:

Performance Test	Observations
Baseline Test	>> Target TPS (above 4,000) achieved >> Higher than expected Error Rate
Stress Test 1x	>> Target TPS (above 4,000) achieved >> Insignificant increment in error rate observed
Stress Test 1x with Blockchain Erased	>> Target TPS (above 4,000) achieved >> Insignificant increment in error rate observed
Availability Test (Baseline Test with Node Offline)	>> Target TPS (above 4,000) achieved >> Increment in error rate observed

2 Test Summary

The STACS Blockchain environment consists of 5 blockchain nodes with each node deployed on a single bare-metal dedicated server. The performance of a blockchain is primarily the Transactions Per Second (TPS) that a blockchain can support in different conditions that we simulate here.

Testing was done with Apache JMeter and the test results are recorded live with each node exposing a JSON report via HTTP ports that records and displays raw measurements aside from TPS. These reports are displayed as screenshots in each of the tests conducted.

TPS is measured by the 1-minute TPS measurement as indicated in the JSON report from each node that is highlighted in the screenshots below.

Since each node is deployed to an Apache Tomcat server, we limited the Max Threads supported by Tomcat for each node to 2000 concurrent threads after a few rounds of local optimization. In future testing, this will be an additional parameter to further optimize and increase the TPS of the STACS blockchain environment.

2.1 Baseline Test

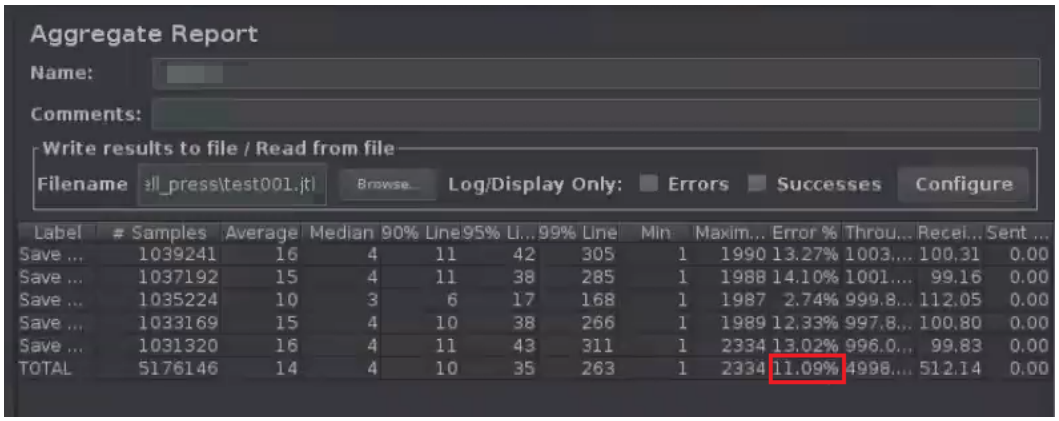
We conduct a baseline test with 10,000 concurrent requests (users) with 800 cycles (threads) to measure the baseline TPS and performance.

Configuration Type	Configuration Settings
Users	10,000
Threads	800
Max Threads	2000

2.1.1.1 Test Result – TPS


```
"packageTx.p999": "500.00",
"packageTx.value": 500,
"timer.mean.value": 0,
"timestamp": 1582785463263,
"tx.count": 12747509,
"tx.rate.15m": "2481.08 calls/second",
"tx.rate.1m": "4527.93 calls/second",
"tx.rate.5m": "4061.60 calls/second",
"tx.rate.mean": "1042.22 calls/second",
"tx.snapshot.75%": "0.03 millisecond",
"tx.snapshot.95%": "0.06 millisecond",
"tx.snapshot.98%": "0.07 millisecond",
"tx.snapshot.99%": "0.09 millisecond",
"tx.snapshot.99.9%": "0.29 millisecond",
```

2.1.1.2 Test Result – Error Rate



Label	# Samples	Average	Median	90% Line	95% Li...	99% Line	Min	Maxim...	Error %	Throu...	Recei...	Sent ...
Save ...	1039241	16	4	11	42	305	1	1990	13.27%	1003....	100.31	0.00
Save ...	1037192	15	4	11	38	285	1	1988	14.10%	1001....	99.16	0.00
Save ...	1035224	10	3	6	17	168	1	1987	2.74%	999.8...	112.05	0.00
Save ...	1033169	15	4	10	38	266	1	1989	12.33%	997.8...	100.80	0.00
Save ...	1031320	16	4	11	43	311	1	2334	13.02%	996.0...	99.83	0.00
TOTAL	5176146	14	4	10	35	263	1	2334	11.09%	4998....	512.14	0.00

2.1.1.3 Test Observations

A transaction per second (TPS) of **4527** was achieved with a higher than expected error rate of **11.09%**. After multiple rounds of verifying the setup at the physical layer and optimizing the maximum number of threads at the software layer, the probable causes for this higher than expected error rate would most likely be but not limited to:

1. Unoptimized Jmeter Proxy setting
2. Unoptimized Kubernetes networking setup such as the flannel at the container level

Further testing will be necessary to pinpoint the actual cause where a patch can be deployed to further minimize the error rate.

Since this error occurs at the Node level where requests sent to the nodes in the Blockchain environment are dropped before being processed, minimization of the error rate will lead to an increase in the baseline TPS.

2.2 Stress Test 1x

We conduct a stress test with 10,000 concurrent requests (users) with 1000 cycles (threads) to measure the TPS and performance with stress conditions.

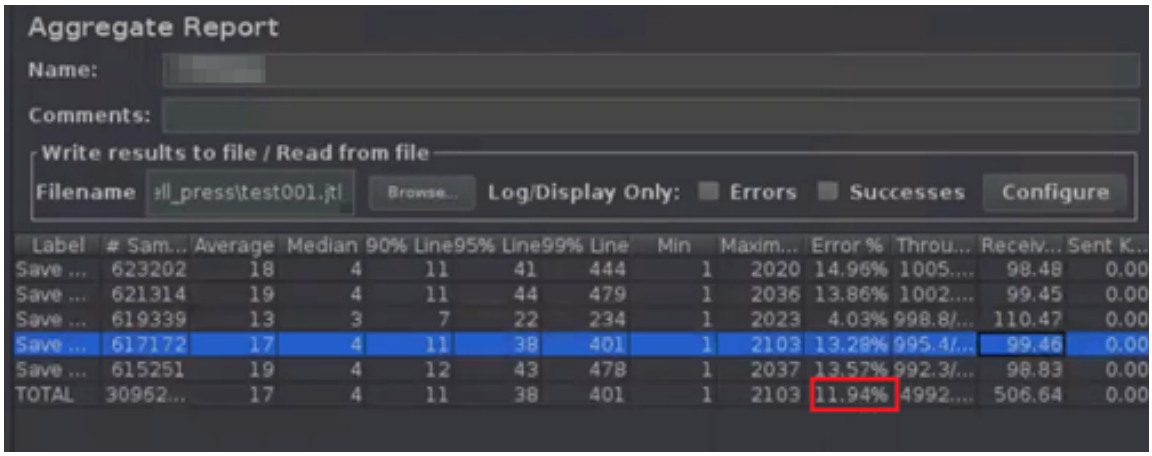
The existing number of blocks in the system is about 40 million transactions where the Blockchain must simultaneously manage existing blocks and add new blocks based on a higher thread count.

Configuration Type	Configuration Settings
Users	10,000
Threads	1.000
Max Threads	2,000

2.2.1.1 Test Result – TPS


```
"packageTx.p99": "500.00",
"packageTx.p999": "500.00",
"packageTx.value": 412,
"timer.mean.value": 0,
"timestamp": 1582790219571,
"tx.count": 3944994,
"tx.rate.15m": "2592.04 calls/second",
"tx.rate.1m": "4487.32 calls/second",
"tx.rate.5m": "3866.22 calls/second",
"tx.rate.mean": "2606.33 calls/second",
"tx.snapshot.75%": "0.03 millisecond",
"tx.snapshot.95%": "0.06 millisecond",
"tx.snapshot.98%": "0.07 millisecond",
"tx.snapshot.99%": "0.10 millisecond",
```


2.2.1.2 Test Result – Error Rate



Label	# Sam...	Average	Median	90% Line	95% Line	99% Line	Min	Maxim...	Error %	Throu...	Receiv...	Sent K...
Save ...	623202	18	4	11	41	444	1	2020	14.96%	1005....	98.48	0.00
Save ...	621314	19	4	11	44	479	1	2036	13.86%	1002....	99.45	0.00
Save ...	619339	13	3	7	22	234	1	2023	4.03%	998.8/...	110.47	0.00
Save ...	617172	17	4	11	38	401	1	2103	13.28%	995.4/...	99.46	0.00
Save ...	615251	19	4	12	43	478	1	2037	13.57%	992.3/...	98.83	0.00
TOTAL	30962...	17	4	11	38	401	1	2103	11.94%	4992....	506.64	0.00

2.2.1.3 Test Observations

A transaction per second (TPS) of **4482 was achieved** with a higher than expected error rate of **11.94%**. We note that increasing the number of threads does not decrease TPS significantly despite an existing number of 40 million blocks.

Whilst we expect TPS to be inversely correlated with Error Rate, there was a deviance from initial hypothesis between Stress Test 1x and Baseline Test. We note that the deviance of error rate (0.8%) is insignificant.

2.3 Stress Test 1x with Blockchain erased

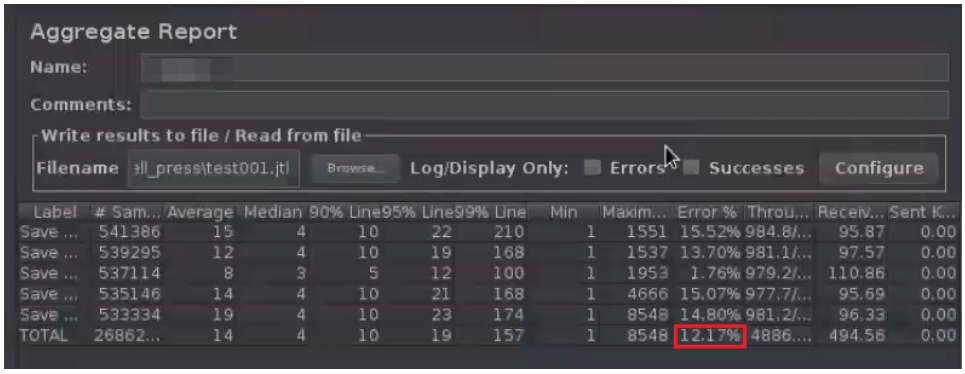
We conduct another stress test with 10,000 concurrent requests (users) with 1000 cycles (threads) to measure the baseline TPS and performance without the existing blocks and data in the Blockchain environment.

Configuration Type	Configuration Settings
Users	10,000
Threads	1,000
Max Threads	2,000

2.3.1.1 Test Result – TPS


```
packageTx.p95 : 500.00 ,
"packageTx.p98": "500.00",
"packageTx.p99": "500.00",
"packageTx.p999": "500.00",
"packageTx.value": 6,
"timer.mean.value": 0,
"timestamp": 1582792253631,
"tx.count": 1482552,
"tx.rate.15m": "1370.22 calls/second",
"tx.rate.1m": "4467.97 calls/second",
"tx.rate.5m": "2968.05 calls/second",
"tx.rate.mean": "2611.65 calls/second",
"tx.snapshot.75%": "0.03 millisecond",
"tx.snapshot.95%": "0.06 millisecond",
"tx.snapshot.98%": "0.06 millisecond",
"tx.snapshot.99%": "0.07 millisecond",
```


2.3.1.2 Test Result – Error Rate



2.3.1.3 Observations

A transaction per second (TPS) of **4467.97** with an error rate of **12.17%** was achieved with blockchain data wiped and erased. We note that the STACS blockchain is scalable - the performance of the blockchain (transaction throughput) does not degrade with increased block height. The speed at which new blocks are added is not impeded by the total number of blocks existing in the network.

Transaction Finality is achieved and maintained consistently at the baseline TPS rate as the blockchain network grows.

2.4 Availability test (Baseline Test with 1 Node Offline)

We conduct an availability test with 10,000 concurrent requests (users) with 800 cycles (threads) to measure the baseline TPS and performance with 1 node offline.

This test serves to measure the degradation of TPS performance in common Production scenarios where nodes could be temporarily unavailable to participate in the consensus rounds due to a variety of reasons which could be environmental (e.g. network is not available) or internal (e.g. node's block state has deviated from the other nodes in the network).

The offline status of a node will still require the incoming requests to be forwarded to the offline node during the initial stages of the Transaction lifecycle while the consensus round of the STACS blockchain ignores the request as the node is still registered in all nodes' gatekeepers since STACS is a permissioned network. In such cases, the blockchain will wait until timeout before proceeding with consensus, which should lead to a slowdown in TPS performance.

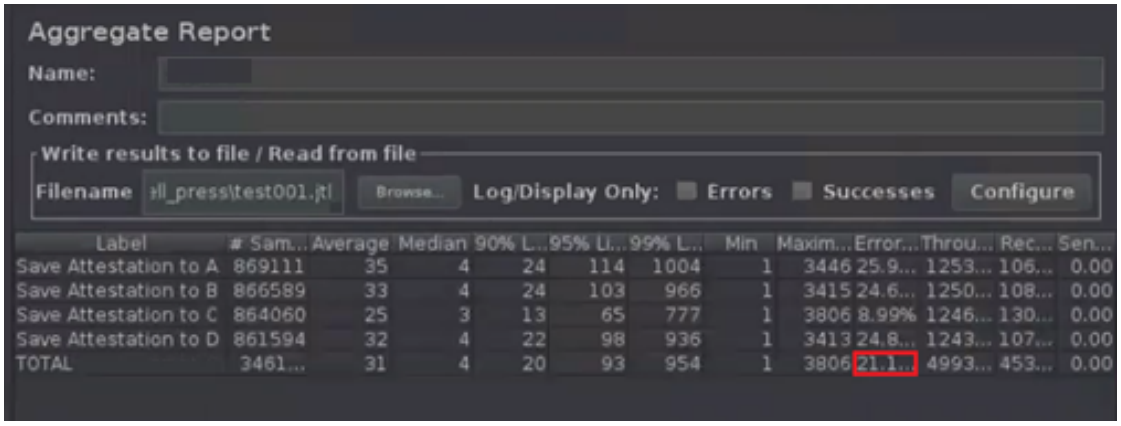
Note that nodes that are completely removed from the network will not have the status of "Offline" and are instead deleted from the nodes' gatekeepers which is not applicable in this test.

Configuration Type	Configuration Settings
Users	10,000
Threads	800
Max Threads	2,000

2.4.1.1 Test Result – TPS


```
"packageTx.p98": "500.00",
"packageTx.p99": "500.00",
"packageTx.p999": "500.00",
"packageTx.value": 377,
"timer.mean.value": 0,
"timestamp": 1582794925631,
"tx.count": 7682078,
"tx.rate.15m": "2558.97 calls/second",
"tx.rate.1m": "4172.73 calls/second",
"tx.rate.5m": "3218.15 calls/second",
"tx.rate.mean": "2371.25 calls/second",
"tx.snapshot.75%": "0.04 millisecond",
"tx.snapshot.95%": "0.06 millisecond",
"tx.snapshot.98%": "0.08 millisecond",
"tx.snapshot.99%": "0.09 millisecond",
"tx.snapshot.99.9%": "0.13 millisecond",
```


2.4.1.2 Test Result – Error Rate



Label	# Sam...	Average	Median	90% L...	95% Li...	99% L...	Min	Maxim...	Error...	Throu...	Rec...	Sen...
Save Attestation to A	869111	35	4	24	114	1004	1	3446	25.9...	1253...	106...	0.00
Save Attestation to B	866589	33	4	24	103	966	1	3415	24.6...	1250...	108...	0.00
Save Attestation to C	864060	25	3	13	65	777	1	3806	8.99%	1246...	130...	0.00
Save Attestation to D	861594	32	4	22	98	936	1	3413	24.8...	1243...	107...	0.00
TOTAL	3461...	31	4	20	93	954	1	3806	21.1...	4993...	453...	0.00

2.4.1.3 Observations

A transaction per second (TPS) of **4172.73** with an error rate of **21.1%** was achieved with 1 node offline.

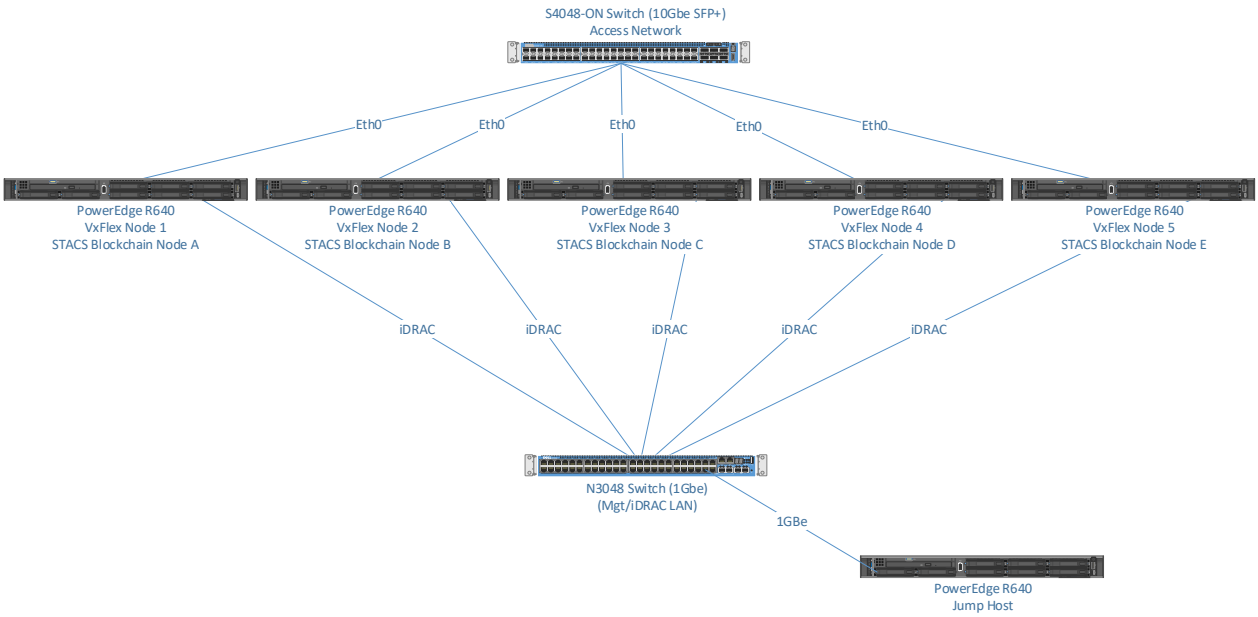
The degradation in TPS is maintained well above 4000, which indicates that the true performance of the Blockchain in a real-world setting can be expected as such and does not deviate too far from the baseline test.

During the initial transaction lifecycle stages, the network will need to wait for time-out confirmation that the node is continuously offline since offline is a temporary node state, hence attributing to a slower recorded TPS. Additionally, the increase in error rate is expected since requests sent to the offline node are not processed, contributing to the error rate.

3 Test Environment

The test environment consists of 5x Dell PowerEdge R640 servers and 1x Dell PowerEdge R640 server Jump Host. Each of these servers are connected a single 10Gbe SFP+ Dell switch and a single 1Gbe management Dell switch. Primary data transmission between server nodes, which houses 5 individual STACS Blockchain nodes, are based on 10Gbe link speeds.

3.1 POC Logical Diagram



3.2 Conceptual Architectures

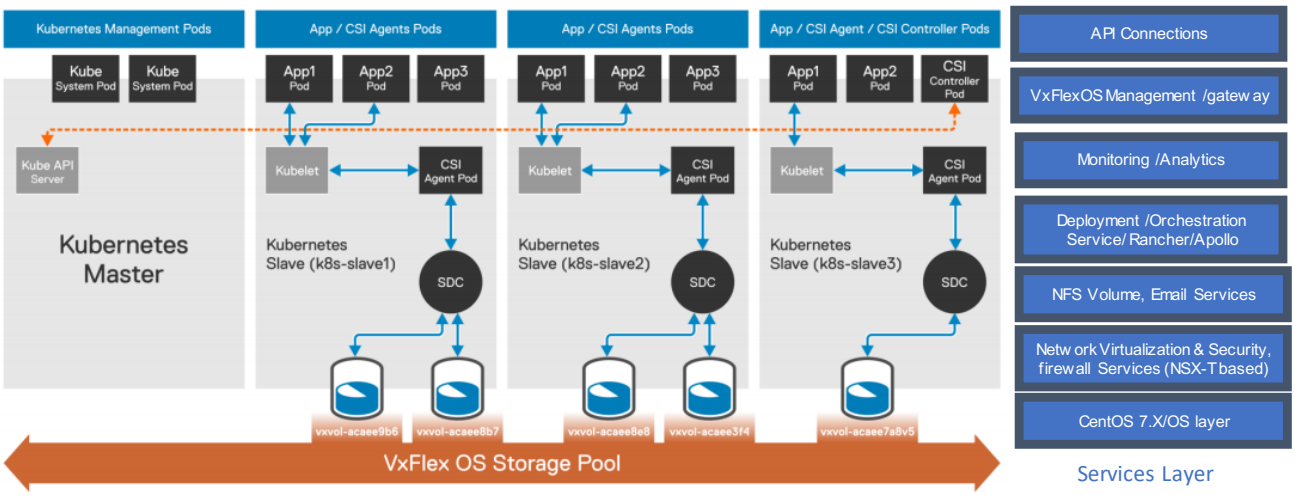
From this POC, we have derived two conceptual architectures to address to different Production scenarios. Each architecture addresses to a different set of needs and can be modified to suit any customised requirements. These concepts are currently still a work-in-progress and will be finalized, once further testing and validation has been done.

3.2.1.1 VxFlex Appliance (4 node)

Like the POC environment, the 4 node Dell VxFlex Appliance, is catered to end-customers who want a fully on-premise solution, where STACS Blockchain nodes can be scaled horizontally as well as vertically to cloud-based nodes, where necessary. Such an environment allows customers to have the capability of testing on cloud first and moving from cloud to on-premise eventually.

Customers also can choose to have a deployment model where Physical flex appliances can work in conjecture with cloud-based compute instances. In this model, It is given that stacs will handle all the block replication and manage the cluster read/writes across the boundaries of on prem DC and cloud .

In an actual production environment, VxFlexOS persistent disk will be used as storage solution for container infrastructure. Network availability will be guaranteed through dual access Layer switches(10/25G).This would prevent any infrastructure single-point-of-failure and to provide resiliency across all VxFlex nodes.



Kubernetes Cluster on VxFlexOS SDC (Storage Data Client) interacts with CSI components to deliver persistent storage.

3.2.1.2 VMware Appliance (single node)

To address to the need of a trial/test unit, a single server running VMware with multiple VMs (Virtual Machines) can be used in such environments. Eventually this will also allow hybrid deployments, where certain STACS Blockchain nodes can reside on-premise as well as cloud (i.e Google), via extensions.