Red Hat OpenShift on IBM Z - Performance Experiences, Hints and Tips

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Agenda

- Introduction
- Performance measurement and tuning approach
- Observations and recommendations
  - CPU-intensive workloads
  - Network-intensive workloads
- General tips for cloud-native applications
- Summary

Introduction

- Red Hat® OpenShift® is a ***hybrid cloud***, enterprise ***Kubernetes®*** platform
  - OpenShift website: *"…includes security, performance, and defect fixes, validated and tested integrations for third-party plugins, and enterprise lifecycle support"*
- Since it's a ***new technology*** for many IBM Z® customers, it brings its own set of requirements, pitfalls, etc.
  - Normal for new technologies
- ***Question***: Why is network performance ***important*** for applications running on OpenShift?
- ***Answer***: The general expectation is that most applications on OpenShift will be ***cloud-native*** type of applications, which are typically ***very network-sensitive***.
  - Highly componentized, built on ***micro-services***, ***distributed*** across the cluster
  - What used to be a ***function call*** for traditional applications is often a ***REST*** call now

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High-level environment setup

- IBM z15™
- z/VM® LPAR
  - 3 master nodes
  - 5 worker nodes
- Bastion server LPAR
  - Software load balancer
- uperf target LPAR
  - Simulating an external system

- IBM DS8950F
- ECKD disks
- Model 9s for z/VM
- *Extended Address Volumes* (EAVs) for z/VM guests
- 5 x HyperPAV aliases for each z/VM guest

Approach

- First step was to install a ***basic OpenShift cluster*** with 3 master nodes and 5 worker nodes
  – First OpenShift version was 4.2.x, which got upgraded many times
- Got familiar with both the OpenShift web console and the ***Command Line Interface*** (CLI)
  – For "serious" work like scripting, etc., the CLI is much better suited
- Ran a selection of ***microbenchmarks*** that we typically use for a Linux® distribution evaluation
  – CPU-intensive, network-intensive, disk I/O-intensive, crypto-intensive, etc.
- Pre-requisite for running microbenchmarks: ***containerize*** workloads
  – In OpenShift, every application runs in one or more container(s)
- Used our Linux distribution evaluation results as a ***baseline*** for comparison
  – When doing performance work, a solid baseline is extremely important

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Disclaimer

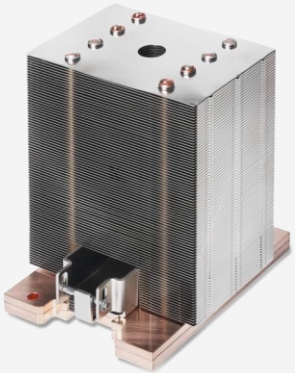
- The following is ***important*** – please read it carefully

- The performance test results in the following charts were obtained in a ***controlled lab environment***. The measured differences in performance – latency, throughput, etc. – might not be observed in real-life scenarios and customer production environments.

- All test runs were performed with IBM z15, z/VM 7.1, OpenShift 4.5.8, Red Hat® Enterprise Linux® CoreOS release 4.5, and uperf 1.0.3-beta. ***Other*** products and / or other product ***versions*** might produce ***different*** performance results.

CPU-intensive workloads

- Ran a selection of both ***CPU*** and ***memory-intensive*** workloads
  – Mostly Java®-based workloads
- Outcome: virtually ***no overhead*** compared to Linux distro baseline
  – Great result – expectation was to see at least a small degradation
- No need for further investigation



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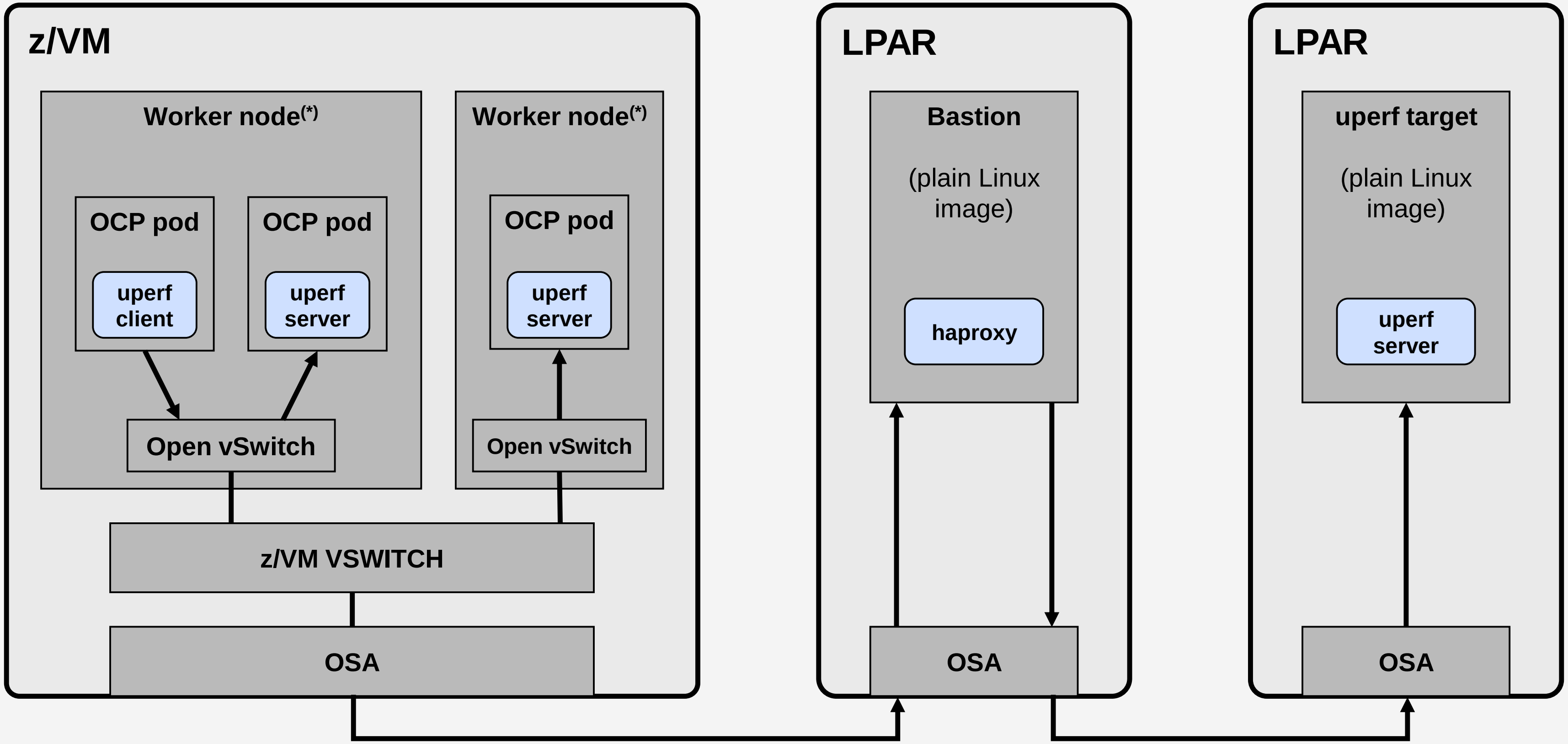
Network-intensive workloads

- First impression: network performance results were ***below our expectations***
  - Caveat: in the beginning, we did not understand OpenShift network architecture well enough

- Had to invest ***quite some time*** in order to get familiar with OpenShift network concepts
  - Recommendation: set some time aside to read through the OpenShift online documentation

OpenShift network performance: the big picture



(*)For the sake of simplicity, this overview diagram only contains the most relevant components. In reality, there are many more.

Some OpenShift network concepts

- OpenShift makes heavy use of the ***Software Defined Network*** (SDN) approach
  – One physical network device per pod would be way too much – virtualized network is required

- Every ***pod*** has its own ***virtual*** network interface
  – Inside the pod, this is called `eth0`

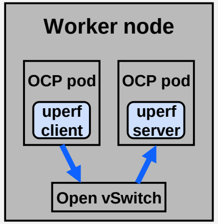
- This virtual network interface is connected to an ***Open vSwitch*** – not to be confused with z/VM VSWITCH
  – One Open vSwitch instance running per node

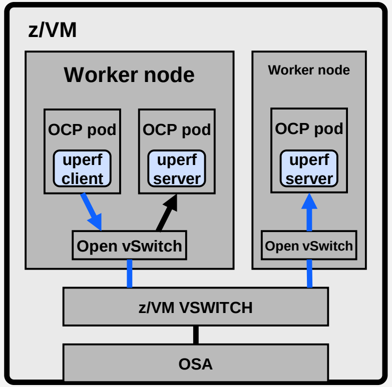
- Every Open vSwitch instance is configured based on ***OpenFlow™*** rules
  – Rules determine what packets are flowing where in the virtual network

- Network traffic that goes ***in and out of the cluster*** must pass through a ***load balancer*** of some form, which is the ***Bastion*** server in our test cluster
  – Load balancer can be either software-based or hardware-based

Network performance test scenarios

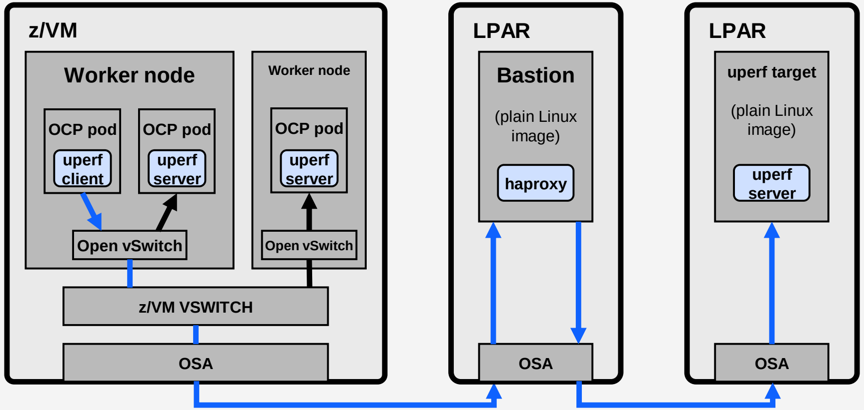
- Scenario #1: pod-to-pod communication ***inside the same*** worker node
  – Network traffic at the Open vSwitch layer only





- Scenario #2: pod-to-pod communication ***across*** worker nodes
  – In addition to scenario #1, z/VM VSWITCH is being used

- Scenario #3: pod-to-external communication
  – Traffic ***leaves*** the OpenShift cluster
  – All network layers are involved



Network performance evaluation basics

- Focus on ***latency*** and / or ***throughput***
  - Different requirements – high throughput doesn't necessarily mean low latency

- ***Small*** number of parallel connections versus ***large*** number of parallel connections
  - Single connection scenarios like backup, for example, versus online banking

- ***Transactional*** workloads ("ping-pong" type of communication) versus ***streaming*** workloads
  - Small network packets versus large or very large network packets

- A ***thorough*** analysis should consider either all or at least most of the above aspects

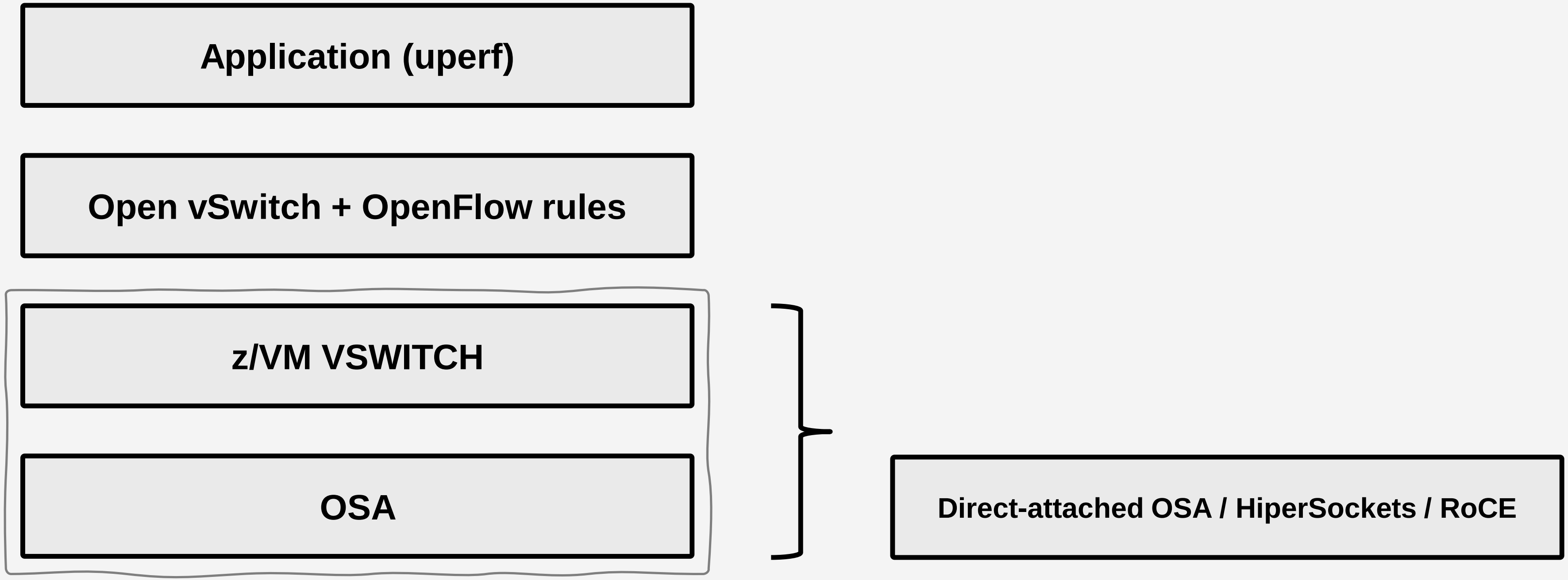
Network performance tuning

- Our goal: ***improve*** OpenShift network performance and give both easy-to-understand and easy-to-implement ***tuning hints and tips*** to existing and prospective customers

- Tuning category #1: change network configuration at the ***hardware level***
  - Exchange z/VM VSWITCH with direct-attached OSA card, HiperSockets, or RoCE card

- Tuning category #2: find ***configuration parameters*** that improve network performance
  - Much more complex, since there are literally hundreds of different configuration settings spread across the entire ***network*** and ***virtualization*** stack
  - Requires ***deep technical knowledge*** of different components of overall architecture (both virtualization and network)

Tuning category #1: hardware alternatives



Tuning category #2: network tuning options

- ***Finding*** and ***testing*** the below mentioned parameters and settings required an ***enormous*** amount of effort
  – Had to verify whether all scenarios either benefit or are at least not impacted

- Tuning recommendation #1: ***Receive Packet Steering*** (RPS)
  – Allows multiple CPUs to participate in network packet processing

- Tuning recommendation #2: adding one or more ***static route(s)*** for external traffic
  – Depends on your network architecture

- Tuning recommendation #3: move ***network-intensive*** OpenShift components away from your regular worker nodes out to ***infrastructure nodes***
  – Remedies performance imbalance / performance fluctuations across worker nodes

Tuning recommendation #1: Receive Packet Steering (RPS)

- RPS is controlled via a Linux ***sysfs*** entry called `rps_cpus`
  - Contents is a CPU mask
- Turned ***off***:

```
[root@worker-0 ~]# cat /sys/devices/qeth/0.0.6000/net/enc6000/queues/rx-0/rps_cpus
00000000,00000000
```

- Turned ***on***:

```
[root@worker-0 ~]# cat /sys/devices/qeth/0.0.6000/net/enc6000/queues/rx-0/rps_cpus
00000000,000000ff
```

- Can be changed via a ***udev*** rule, for example

Tuning recommendation #1: Receive Packet Steering (RPS), *continued*

- Create a plain text file called `enable-rps.txt` with the following contents:

```
# turn on Receive Packet Steering (RPS) for all network interfaces
ACTION=="add", SUBSYSTEM=="net", KERNEL=="*", ATTR{queues/*/rps_cpus}="ff"
```

- ***Question***: How can I apply this to all my worker nodes?

- ***Answer***: Make use of a ***Machine Config Object*** (MCO).

- Rule text has to be ***encoded*** like so:

```
cat enable-rps.txt |
python3 -c "import sys, urllib.parse; print(urllib.parse.quote(''.join(sys.stdin.readlines())))"
```

Tuning recommendation #1: Receive Packet Steering (RPS), *continued*

- Create a YAML file called `enable-rps.yaml` with the following contents:


```yaml
apiVersion: machineconfiguration.openshift.io/v1
kind: MachineConfig
metadata:
  labels:
    machineconfiguration.openshift.io/role: worker
  name: 50-enable-rps
spec:
  config:
    ignition:
      version: 2.2.0
    storage:
      files:
      - contents:
          source: data:text/plain;charset=US-
ASCII,%23%20turn%20on%20Receive%20Packet%20Steering%20%28RPS%29%20for%20all%20network%20interfaces%0A
ACTION%3D%3D%22add%22%2C%20SUBSYSTEM%3D%3D%22net%22%2C%20KERNEL%3D%3D%22%2A%22%2C%20ATTR%7Bqueues/%2A
/rps_cpus%7D%3D%22ff%22%0A
        filesystem: root
        mode: 0644
        path: /etc/udev/rules.d/71-net-tunings.rules
```

Tuning recommendation #1: Receive Packet Steering (RPS), *continued*

- Create a new MCO by running `oc create -f enable-rps.yaml`
- Double-check whether the MCO has been created: `oc get machineconfigs`
- Sample output on our test cluster:

```
NAME                                                        GENERATEDBYCONTROLLER                      IGNITIONVERSION   CREATED
00-master                                                   fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
00-worker                                                   fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
01-master-container-runtime                                 fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
01-master-kubelet                                           fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
01-worker-container-runtime                                 fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
01-worker-kubelet                                           fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
50-enable-rps                                                                                          2.2.0             5s
99-master-baa9a00d-7409-11ea-9cdc-02012c000005-registries   fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
99-master-ssh                                                                                          2.2.0             54d
99-worker-baaa415e-7409-11ea-9cdc-02012c000005-registries   fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
99-worker-ssh                                                                                          2.2.0             54d
rendered-master-782c5c9c34201d09133e3a83fa6db5bd            6e0df82cf15edec97b685e4e71f5385cebef50d2   2.2.0             54d
rendered-master-80ff9447b6f3bb017bace3eedf8e575d            fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             54d
rendered-master-9d2e28683c6f08b8e3e9e7cb262abf5d            fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             33d
rendered-worker-56ba8042a89644757398af2f22b39054            fac5a23280e6467ec95bb0237fae3ce387d04f0b   2.2.0             19d
...
```

Tuning recommendation #1: Receive Packet Steering (RPS), *continued*

- Check whether the MCO has been successfully applied on all matching nodes:

```
oc get machineconfigpools
```

- Sample output on our test cluster:

```
NAME     CONFIG                                             UPDATED   UPDATING   DEGRADED
master   rendered-master-9d2e28683c6f08b8e3e9e7cb262abf5d   True      False      False
worker   rendered-worker-7c4d650eee93c040333ffe2770ce720e   False     True       False
```

Tuning recommendation #1: Receive Packet Steering (RPS), *continued*

- Be ***patient***: this process takes quite some time to complete

- You can check the current status of the nodes with the following command:

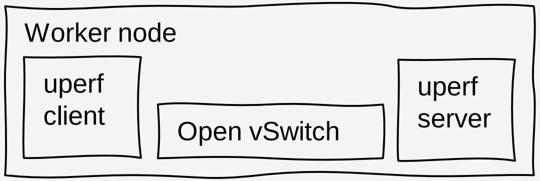
```
watch -n 5 oc get nodes
```

- Sample output on our test cluster:

```
NAME                          STATUS                          ROLES           AGE   VERSION
master-0.<our_domain_name>    Ready                           master,worker   54d   v1.14.6-152-g117ba1f
master-1.<our_domain_name>    Ready                           master,worker   54d   v1.14.6-152-g117ba1f
master-2.<our_domain_name>    Ready                           master,worker   54d   v1.14.6-152-g117ba1f
worker-0.<our_domain_name>    Ready,SchedulingDisabled        worker          54d   v1.14.6-152-g117ba1f
worker-1.<our_domain_name>    Ready                           worker          54d   v1.14.6-152-g117ba1f
worker-2.<our_domain_name>    Ready                           worker          54d   v1.14.6-152-g117ba1f
worker-3.<our_domain_name>    Ready                           worker          54d   v1.14.6-152-g117ba1f
worker-4.<our_domain_name>    Ready                           worker          54d   v1.14.6-152-g117ba1f
```

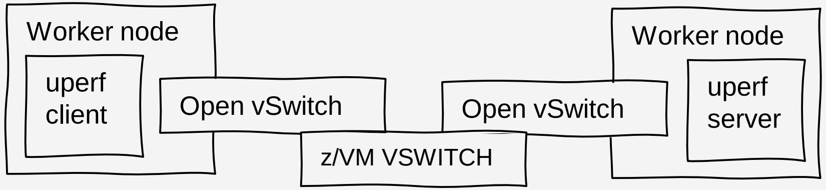
Tuning recommendation #1 (RPS): results

- **Scenario #1**: pod-to-pod, same worker



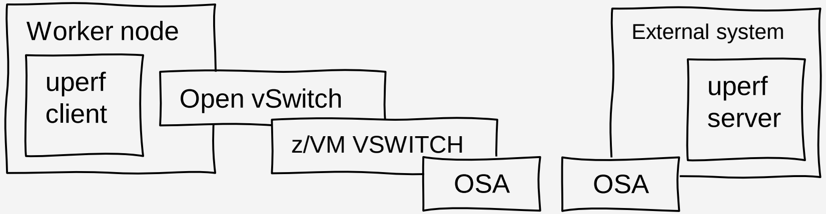
- Enabling RPS is ***not*** recommended if your OpenShift network traffic is mostly within the same worker node, since both latency and throughput ***degrade*** with this option turned on

- **Scenario #2**: pod-to-pod, cross-worker



- In this scenario, enabling RPS is ***recommended***, since it improves (a) latency ***up to 59%*** and (b) throughput ***up to 2.7x***, depending on the network connectivity and number of parallel connections

- **Scenario #3**: pod-to-external



- In this scenario, enabling RPS is ***recommended***, since it improves latency ***up to 35%***, depending on the network connectivity and number of parallel connections; throughput is either equal or higher, except for two individual measurements

Tuning recommendation #2: adding one or more static route(s)

- During our performance evaluation, we noticed that all network traffic to our external uperf target system had to ***pass through*** the load balancer due to a different IP subnet (see next page)
  – One additional network hop

- For outgoing traffic, this is ***not strictly required***
  – Might be different in your environment

- Goal: allow the traffic to flow ***directly*** to the uperf target system
  – Idea: avoid the additional hop by defining a static route

- RHEL systems: additional file in `/etc/sysconfig/network-scripts` called `route-enc9000`

```
A.B.D.0/24 dev enc9000
```

- Expectation: tuning recommendation applies to ***pod-to-external*** scenario only

Tuning recommendation #2: adding one or more static route(s), *continued*

- Before:

```
[root@worker-0 ~]# route -n
Kernel IP routing table
Destination  Gateway     Genmask         Flags   Iface
0.0.0.0      A.B.C.101   0.0.0.0         UG      enc9000
A.B.C.0      0.0.0.0     255.255.255.0   U       enc9000
A.E.0.0      0.0.0.0     255.252.0.0     U       tun0
172.x.0.0    0.0.0.0     255.255.0.0     U       tun0
```

- This is the routing table on the ***worker node***, not inside the pod

- IP address of the uperf target system: `A.B.D.254`

- **Note** that `A.B.C.101` is the Bastion server, which acts as a gateway in our test cluster

- After:

```
[root@worker-0 ~]# route -n
Kernel IP routing table
Destination  Gateway     Genmask         Flags   Iface
0.0.0.0      A.B.C.101   0.0.0.0         UG      enc9000
A.B.D.0      0.0.0.0     255.255.255.0   U       enc9000
A.B.C.0      0.0.0.0     255.255.255.0   U       enc9000
A.E.0.0      0.0.0.0     255.252.0.0     U       tun0
172.x.0.0    0.0.0.0     255.255.0.0     U       tun0
```

- **Result**: no more traffic through the Bastion server in scenario #3

- Note that ***incoming*** traffic still has to flow through the load balancer

Tuning recommendation #2: adding one or more static route(s), *continued*

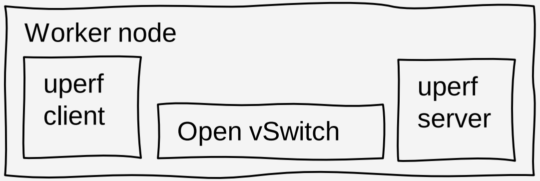
- Create a YAML file called `add-static-route.yaml` with the following contents:

```
apiVersion: machineconfiguration.openshift.io/v1
kind: MachineConfig
metadata:
  labels:
    machineconfiguration.openshift.io/role: worker
  name: 51-add-static-route
spec:
  config:
    ignition:
      version: 2.2.0
    storage:
      files:
      - contents:
          source: data:text/plain;charset=US-ASCII,A.B.D.0/24%20dev%20enc9000%0A
        filesystem: root
        mode: 0644
        path: /etc/sysconfig/network-scripts/route-enc9000
```

- Activate this configuration with `oc create -f add-static-route.yaml`

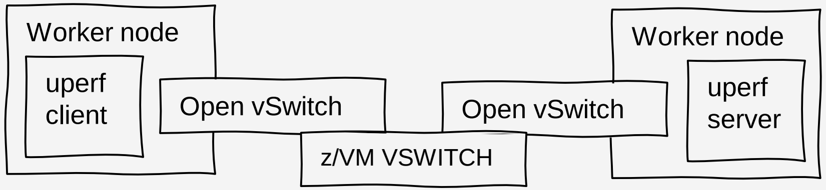
Tuning recommendation #2 (static route): results

- **Scenario #1**: pod-to-pod, same worker



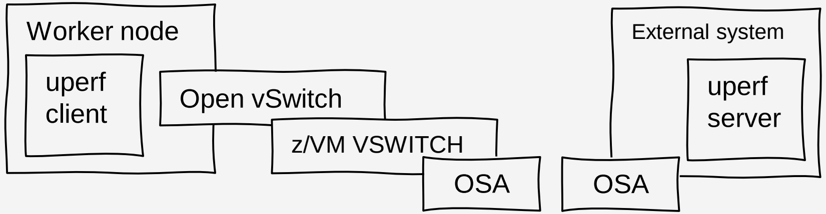
- Result: ***neutral*** – as expected, configuring a static route doesn't impact this scenario. Or in other words: it doesn't hurt, but it doesn't help either.

- **Scenario #2**: pod-to-pod, cross-worker



- Result: ***neutral*** – as expected, configuring a static route doesn't impact this scenario. Or in other words: it doesn't hurt, but it doesn't help either.

- **Scenario #3**: pod-to-external



- In this scenario, configuring a static route is ***recommended***, since it ***further*** improves (a) latency ***up to 51%*** and (b) throughput ***up to 52%***, depending on the network connectivity and number of parallel connections

Tuning recommendation #3: relocate heavy components

- In our performance analysis, we noticed that both latency and throughput were ***varying heavily***, depending on which exact worker node was selected for running the uperf tests
- Goal: achieve the ***same*** network ***performance*** on all worker nodes
  - Idea: use dedicated ***infrastructure*** nodes
- Relocating components is a ***2-step*** process:
  - First, define infrastructure nodes
  - Second, tell OpenShift to move network-heavy components out to infra nodes

Tuning recommendation #3: relocate heavy components

- Turn a ***worker*** node into an ***infra*** node with `oc edit node <name_of_the_node>` and change:

```
metadata:
  labels:
    node-role.kubernetes.io/worker: ""
```

  to:

```
metadata:
  labels:
    node-role.kubernetes.io/infra: ""
```

- You might want to ***add*** worker nodes to your cluster ***before*** converting worker nodes

Tuning recommendation #3: relocate heavy components, *continued*

- Create a YAML file with the following content:

```
apiVersion: v1
kind: ConfigMap
metadata:
  name: cluster-monitoring-config
  namespace: openshift-monitoring
data:
  config.yaml: |+
    alertmanagerMain:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    prometheusK8s:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    prometheusOperator:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    grafana:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
```

… (continued on the right) …

… (continued from the left) …

```
    k8sPrometheusAdapter:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    kubeStateMetrics:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    telemeterClient:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
    openshiftStateMetrics:
      nodeSelector:
        node-role.kubernetes.io/infra: ""
```

- All components are related to ***monitoring***
- Activate this configuration with

```
oc create -f <your_file_name_here>.yaml
```

Tuning recommendation #3: relocate heavy components, *continued*

- You can check the current ***placement*** of the corresponding pods with the following command:

```
watch -n 5 oc get pods -n openshift-monitoring -o wide
```

- Sample output on our test cluster after applying this configuration:

```
NAME                            READY   STATUS    NODE
alertmanager-main-0             5/5     Running   worker-4.<our_domain_name>
alertmanager-main-1             5/5     Running   worker-4.<our_domain_name>
alertmanager-main-2             5/5     Running   worker-4.<our_domain_name>
…
grafana-dc7ff648b-dx2rj         2/2     Running   worker-4.<our_domain_name>
…
prometheus-k8s-0                7/7     Running   worker-4.<our_domain_name>
prometheus-k8s-1                7/7     Running   worker-4.<our_domain_name>
…
```

- **Note**: some columns were cut in the above output in order to make it fit the page

Tuning recommendation #3: relocate heavy components, *continued*

- Move the ***router*** with `oc edit ingresscontroller default -n openshift-ingress-operator -o yaml` and change:

  ```
  spec:
      nodePlacement:
        nodeSelector:
          matchLabels:
            node-role.kubernetes.io/worker: ""
  ```

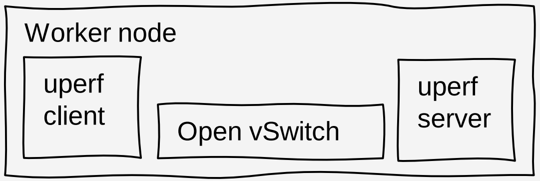
  to:

  ```
  spec:
      nodePlacement:
        nodeSelector:
          matchLabels:
            node-role.kubernetes.io/infra: ""
  ```

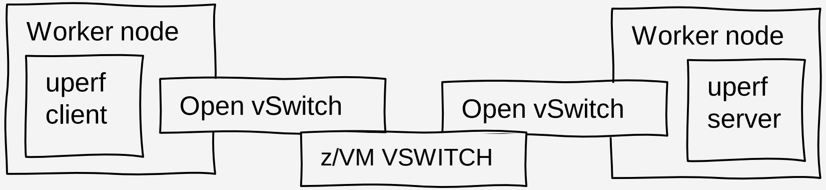
- If `nodePlacement` is missing, add it to the `spec` section

Tuning recommendation #3 (relocate components): results

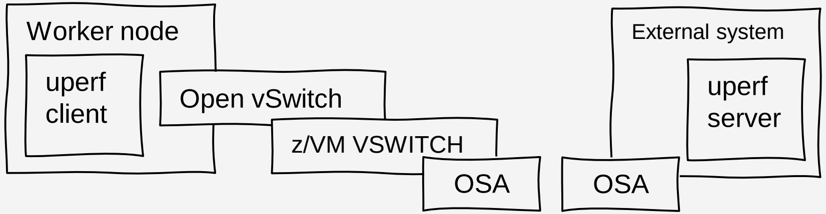
- **Scenario #1**: pod-to-pod, same worker



- **Scenario #2**: pod-to-pod, cross-worker



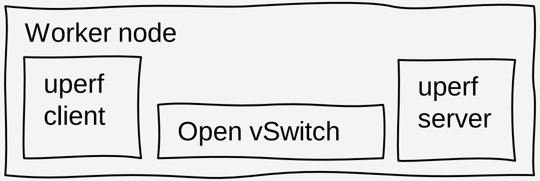
- **Scenario #3**: pod-to-external

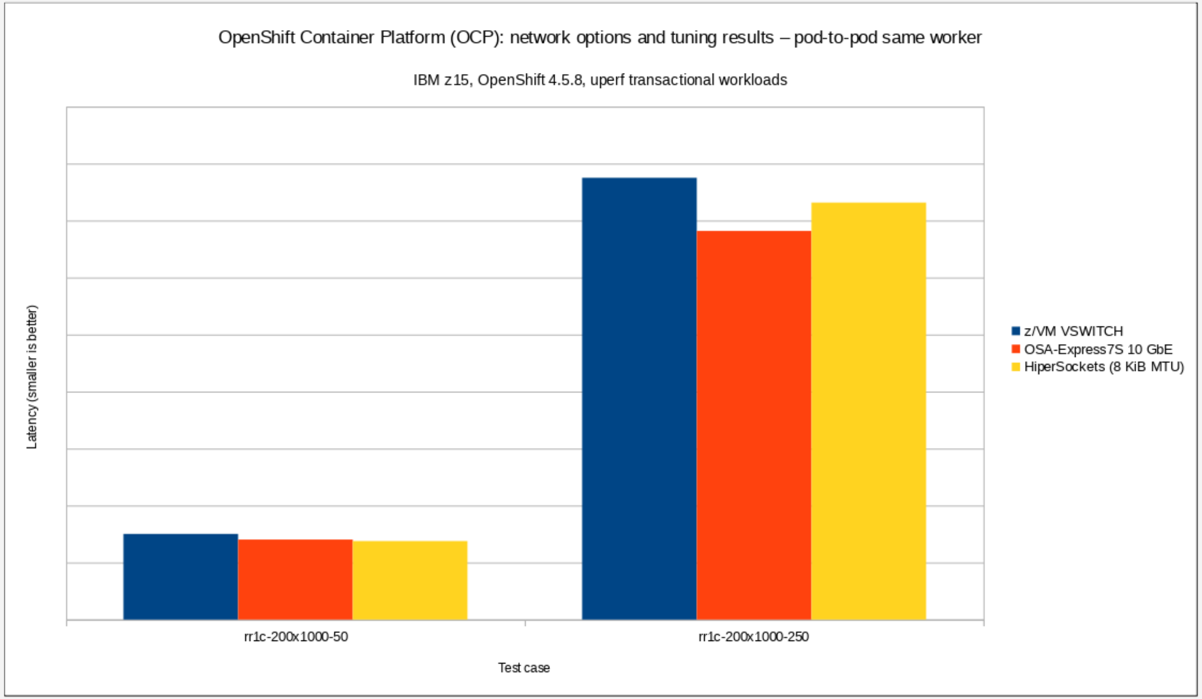


- Relocating the mentioned network-heavy components is ***recommended*** for all three scenarios

- Without this tuning recommendation, we measured latency differences between worker nodes of ***up to 87%***, despite the fact that all worker nodes were configured equal regarding CPU and memory

Scenario #1: *latency* results

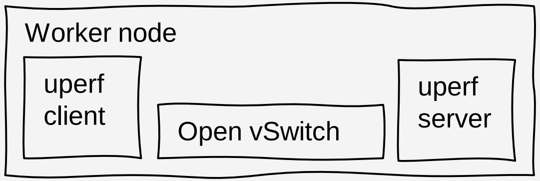


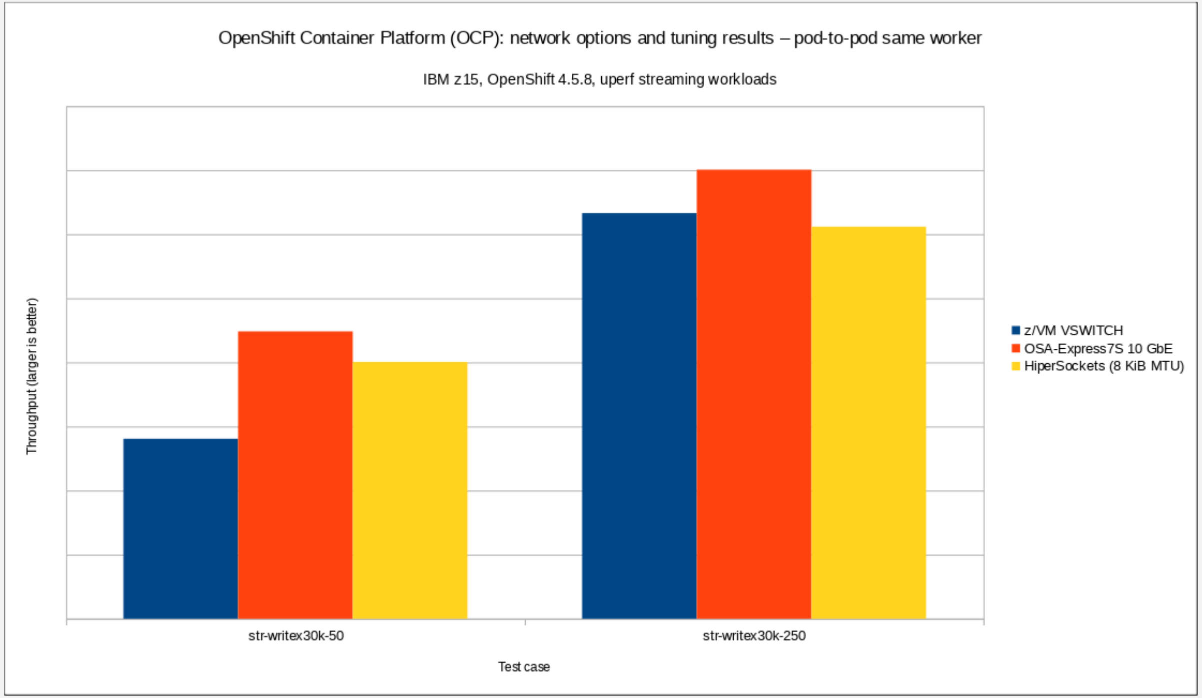


Key takeaways

- Network connectivity option – z/VM VSWITCH, OSA, or HiperSockets – only marginally impacts latency in the pod-to-pod, same worker scenario
- Enabling RPS is ***not*** recommended
- Static route doesn't impact performance in this scenario

Scenario #1: ***throughput*** results

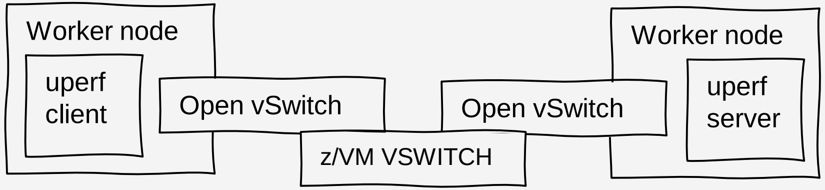


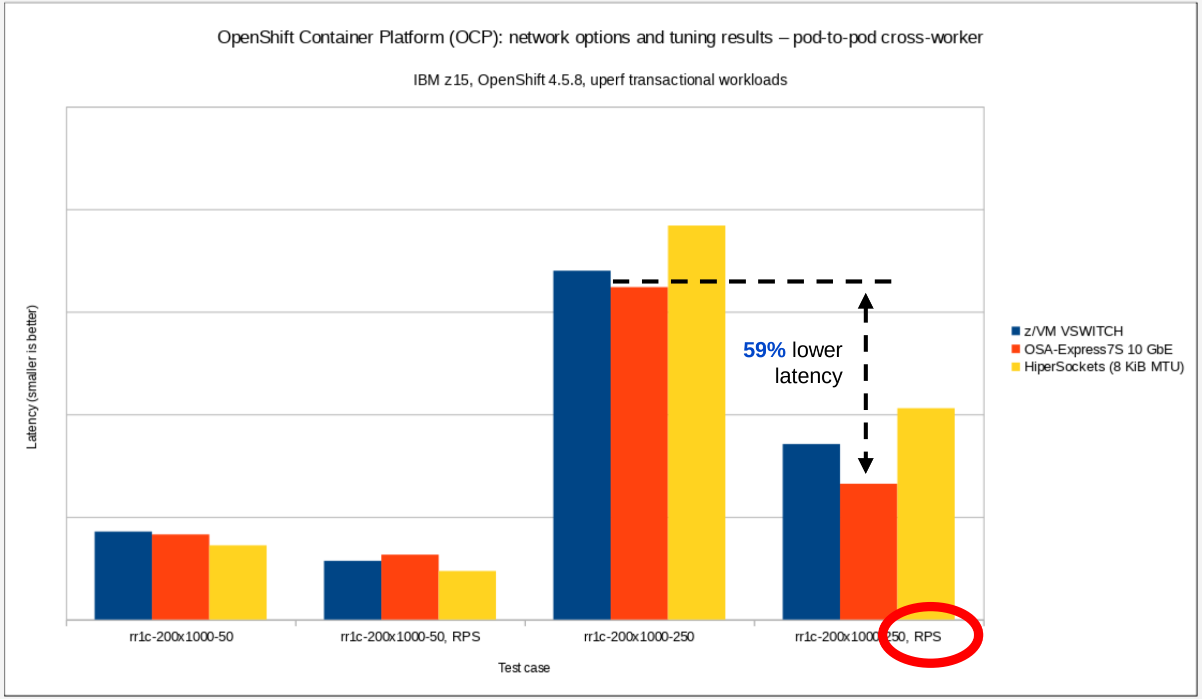


Key takeaways

- Network connectivity option only marginally impacts throughput in the pod-to-pod, same worker scenario
- Enabling RPS is ***not*** recommended
- Static route doesn't impact performance in this scenario

Scenario #2: ***latency*** results

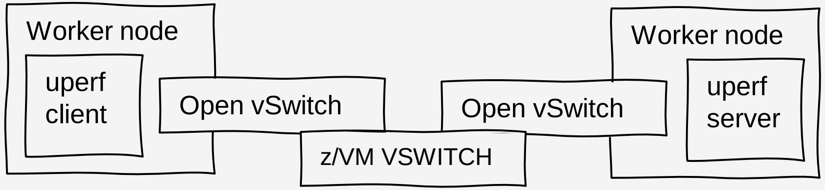


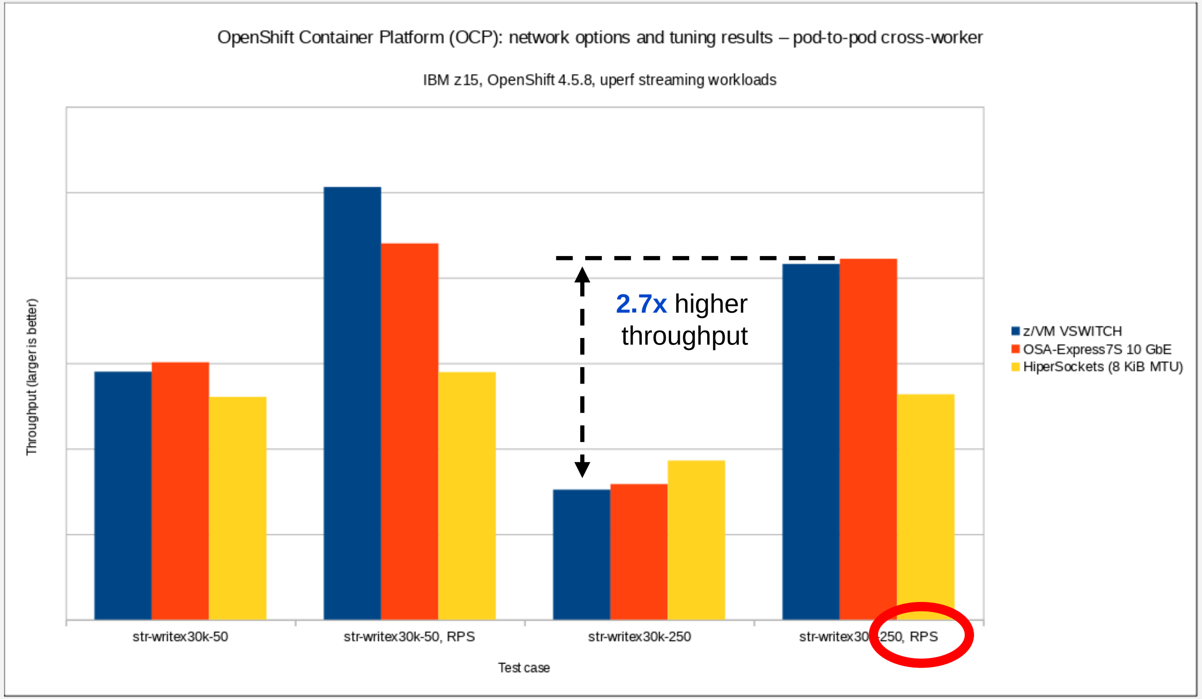


Key takeaways

- Enabling RPS is ***highly recommended*** in this scenario
- Static route has no impact
- For a high number of parallel connections (250), OSA has a ***slight*** advantage over z/VM VSWITCH and HiperSockets, but only when RPS is enabled

Scenario #2: ***throughput*** results

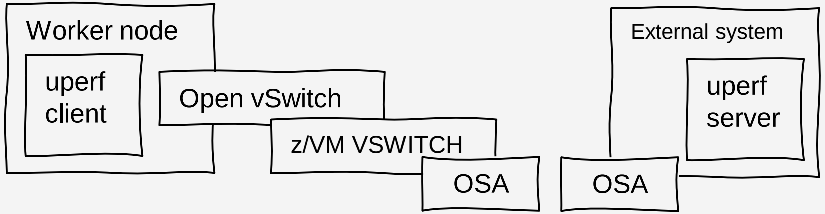


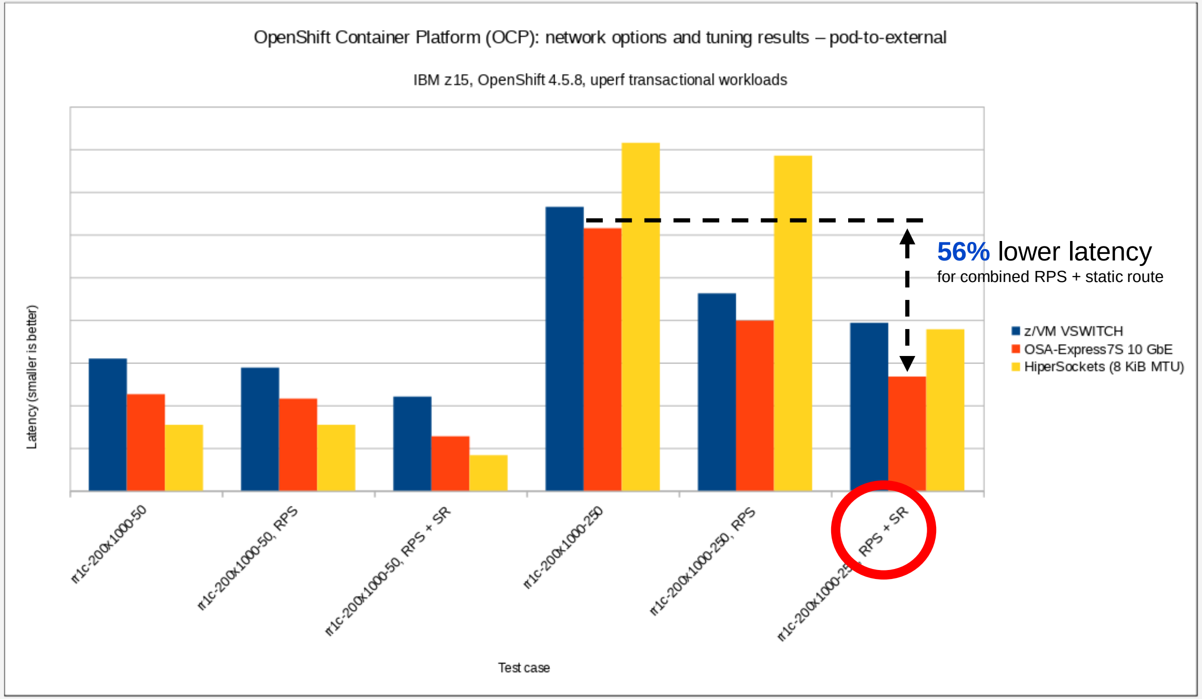


Key takeaways

- Enabling RPS is ***highly recommended*** in this scenario
- Static route has no impact
- For a medium number of parallel connections (50), z/VM VSWITCH has a ***slight*** advantage over OSA and HiperSockets, but only when RPS is enabled
- HiperSockets throughput performance can be increased significantly by adjusting ***MTU*** size

Scenario #3: ***latency*** results

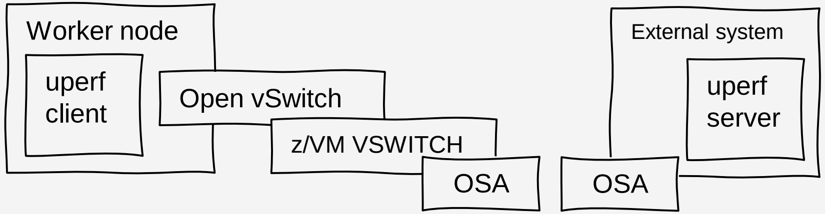


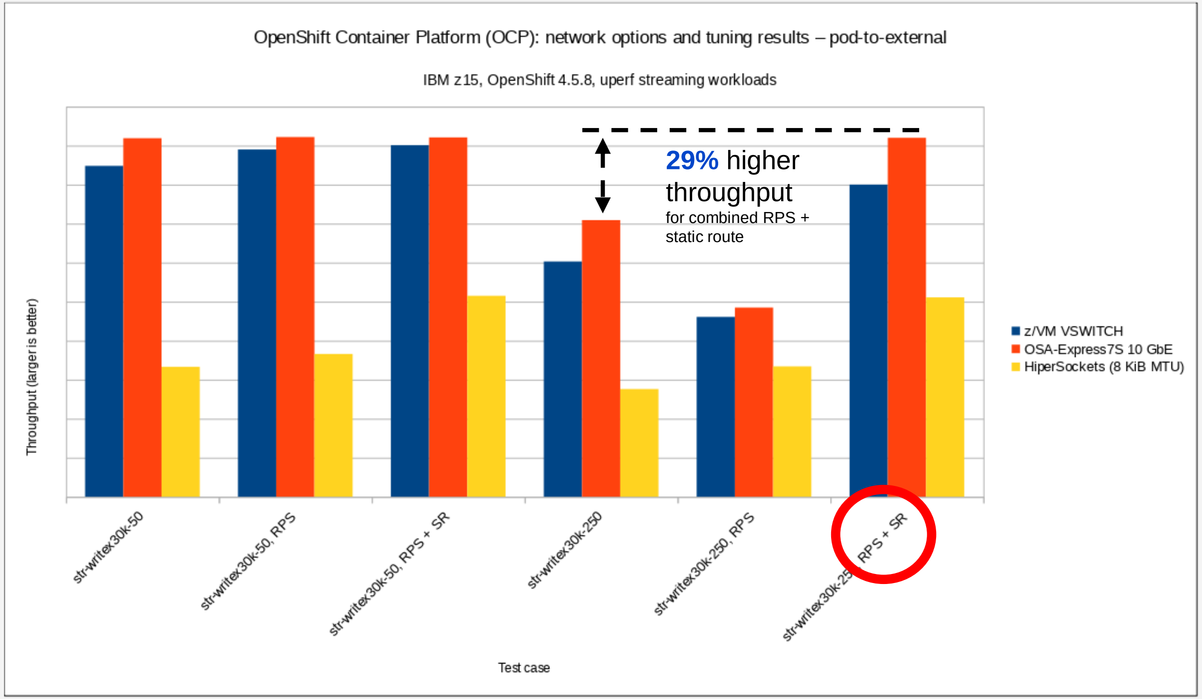


Key takeaways

- Enabling RPS and adding a static route is ***highly recommended*** in this scenario
- For a medium number of parallel connections (50), HiperSockets have a ***clear*** advantage over z/VM VSWITCH and OSA
- For a high number of parallel connections (250), OSA has a ***slight*** advantage over z/VM VSWITCH and HiperSockets

Scenario #3: ***throughput*** results





Key takeaways

- Enabling RPS and adding a static route is ***highly recommended*** in this scenario
- For a medium number of parallel connections (50), z/VM VSWITCH and OSA are ***equally well*** suited
- For a high number of parallel connections (250), OSA has a ***slight*** advantage over z/VM VSWITCH and HiperSockets
- HiperSockets throughput performance can be increased significantly by adjusting ***MTU*** size

Agenda

- Introduction
- Performance measurement and tuning approach
- Observations and recommendations
  - CPU-intensive workloads
  - Network-intensive workloads
- General tips for cloud-native applications
- Summary

General tips for cloud-native applications

- ***Stay current*** with OpenShift releases – even minor updates can improve performance ***significantly***
  – Minor updates: 4.x.y ⇨ 4.x.y+1

- When using ECKD disks for your z/VM guests, define ***HyperPAV*** aliases
  – Not using HyperPAV aliases can turn into a bottleneck for disk I/O-intensive workloads

- For ***production*** environments, use a ***hardware-based*** load balancer
  – Software-based load balancers can also work, but need much more fine-tuning

General tips for cloud-native applications, *continued*

- ***Don't*** use OpenJDK™ ***V8*** with ***HotSpot***, since it doesn't contain a *Just-In-Time* (JIT) compiler
  – Up to ***100x*** slower than a Java SDK that contains a JIT

- For best performance on Linux on IBM Z, use latest / greatest ***IBM Java V8***

- If you have a ***strict*** requirement for OpenJDK, use OpenJDK with ***OpenJ9***
  – OpenJ9 is the Open Source version of IBM Java
  – Doesn't matter whether your requirement is for V8 or V11

- If it really ***has*** to be HotSpot for some reason, then use OpenJDK ***V11***
  – On IBM Z, OpenJDK V11 with HotSpot contains a JIT compiler sponsored by SAP®

Agenda

- Introduction
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Summary

- Network performance is ***extremely important*** for good overall performance of an OpenShift cluster
  – Due to the nature of cloud-native applications

- There are some easy-to-implement ***tuning recommendations*** that will boost network performance
  – Receive Packet Steering, adding one or more static route(s), relocation of network-heavy components

- Before applying any of the changes, please ***double-check*** your environment for ***workload patterns***
  – Transactional vs. streaming workloads
  – Small amount vs. large amount of parallel connections

- ***Improvements*** speak for themselves
  – Up to 59% lower latency
  – Up to 2.7x higher throughput

Thank you!

Resources

- Linux on IBM Z and IBM LinuxONE
  - Official homepage: http://www.ibm.com/systems/z/os/linux
  - Documentation: http://www.ibm.com/support/knowledgecenter/linuxonibm/liaaf/lnz_r_lib.html
  - Tuning hints and tips: http://www.ibm.com/support/knowledgecenter/linuxonibm/liaag/tuning/tuning.htm

- Red Hat OpenShift Container Platform Documentation
  https://docs.openshift.com/container-platform/4.5/welcome/index.html

- Red Hat OpenShift on IBM Z Installation Guide
  http://www.redbooks.ibm.com/abstracts/redp5605.html

- Relocating OpenShift infrastructure components
  https://docs.openshift.com/container-platform/4.5/machine_management/creating-infrastructure-machinesets.html

- IBM Java SDK Downloads
  https://www.ibm.com/support/pages/java-sdk-downloads

- OpenJDK 8 with OpenJ9 on AdoptOpenJDK
  https://adoptopenjdk.net/releases.html?variant=openjdk8&jvmVariant=openj9