KubeCon CloudNativeCon

North America 2024

Does My K8s Application Need CPR?

Performance Evaluation of a Multi-Cluster Workload Management Application

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Agenda

- Motivation
- KubeStellar: Manage workloads across multi-clusters
- Testing framework & Experiments examples
- Lessons learned & Conclusion

Motivation

- Using multiple k8s clusters becomes common
  - Isolation: environments (dev, prod) , teams, etc..
  - Compliance with enterprise security or data governance requirements
  - Access to heterogeneous resources (GPUs, special HW, etc.)

- Multiple solutions already exist (e.g., KubeStellar, Karmada, OCM, etc.)

- Performance is a key factor for **managing workloads** across clusters
  - Users expect timely application deployment & status updates
  - Critical for adoption & success

Performance Evaluation Challenges

- Multi-cluster workload management applications are complex
  - Solutions include many components in different locations
  - Require multiple infrastructure configurations
- Most of the popular performance evaluation tools target single cluster
  - Might need to extend/enhance existing tools
- Scale-testing: need to provision many **clusters** → resource consuming
  - Emulation may not be enough for all test cases
- Such solutions offer a large number of configurable settings
  - Significantly increases the number of test options

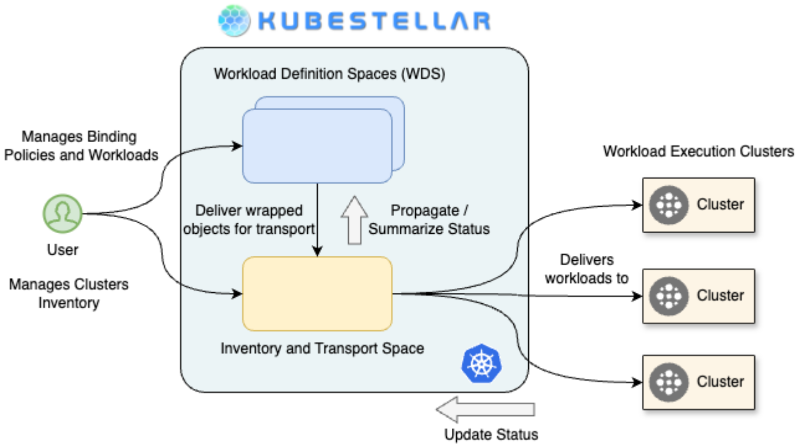
KubeStellar: Background

- A CNCF Sandbox project
- Deploy, configure and manage workloads across multiple K8s clusters
  - Use “native” K8s interfaces
  - Policy-based placement, workload customization, status summarization
- Find more info: https://kubestellar.io/

KUBESTELLAR

KubeStellar: Architecture Overview

- Based on "spaces" abstraction for isolation and multi-tenancy
  - Space: behaves like a regular k8s cluster. Exposes k8s API end-point
- Pluggable transport framework
  - Propagate resources from WDS to the execution cluster(s)
  - Currently using OCM (https://open-cluster-management.io/)
- Customize resources deployed to WEC
- Collect & summarize statuses from WECs


KUBESTELLAR
Workload Definition Spaces (WDS)
Manages Binding Policies and Workloads
User
Manages Clusters Inventory
Deliver wrapped objects for transport
Propagate / Summarize Status
Inventory and Transport Space
Workload Execution Clusters
Cluster
Delivers workloads to
Cluster
Cluster
Update Status

WEC: Workload Execution cluster
WDS: Workload Distribution Space,
ITS: Inventory and Transport Space

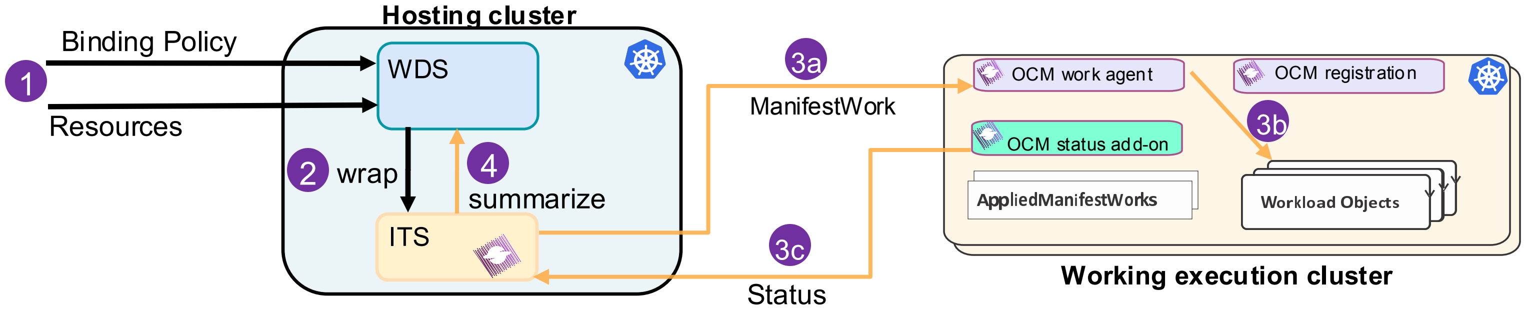
KubeStellar: Binding Policy (BP)

- Defines “what goes where"
- Associates a subset of workload objects in the WDS with a subset of WECs
  - Defined by the user in the WDS
  - Performance implications
- Allows customization of how workload objects are down-synced

```
apiVersion:
control.kubestellar.io/v1alpha1
kind: BindingPolicy
metadata:
  name: nginx
spec:
  clusterSelectors:
  - matchLabels:
      location-group: edge
  downsync:
  - objectSelectors:
    - matchLabels:
        app.kubernetes.io/name: nginx
…....
```

KubeStellar Example: Deploy Workloads

1. User:
    - Deploys workload/resources into WDS
    - Defines the binding policy (desired placement)
2. KS: Transport controller pushes resources into the inventory space (ITS)
    a. Wraps resources into a container object (e.g., ManifestWork)
3. Transport mechanism (OCM)
    a. Distributes wrapped resources into the WEC
    b. Unwraps & deploys resources in the WEC
    c. Status is returned through the KS transport status plugin
4. KS: Propagates status into WDS (user facing objects)

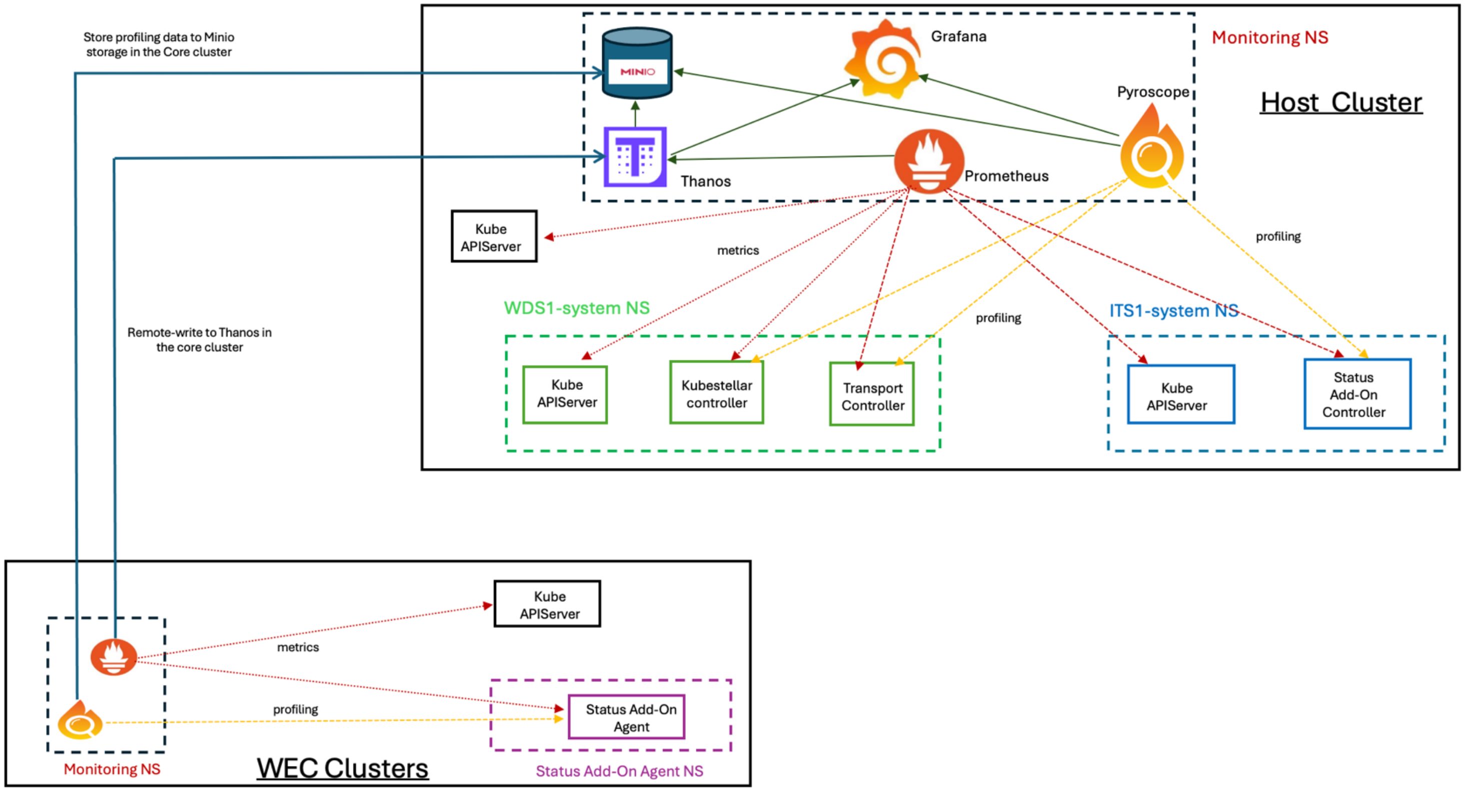


Open-Source Tools

Leverage existing tools when possible

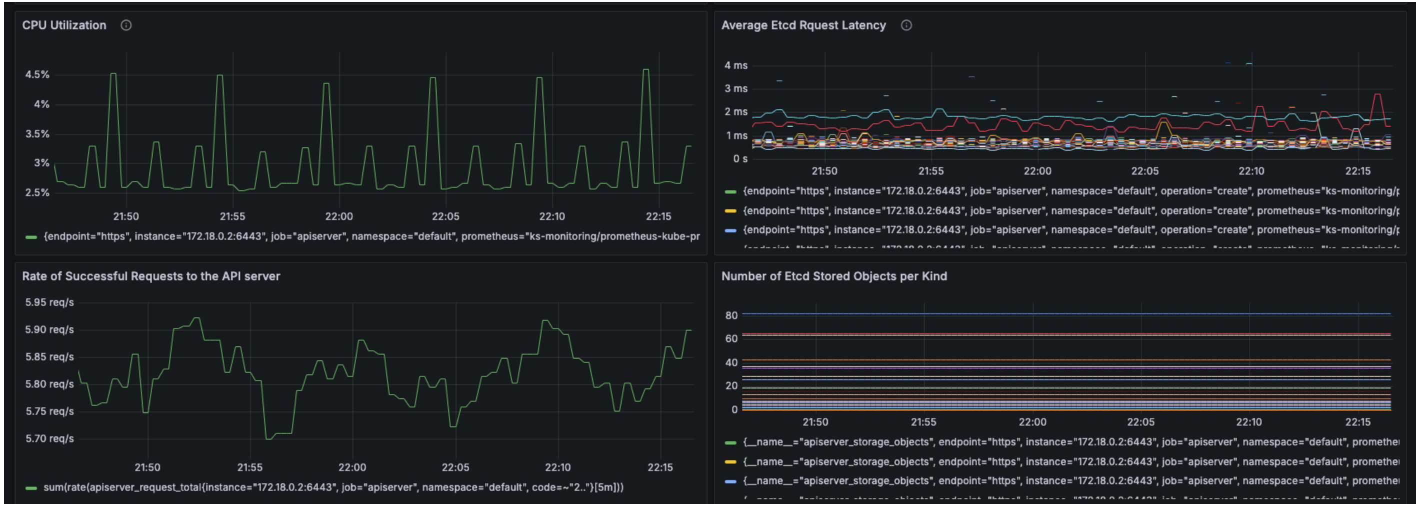
- **ClusterLoader2:** Kubernetes cluster performance test tool
- **Prometheus/Thanos, Pyroscope & Grafana:** Monitoring, profiling, visualization
- **Kind**: Running Kubernetes clusters using Docker container "nodes"
- **Kwok**: Kubernetes WithOut Kubelet, simulating any number of nodes and maintain pods on those nodes
- **Kube-burner**: Performance and scale test orchestration toolset. Mimic production workloads used to stress Kubernetes clusters

Framework Architecture: Monitoring Setup



Framework Architecture: Metrics Collection

- Targets: KS control plane (e.g., WDS & ITS API servers, transport, etc.)
- Single pane of glass to monitor KS hub and remote clusters



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sum(rate(apiserver_request_total{instance="172.18.0.2:6443", job="apiserver", namespace="default", code=~"2.."}[5m]))

{__name__="apiserver_storage_objects", endpoint="https", instance="172.18.0.2:6443", job="apiserver", namespace="default", promethe

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Grafana dashboards to monitor API server, APF and KS controllers

Workload Profile

Used two profiles from Kube-burner reference workloads

Workload benchmark for plain Kubernetes environments

Cluster-density profile
1 deployments, with two pod replicas (pause), mounting 2 secrets, 2 config maps
3 services, the first service points to the TCP/8080 port of the deployments
10 secrets containing a 2048-character random string
10 configmaps

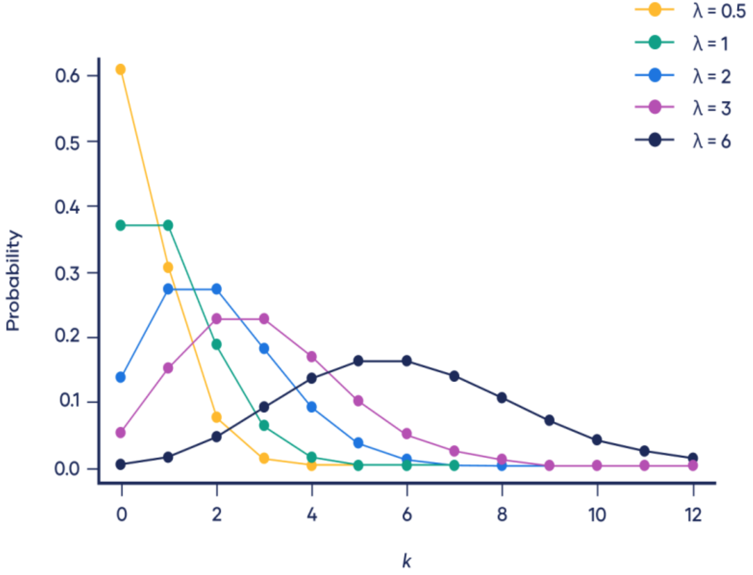
Workload benchmark for OpenShift environments

Cluster-density-ms profile
1 image stream
4 deployments, each with two pod replicas (pause), mounting 4 secrets, 4 config maps, and 1 downward API volume each
2 services, each pointing to the TCP/8080 and TCP/8443 ports of the first and second deployments
1 edge route pointing to the first service
20 secrets containing a 2048-character random string
10 configmaps containing a 2048-character random string

Workload Generation

- Poisson Workload generator function:
  - Introduce some randomness in the workload

- Extended ClusterLoader2 (CL2)
  - Support poisson distribution tuning set*
  - Add KubeStellar provider**



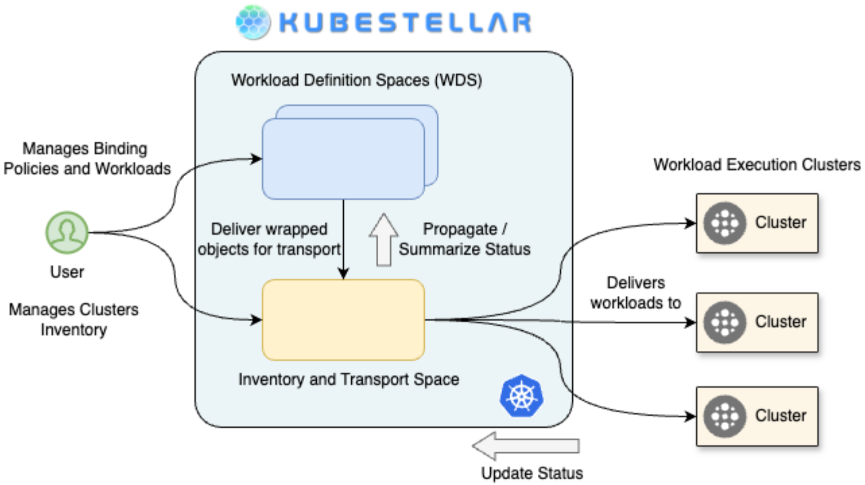
* Merged PR: https://github.com/kubernetes/perf-tests/pull/2633
** Merged PR: https://github.com/kubernetes/perf-tests/pull/2632

[1] reference: https://www.scribbr.com/statistics/poisson-distribution/#:~:text=A%20Poisson%20distribution%20is%20a,the%20mean%20number%20of%20events.

Performance Variables

Selected KubeStellar performance parameters:

- **Number of binding Policies**
- **Number of workload execution clusters (WEC)**
- Number of workload description space (with shared ITS)
- Number of workload description space (with dedicated ITS)
- Workload size per binding policy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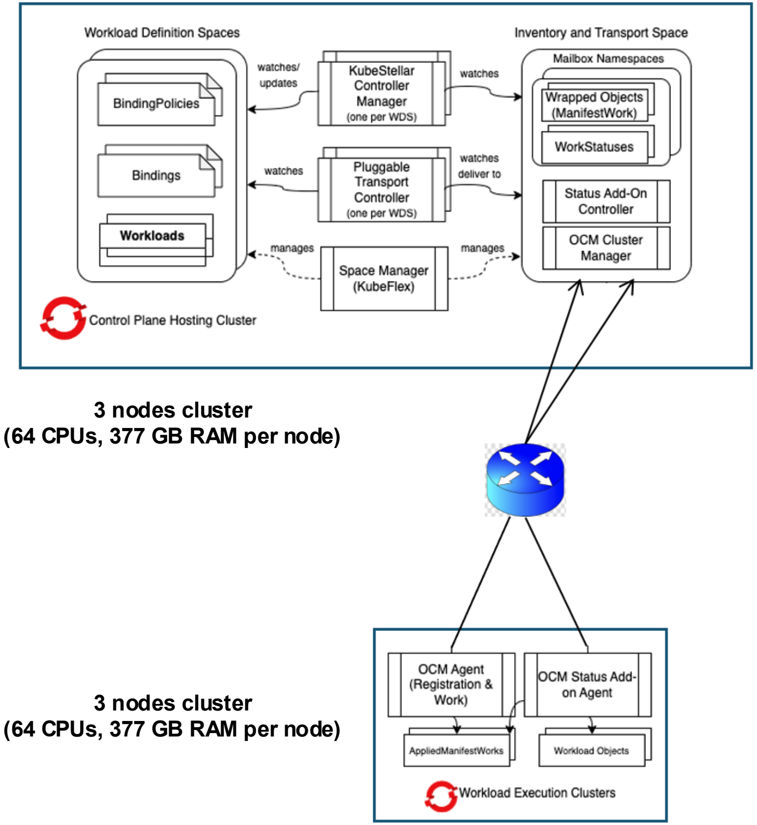
Cluster
Cluster
Update Status

Experiment 1: Number of Binding Policies

- Setup:
  - 2 OCP clusters
- Workload generator function
  - clusterloader2 **Poisson** tuningSet (alpha=0.5)


Workload Definition Spaces
Inventory and Transport Space
BindingPolicies
Bindings
Workloads
watches/ updates
KubeStellar Controller Manager (one per WDS)
watches
Mailbox Namespaces
Wrapped Objects (ManifestWork)
WorkStatuses
watches
Pluggable Transport Controller (one per WDS)
watches deliver to
Status Add-On Controller
manages
Space Manager (KubeFlex)
manages
OCM Cluster Manager
Control Plane Hosting Cluster
OCM Agent (Registration & Work)
OCM Status Add-on Agent
AppliedManifestWorks
Workload Objects
Workload Execution Clusters

3 nodes cluster
(64 CPUs, 377 GB RAM per node)

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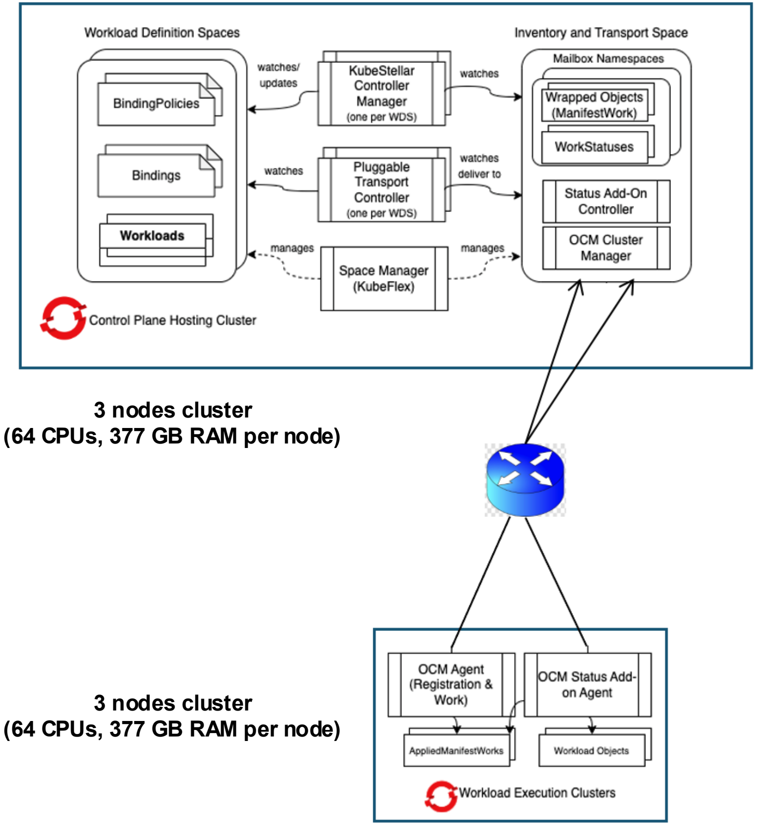
(64 CPUs, 377 GB RAM per node)

Experiment 1: Number of Binding Policies

- Setup:
  - 2 OCP clusters
- Workload:
  - cluster-density-ms

Object type	Total #
BindingPolicies	150
Namespaces	150
Image stream	150
Deployments	600
Secrets	3000
Services	300
Configmaps	1500
routes	150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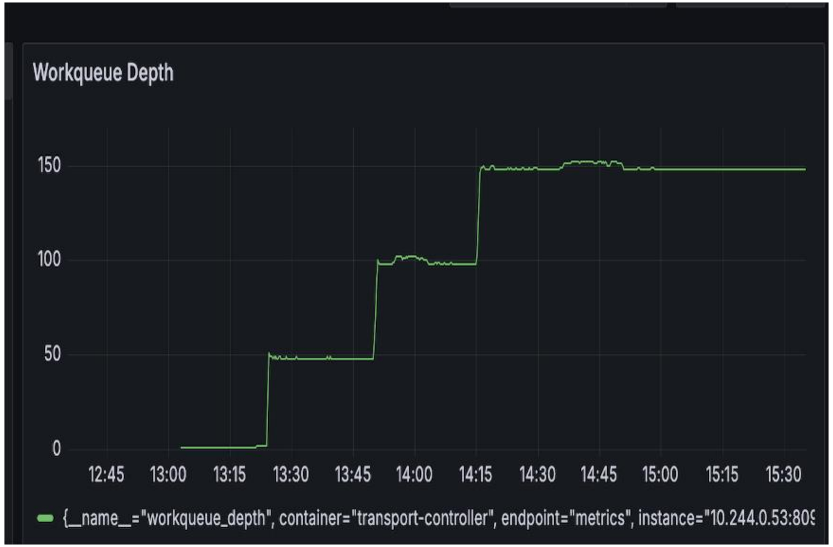
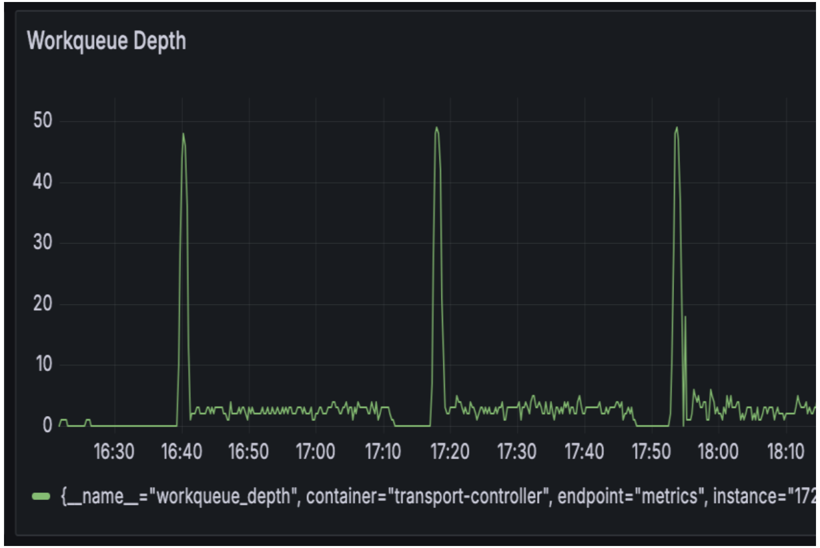
Experiment 1: Number of Binding Policies - Results

Issue detected: controllers fight (component: KS transport controllers)

Before fixes



After fixes



Experiment 2: Long Running Test

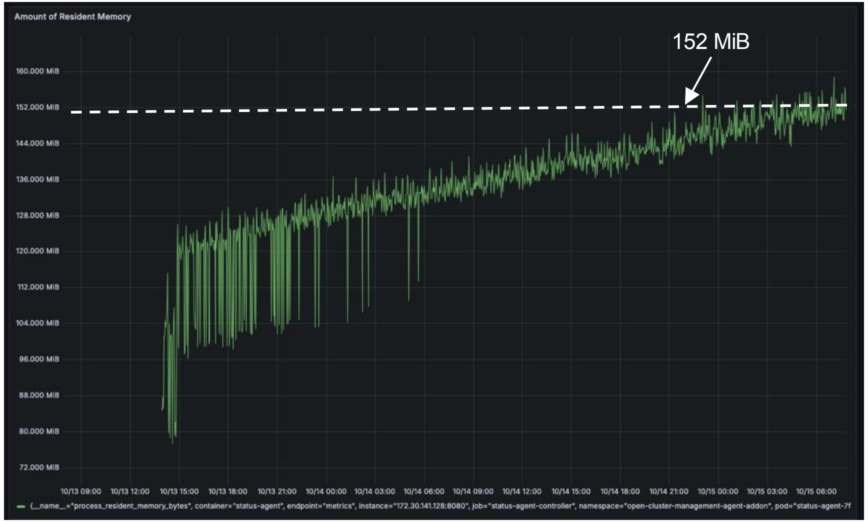
- Setup:
  - 2 OCP clusters

- Long running measurements: 1 binding Policy
  - Workload: pod that sleeps for 20 seconds
  - Workload generator function: clusterloader **RSteppedLoad** tuningSet (burstSize=1 and stepDelay=60 sec)
  - Custom controller: deletes a pod after reaching the completed state – another pod is created after 1 minute with a different name
  - Experiment duration (48 hours): 10/13 - 10/15

Experiment 2: Long Running Test - Results

Issue detected: memory leak (component: status-agent controller)

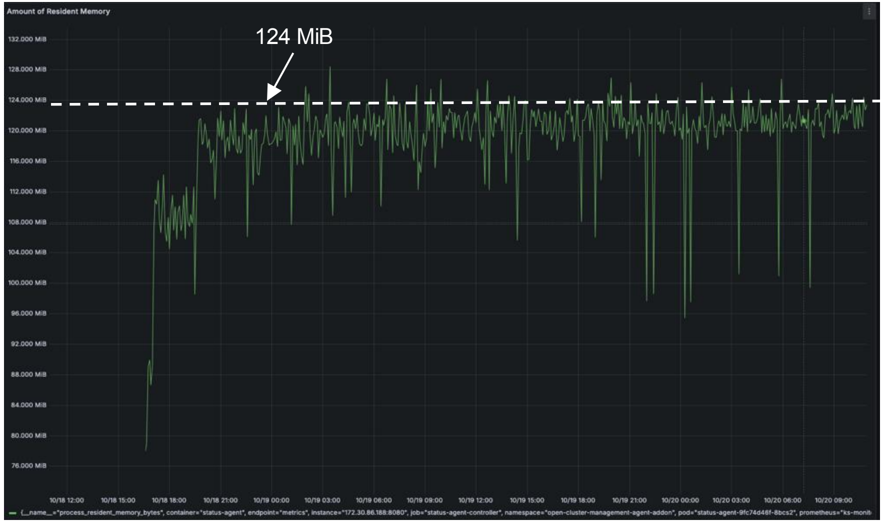
Before fixes



Amount of Resident Memory

152 MiB

After fixes

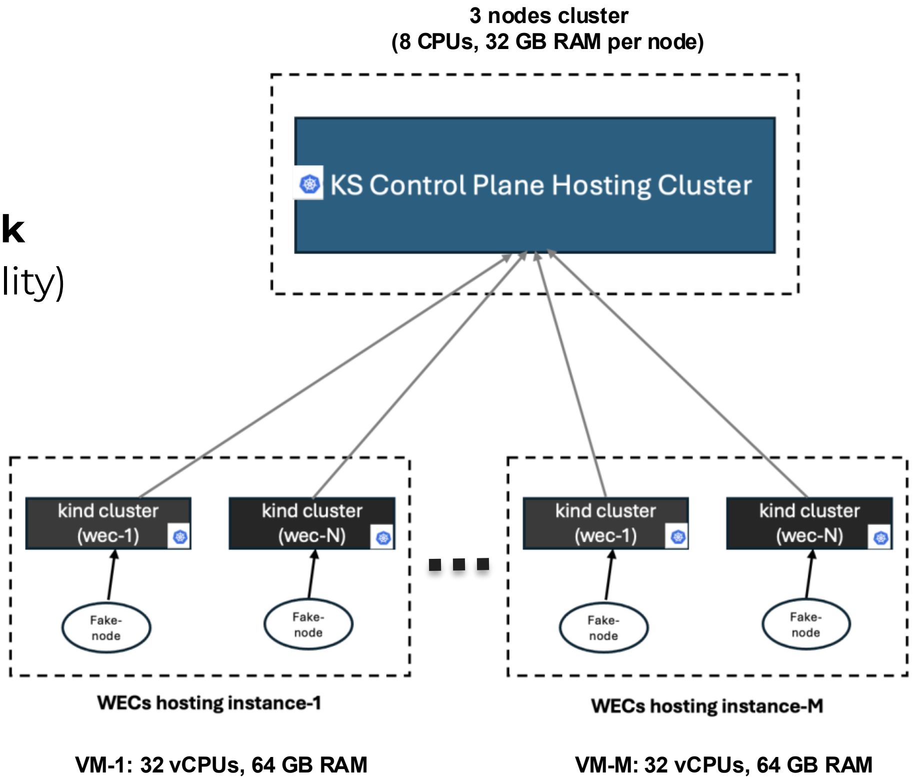


Amount of Resident Memory

124 MiB

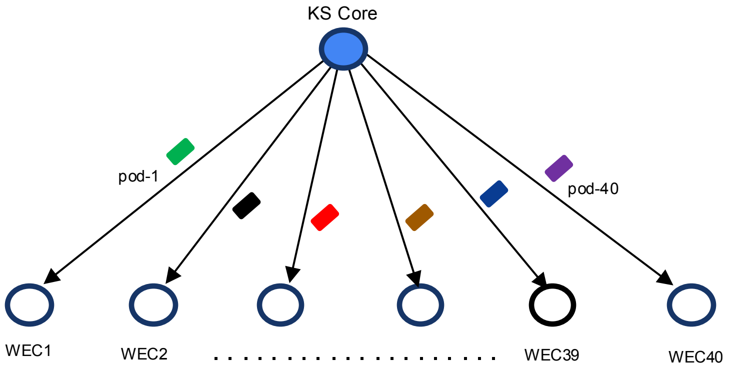
Experiment 3: Number of WECs

- Setup:
    - Ubuntu 24.04 VMs (M = 5)
    - **100 kind clusters** (N = 20)
    - Emulation of nodes & pods with **kwok**
    - Using Ansible automation (repeatability)

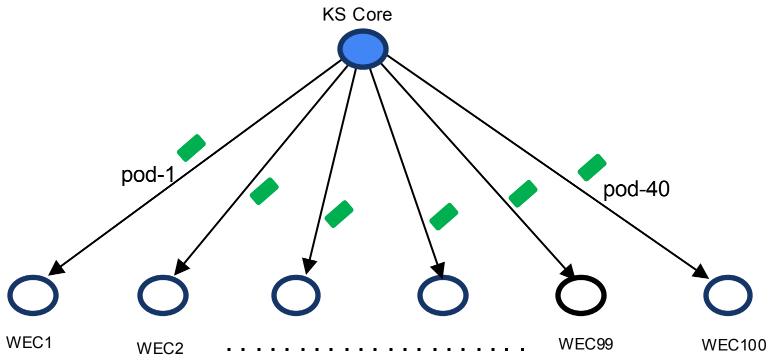


Experiment 3: Number of WECs (Cont.)

- Measurements: E2E & down-sync latencies, resource utilization, etc.
- Workload: kwok fake pod



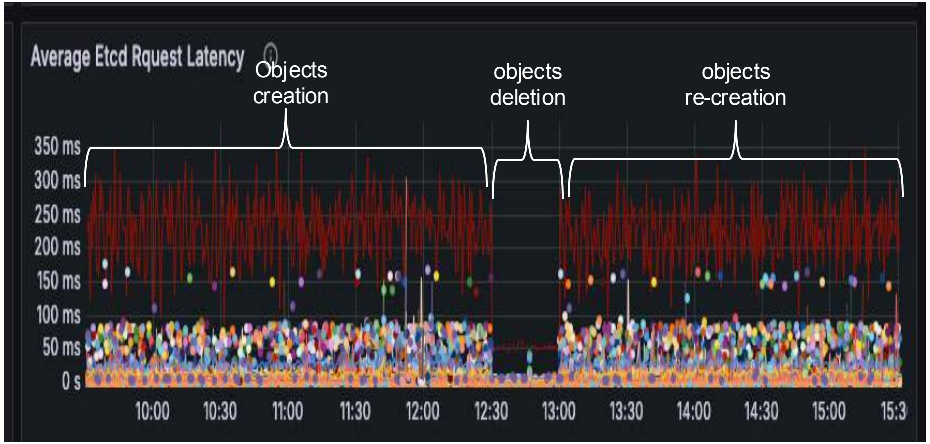
1-1 Deployment
(1 binding Policy per cluster)

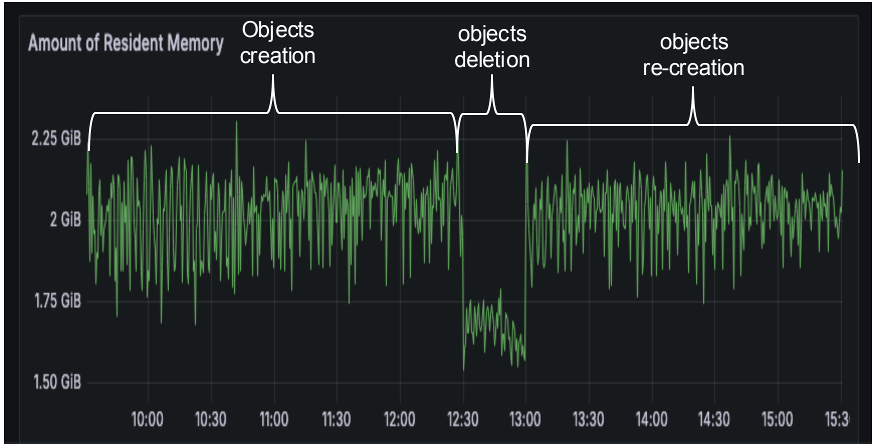


1-Many Deployment
(1 binding Policy for all clusters)

Experiment 3: Number of WECs - Results

Resource Utilization: ITS API Server

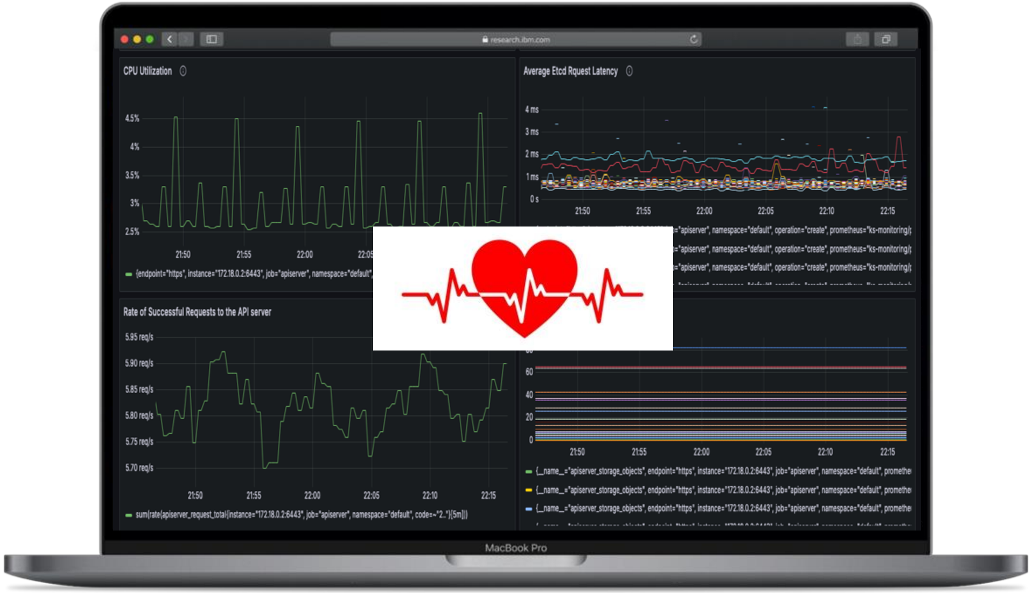




Lessons Learned & Conclusion

- A single pane of glass to analyze performance is extremely helpful
- Define performance variable & stay focused on them
- Long tests are a must – some issues can't be detected without it
- Profiling is your friend
- Leverage existing open-source tools when possible
- Performance analysis should be used to help building usage guidelines/benchmark

So, Does My k8s Application Need CPR?


research.ibm.com
CPU Utilization
4.5%
4%
3.5%
3%
2.5%
21:50
21:55
22:00
22:05
{endpoint="https", instance="172.18.0.2:6443", job="apiserver", namespace="default",
Average Etcd Rquest Latency
4 ms
3 ms
2 ms
1 ms
0 s
21:50
21:55
22:00
22:05
22:10
22:15
="apiserver", namespace="default", operation="create", prometheus="ks-monitoring/
="apiserver", namespace="default", operation="create", prometheus="ks-monitoring/
="apiserver", namespace="default", operation="create", prometheus="ks-monitoring/
Rate of Successful Requests to the API server
5.95 req/s
5.90 req/s
5.85 req/s
5.80 req/s
5.75 req/s
5.70 req/s
21:50
21:55
22:00
22:05
22:10
22:15
sum(rate(apiserver_request_total{instance="172.18.0.2:6443", job="apiserver", namespace="default", code=~"2.."}[5m]))
60
40
20
0
21:50
21:55
22:00
22:05
22:10
22:15
{__name__="apiserver_storage_objects", endpoint="https", instance="172.18.0.2:6443", job="apiserver", namespace="default", promethe
{__name__="apiserver_storage_objects", endpoint="https", instance="172.18.0.2:6443", job="apiserver", namespace="default", promethe
{__name__="apiserver_storage_objects", endpoint="https", instance="172.18.0.2:6443", job="apiserver", namespace="default", promethe
MacBook Pro

No! I can see and hear the **heartbeats** even for my **Multi-Cluster** management app