Adapting Kubernetes to IIoT and Industry 4.0 protocols - An initial performance analysis

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Motivation

- Virtualization and containerization in the field of IIoT/Industry 4.0.
- Interoperability in IIoT/Industry 4.0.
- A lack of interoperability exists and significantly increases complexity and costs for IIoT/Industry 4.0 deployment/integration.
- To overcome the lack of interoperability, ongoing efforts aim at standardizing IIoT/Industry 4.0.

What-if question

- ➢ IIoT/Industry 4.0 communication protocols standardization.
- ➢ Container orchestration tool adaptation and performance impact.

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Contribution

- We present an approach to replace the communication protocol of Kubernetes without modifying the code base.

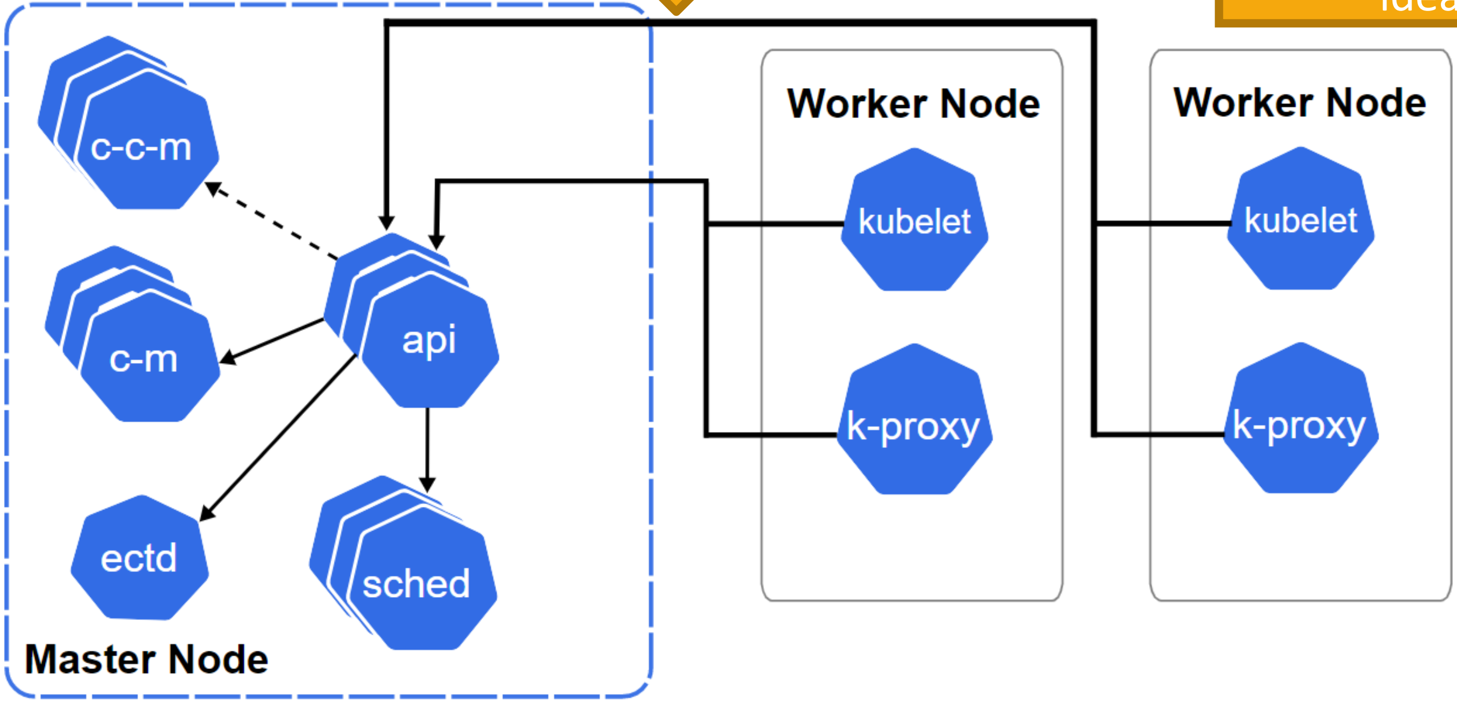
- Communication protocols and information model
  - MQTT: Message Queuing Telemetry Transport
  - AMQP: Advanced Message Queuing Protocol
  - AAS: Asset Administration Shell as an Industry 4.0 information model

Approach

- Kubernetes

Uses a proprietary REST-based protocol

Conflict with the aforementioned standardization ideas

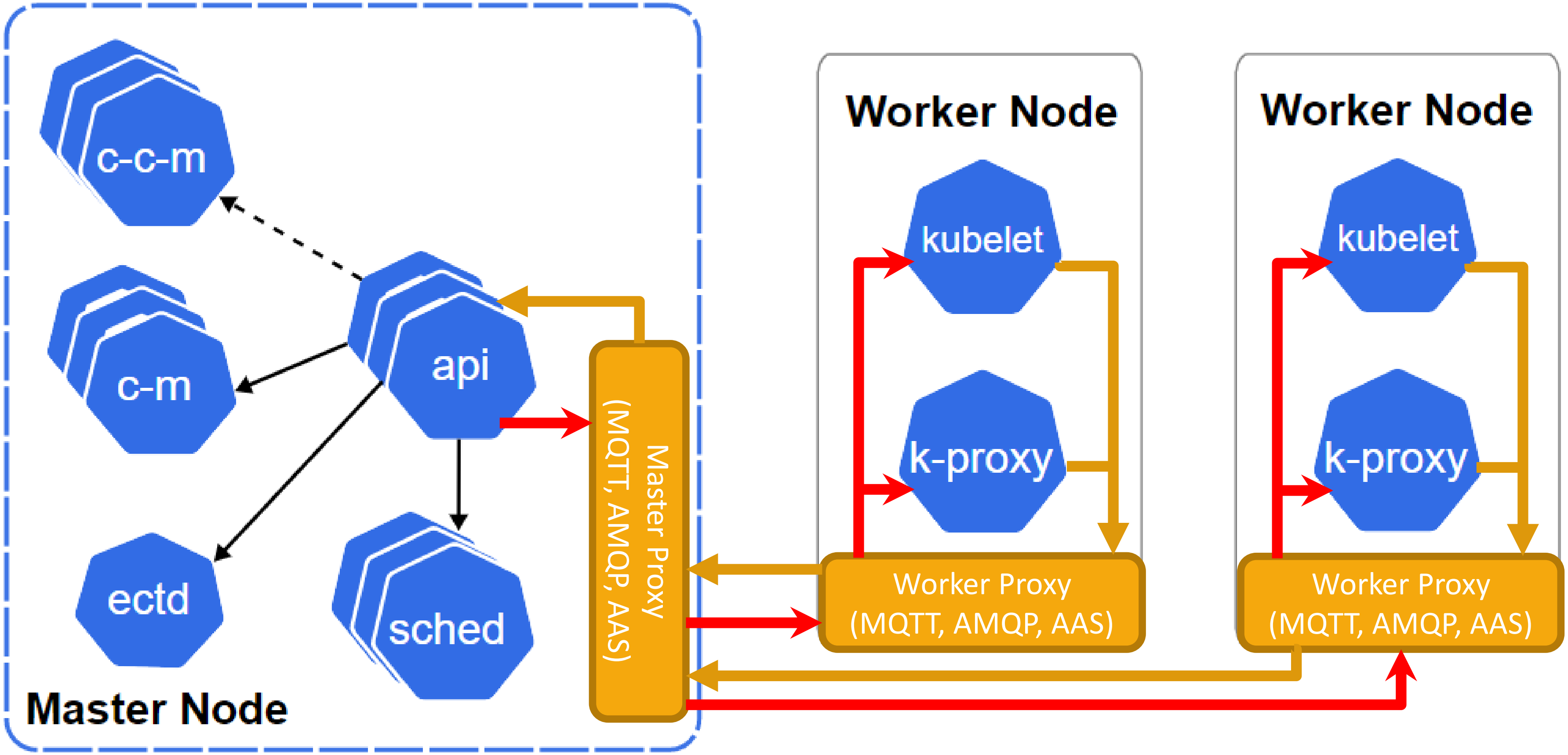


- api: API server
- sched:Scheduler
- c-c-m: Cloud controller manager
- c-m: Controller manager
- kubelet: Kubelet
- k-proxy: Kube-proxy

Approach

- Kubernetes - Container Network Interface (CNI)
  - Network connectivity of containers
  - It does not support changing the master-worker communication protocol.

Approach


c-c-m
c-m
api
ectd
sched
Master Node
Master Proxy (MQTT, AMQP, AAS)
Worker Node
kubelet
k-proxy
Worker Proxy (MQTT, AMQP, AAS)
Worker Node
kubelet
k-proxy
Worker Proxy (MQTT, AMQP, AAS)

- api: API server
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Experiment and Results

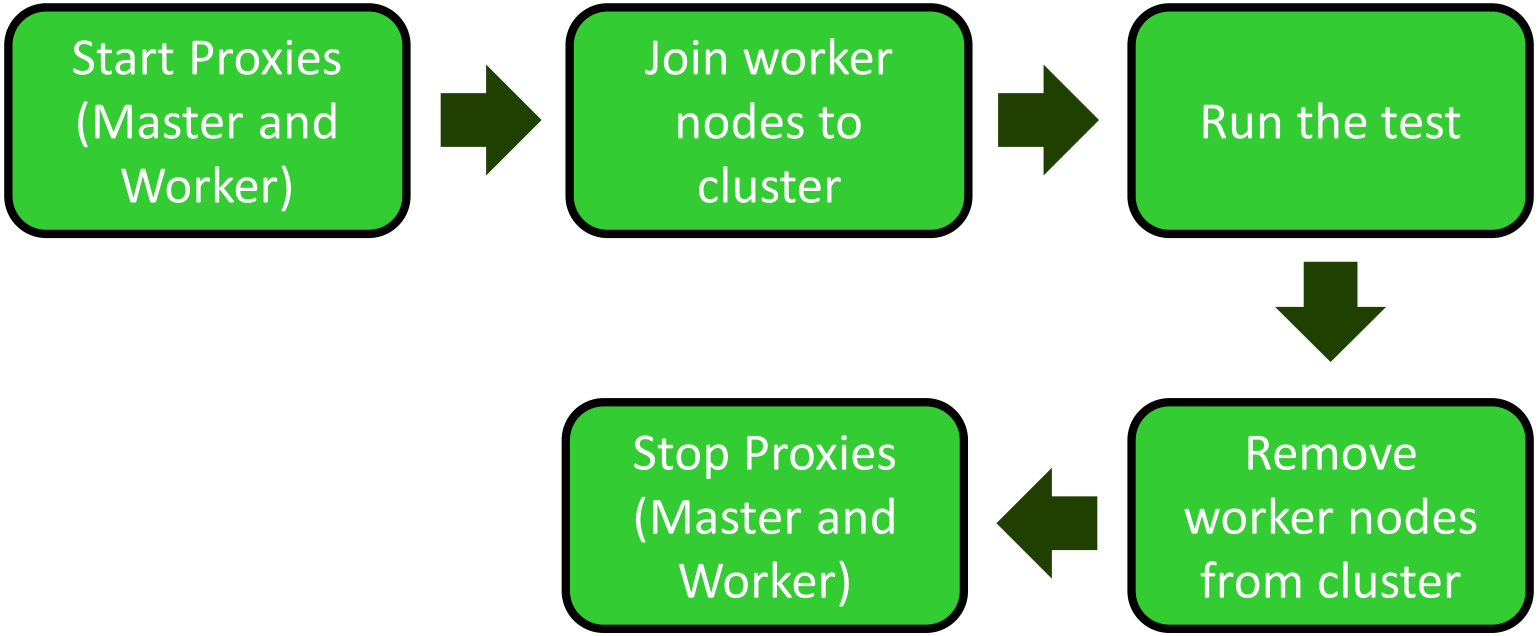
- Orchestrator, we used Kubernetes (v1.23.3).
- VMWare ESXi cluster, 3 Virtual Machines (VM) with Linux Ubuntu Server 20.04.
- We set up four variants, the original Kubernetes and one variant per proxied protocol.
- Kubernetes does not ship with a (required) CNI, we created a simple networking.
- Avoid known CNIs like Calico or Flannel, which may introduce unexpected side effects on the experiment.

Experiment and Results

- Kubernetes test-infra which include 7118 tests.
- **Conformance test** with 348 tests to validate the impact of our proxies on the overall functionality of Kubernetes.
- **Performance test** to evaluate the performance of our proxies on Kubernetes in comparison to the original Kubernetes.

Experiment and Results

- We followed the same procedure for a selected variant/test aspect


Start Proxies (Master and Worker)

Join worker nodes to cluster

Run the test

Remove worker nodes from cluster

Stop Proxies (Master and Worker)

- These procedure is repeated 100 times for the **Performance test**.
- Automated experiment execution and result collection.
- Zenodo Link https://doi.org/10.5281/zenodo.7158281

Experiment and Results

- **Conformance test** execution time is about 89 minutes with a variation of around 6 minutes.
- **Performance test** has 5% of variance.

K8s variant	Min	Max	Avg	Stddev
Original K8s	5,083	5,163	5,108	0,018
AAS	5,086	5,159	5,108	0,017
AMQP	5,085	5,16	5,108	0,016
MQTTv5	5,085	5,152	5,107	0,017

Execution time is in ms

Experiment and Results

- Further, the proxying also increases the resource usage, as we believe in acceptable manner.
- We used **nload** and **top** Linux functionality for the measurements and it is collected over time.

AAS proxy	Master	Worker
CPU load	2.67%	1.35%
Memory usage	4.06%	2.43%
Network traffic	1.99%	0.51%

Conclusion

- We replaced the communication protocol in Kubernetes to IIoT/Industry 4.0 protocols and information model to increase standardization.
- As far as we know, our approach does not cause a major effects on typical functionality or performance of Kubernetes.
- Limitation: the experiment is done on the small testing cluster environment.

Future Work

- Protocol openness (without proxy detours) may be a future interoperability feature of the orchestrators.
- Apply similar approach to other orchestrators such as Docker Swarm or Mesos.
- Evaluate the scalability with different cluster sizes.
- Aim at integrating other relevant protocols, e.g., OPC UA.

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