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Scaling Kubernetes Networking to 1k, 5k, ... 100k Nodes!?

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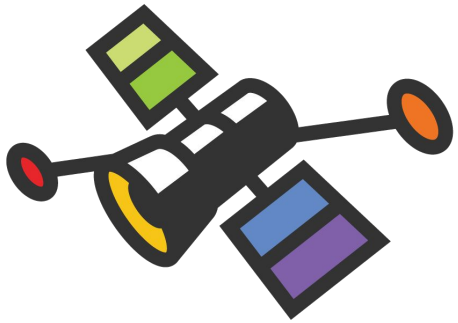
What is Cilium?

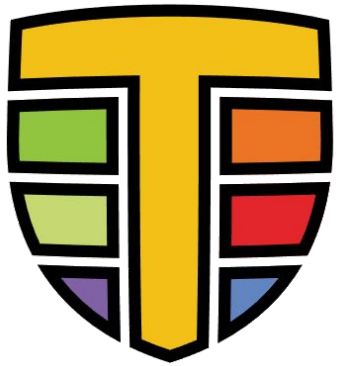
Cilium CNI

Scalable, Secure, High Performance CNI Plugin



Hubble

Network Observability

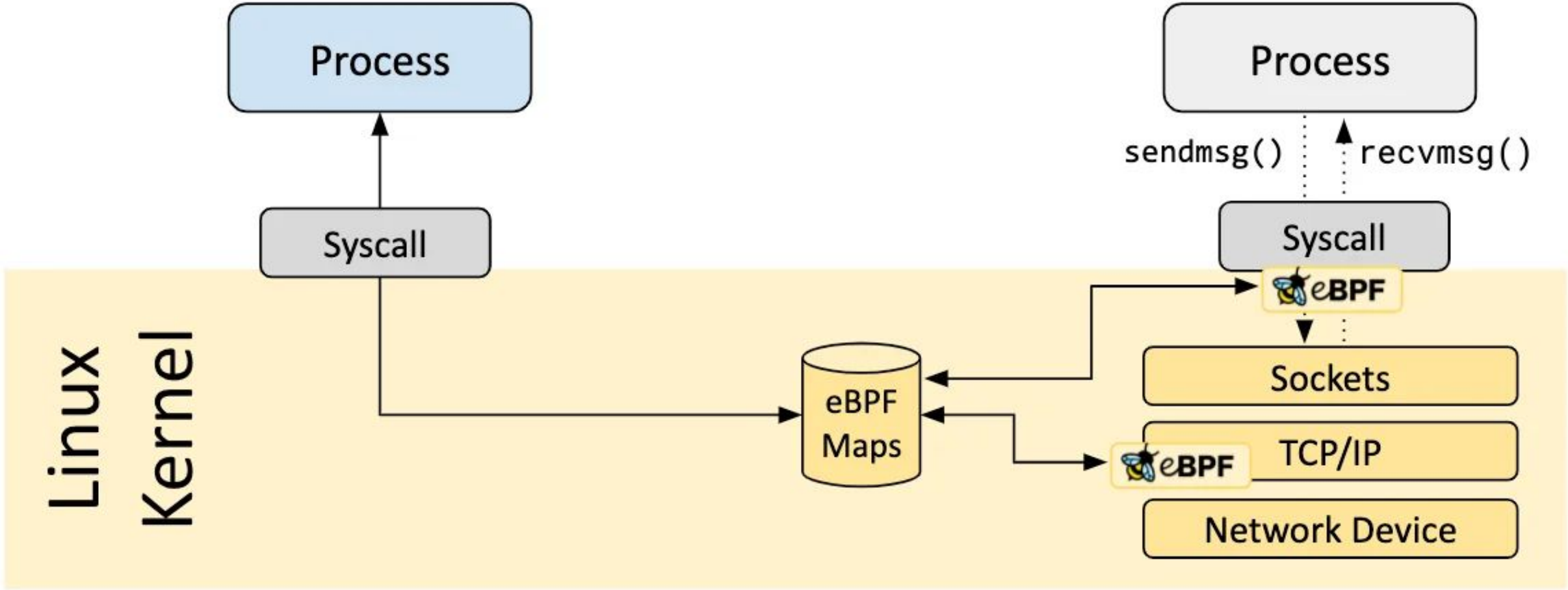


Tetragon

Security Observability & Runtime Enforcement

eBPF

What is eBPF?


Process
Syscall
Linux Kernel
eBPF Maps
Process
sendmsg()
recvmsg()
Syscall
eBPF
Sockets
eBPF
TCP/IP
Network Device

Cilium CNI overview

Efficient and scalable Kubernetes CNI
- IPv4, IPv6, NAT46, SRv6, …
- Overlays, BGP, …

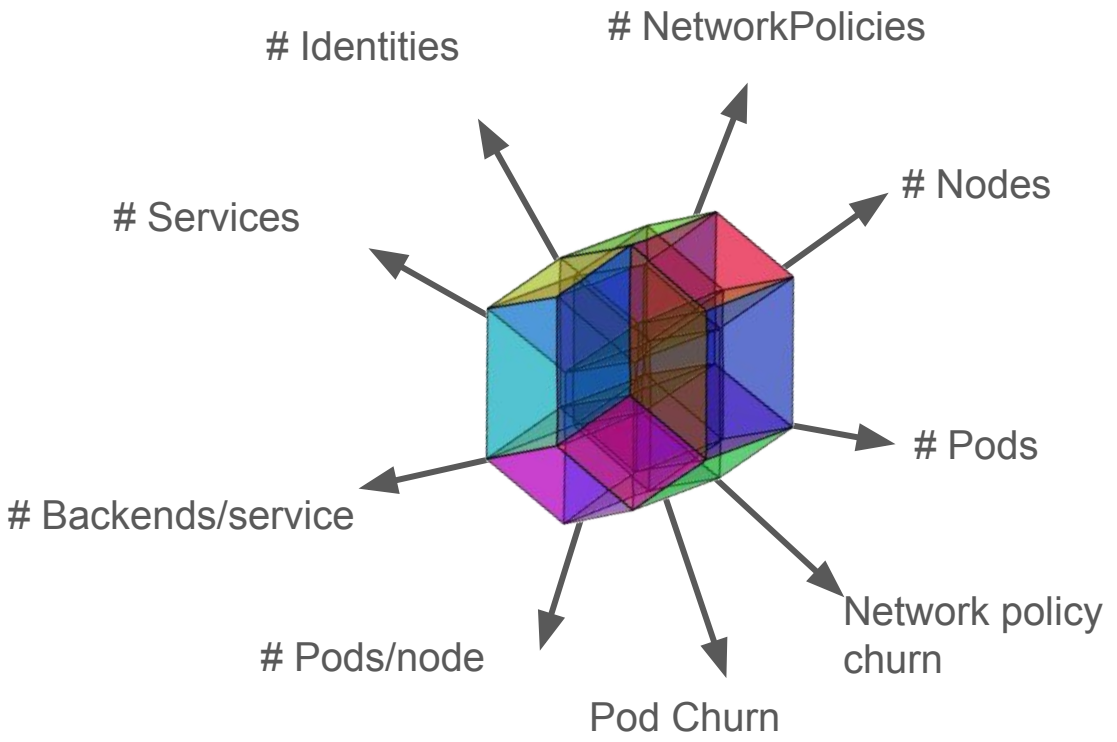
Security
- Kubernetes Network Policy
- Cilium Network Policy (FQDN, L7, …)
- Transparent Encryption

High-performance load balancing
- Kubernetes proxy replacement
- North-South load balancing

Multi-cluster & external workloads
- Global services, service discovery
- Integration of Metal and VMs

But… what does scalability even mean?

~~Scalability = # nodes~~



Networking Scalability SLIs/SLOs

- Pod Startup Latency
- Node Startup Latency
- Network Programming Latency
- Network Policy Enforcement Latency
- In-Cluster Network Latency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Network security on a large scale

Network security on a large scale

How workload security with K8s network policies scales up to 5k nodes and 200k pods on a single cluster?

We are going to cover:

- Target scale
- Network policy implementation
- What challenges we overcame and how?
- Performance & metrics
- Improvements in progress

Network security on a large scale

Target scale

Scalability dimension	Limit
# Nodes	5k
# Pods	200k
Pod churn rate	100 per second
# Network policies	10k
Network policy churn rate	20 per second

Network policy implementation

- Custom resources:
  - Cilium Endpoint - An endpoint created for every pod.
  - Cilium Identity - A security identity created for every unique pod and namespace label set.
- Network policies select pod labels and namespace labels that should be allowed.
- Cilium-agent (daemonset) populates on every node:
  - Policy eBPF maps based on network policy rules and security identities
    - A policy map is created for every local pod
    - It contains a list of identities that are allowed to communicate with the pod
  - IPCache, IP to identity mapping for all pods in the cluster
- When establishing connection. verify if the matching identity for the peer IP exists in the policy map.

Network security on a large scale

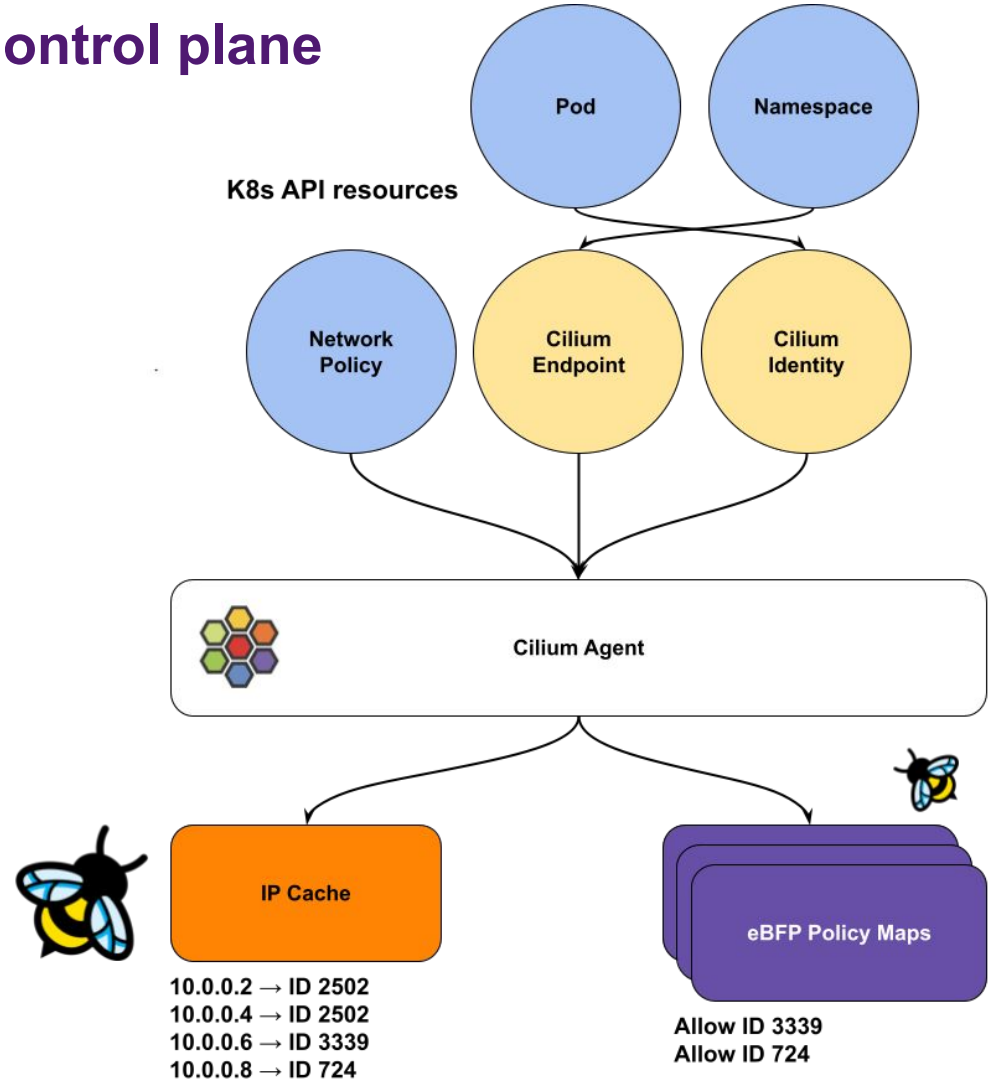
Security Identity 

- Security identity is generated from pod labels and namespace labels
- Network policies select pod labels and namespace labels
- Pod to pod communication is allowed only between pods that have selected identities

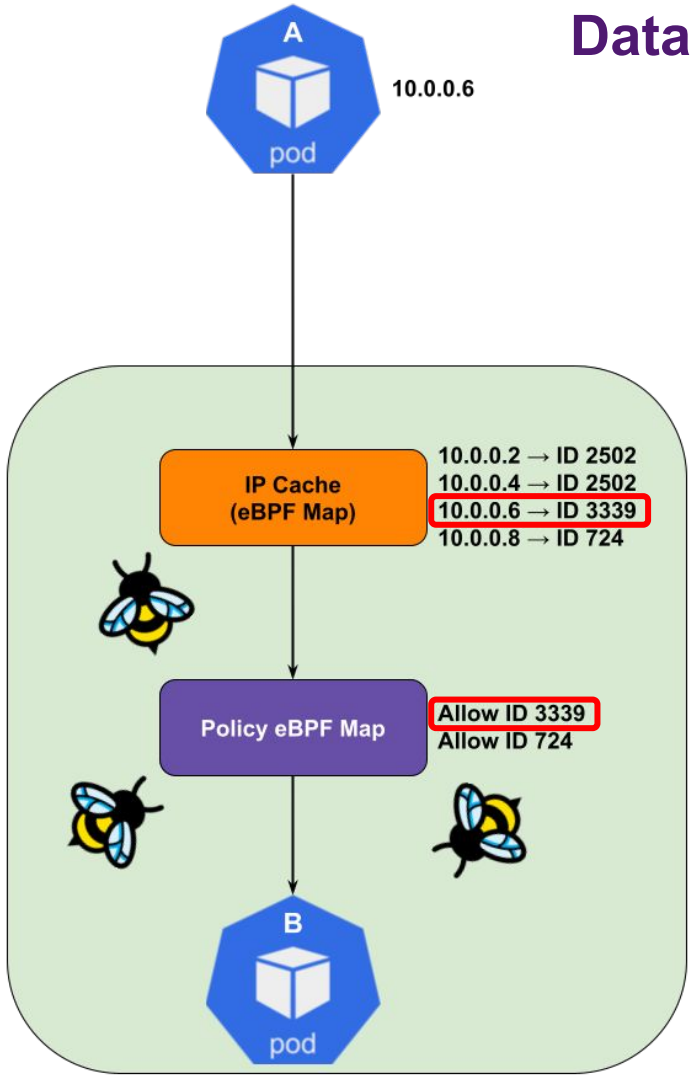
Network security on a large scale

Network policy implementation

Control plane



Data plane

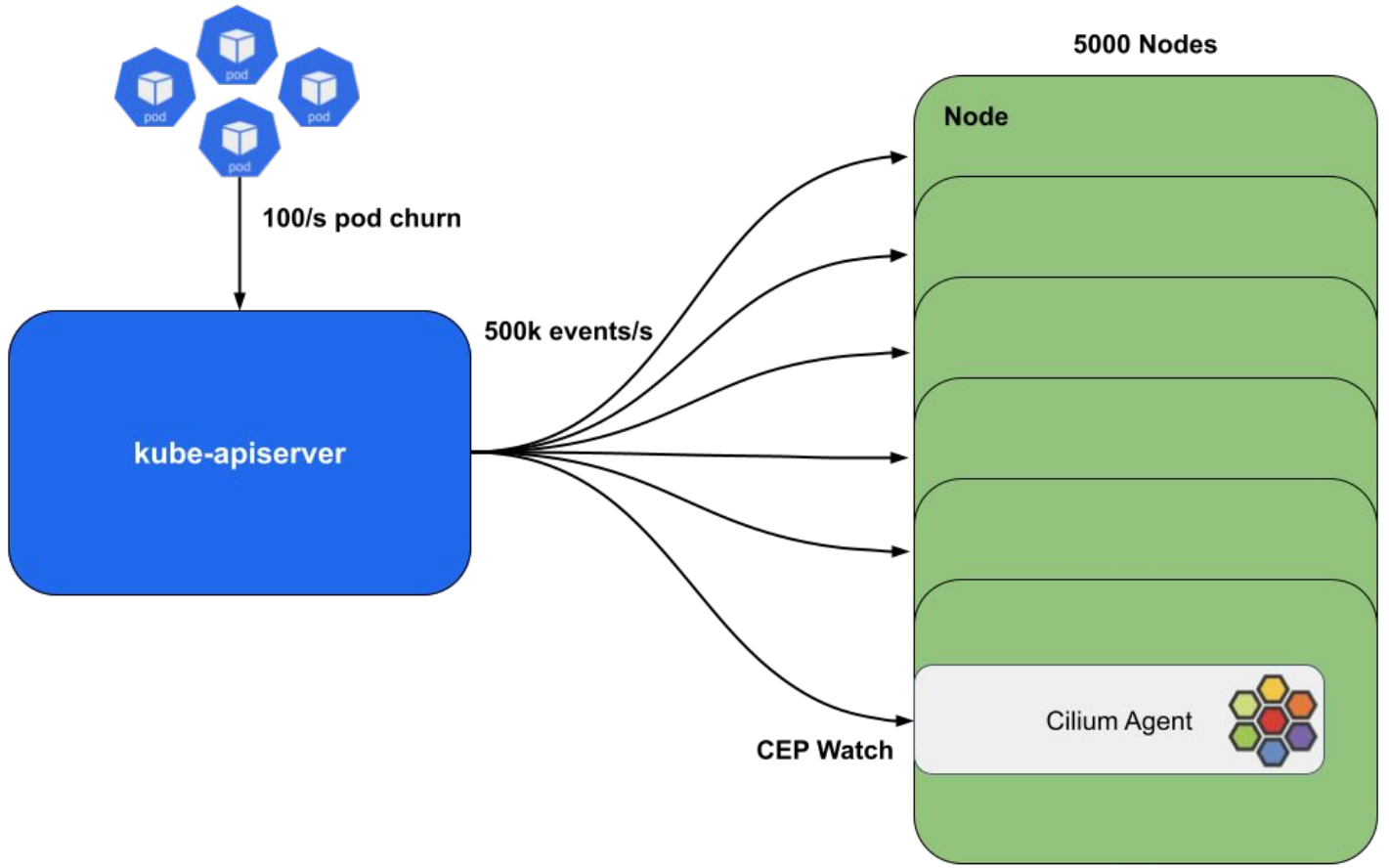


Network security on a large scale

What is the bottleneck?

k8s API events = Nodes * Pod changes

- All nodes need to know about pod IP to pod security ID mapping for every pod.
- 5000 nodes * 100 pod changes per second = 500k events per second
- Kube-apiserver on the most powerful VMs has trouble handling over 100k events/s. The safe limit is up to 1000 nodes for 100 pod changes per second.

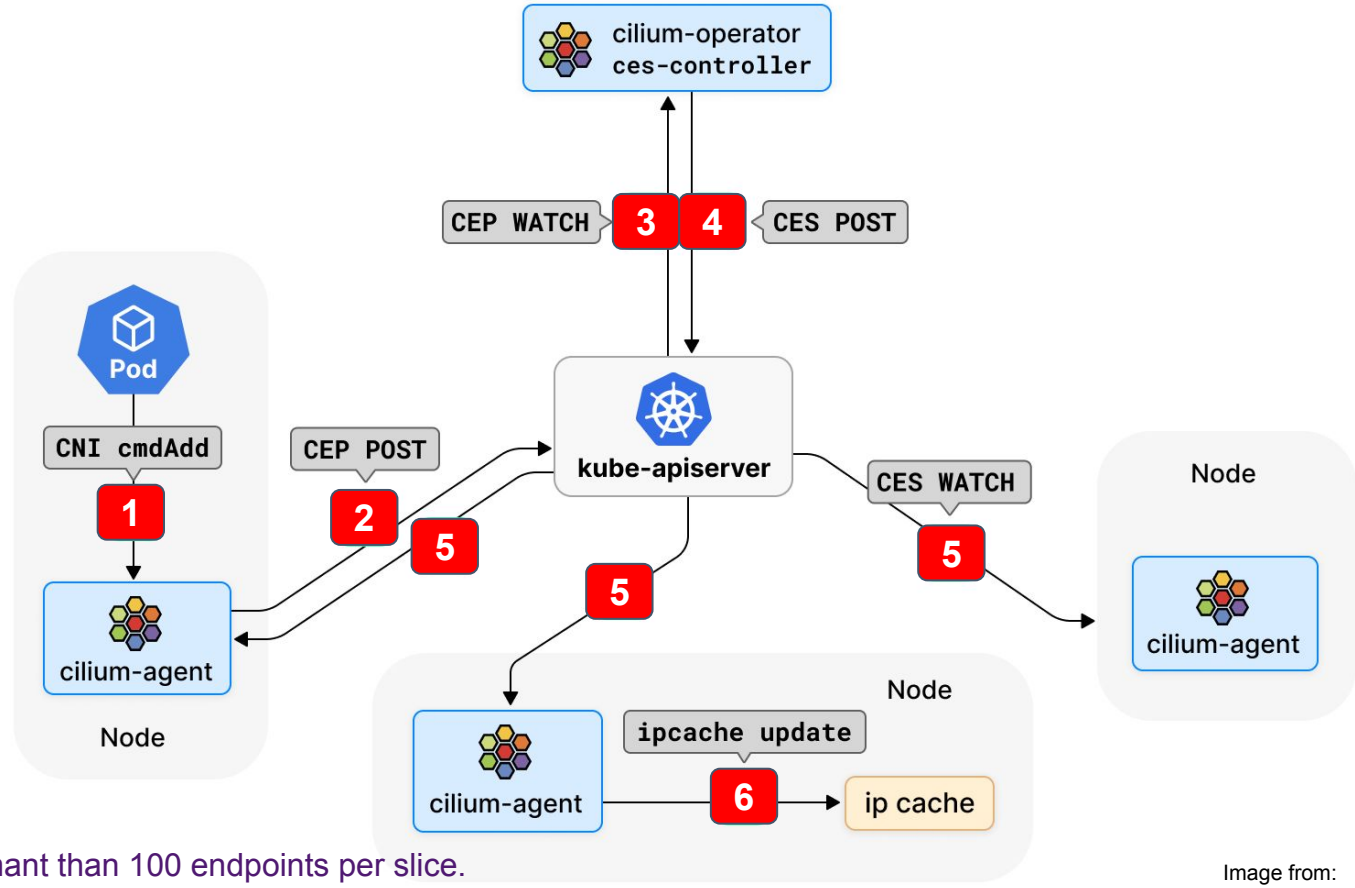


Network security on a large scale

What did we do to overcome it?

Batching Cilium Endpoints ✓

- Inspired by K8s Endpoint Slice
- High number of events of small objects
- Slice the entire pool of endpoints
- Batch them into groups of 50*

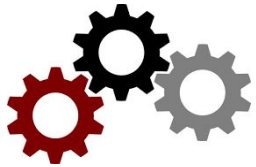


* Based on scalability tests size of 50 endpoints per slice proved to be more performant than 100 endpoints per slice.

Image from: https://isovalent.com/blog/post/2021-12-release-111/#cilium-endpoint-slices

Network security on a large scale

Why does it work?



- Overhead of handling a very high number of events in KCP heavily impacts the performance.
- Sending fewer larger events enables kube-apiserver to handle 100/s pod change rate.
- Cilium Endpoint Slice contains the minimum amount of data from Cilium Endpoints. Having security identity (int64) instead of a set of labels (list of strings) significantly reduces the size of each endpoint.
- One slice contains 50 endpoints. A full slice is on average 5 times smaller than 50 Cilium Endpoints.*

* Measured in json format. Cilium Endpoint size: ~2.2 kB; Full Cilium Endpoint Slice size: ~20.8 kB

Network security on a large scale

Performance

- Cilium Endpoint batching enables the scale to increase from 1000 nodes to 5000 nodes, with 100/s pod churn, and allow for more pods to be running in the cluster, up to 200k pods.

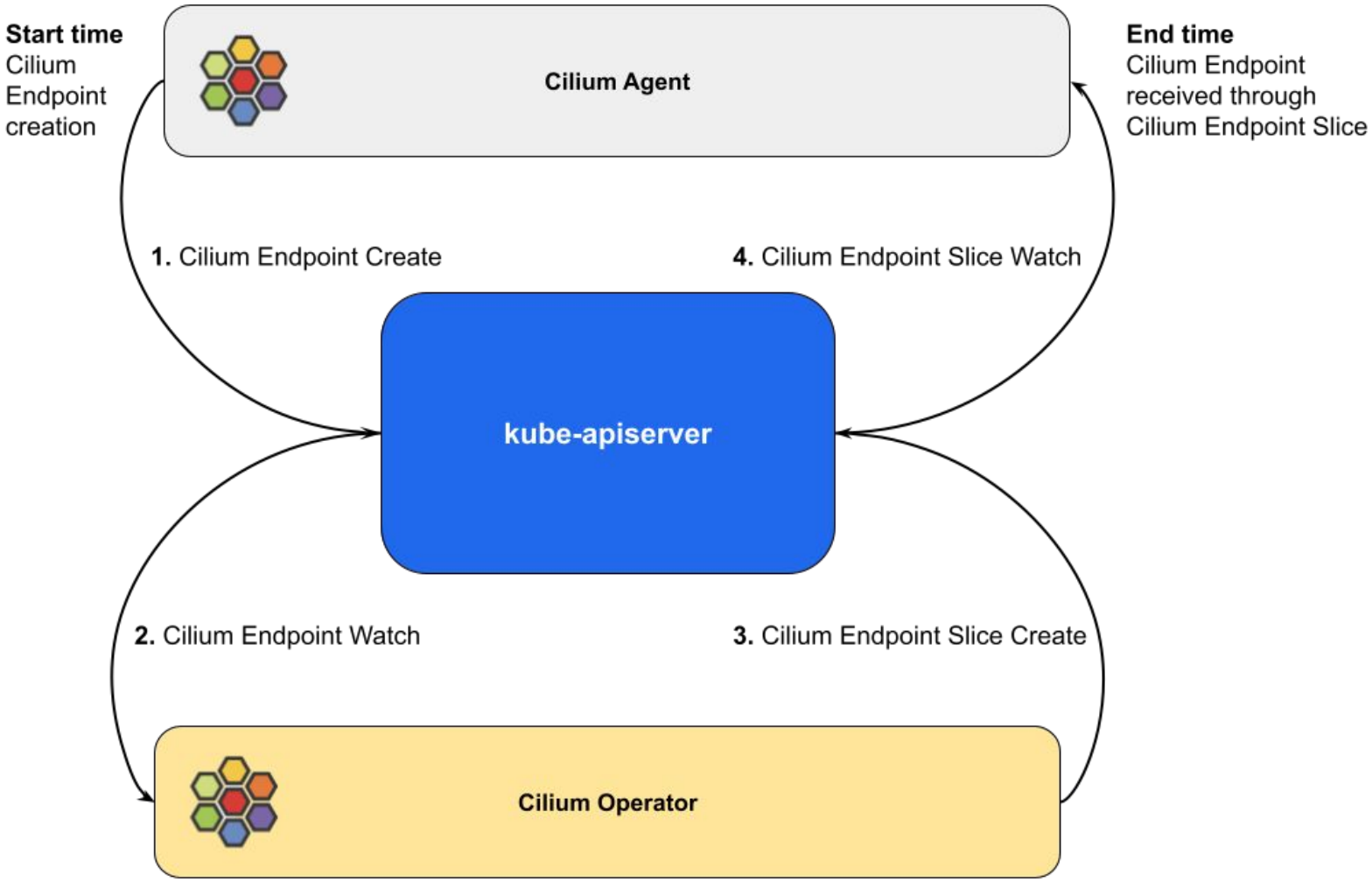
- Cilium Endpoint Slice updates rate limited to 10 per second on 5000 nodes.
  - Up to 500 pod updates per second.
  - Up to 50k Cilium Endpoint Slice events per second.

- Worst case scenario - Update all 200k pods at once
  - 6.67 minutes (400 seconds) = 200k pods / 500 pod updates per second

Network security on a large scale

Metrics / SLI

- Cilium Endpoint propagation delay metric represents Network policy enforcement latency
- Policy programming latency on each node takes low time (<5 sec) after propagation of endpoints, regardless of scale



Network security on a large scale

What are other challenges that we are facing?

Cilium Identity limits 

- Hard limits
  - 65k security identities per cluster
  - 16k security identities per policy eBPF map*
- Triggers
  - All pods have a unique label set
  - Identity duplication
- Remaining issue
  - Namespace label change

* Pods affected by allow-all network policies will be stuck in pod creation stage as long as there are over 16k security identities

Network security on a large scale

What improvements are we currently working on?

Centralized identity management ✓

- Move identity management to cilium-operator from a distributed management by cilium-agents
- Resolves Cilium Identity duplication
- Reduces pod startup latency - Cilium Identities are created on pod creation instead of Cilium Endpoint creation
- Security improvement - cilium-agent loses permission to write to Cilium Identity
- Enables further improvements and optimizations

Network security on a large scale

What are the improvements that we expect to have soon?

- Greatly reduce the number of security identities - “Security relevant labels filter”
- Improve performance and reliability depending on scale - “Dynamic Cilium Endpoint Slice update rate limiting”
- Faster policy enforcement for system critical pods - “Priority propagation of Cilium Endpoint Slices”
- Reduce policy enforcement latency on a large scale* - “Kube-apiserver optimization for processing events for many watchers (K8s 1.29)”

* https://github.com/kubernetes/kubernetes/pull/119801 + https://github.com/kubernetes/kubernetes/pull/120300

Network security on a large scale

Long term goal

- Continue stretching the limits of scalability dimensions with complete and performant network security support
- The improvements in progress make us very hopeful, but there is still a lot of work to be done, and we want to continue thinking more ahead
- Support a wide variety of cases to the full extent by utilizing different configurations (dynamically adjusted) and accepting different trade-offs
- Recognize that “one size fits all” is a much more difficult path when feature and scalability requirements are very diverse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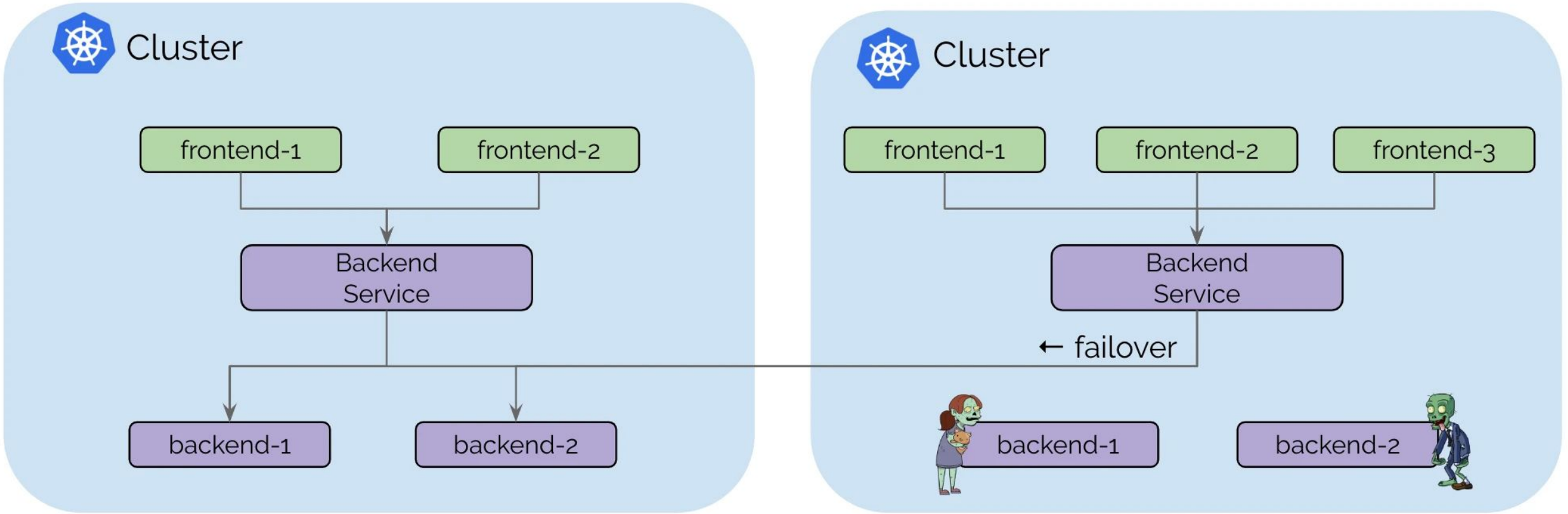
Cilium Clustermesh

Clustermesh in a nutshell

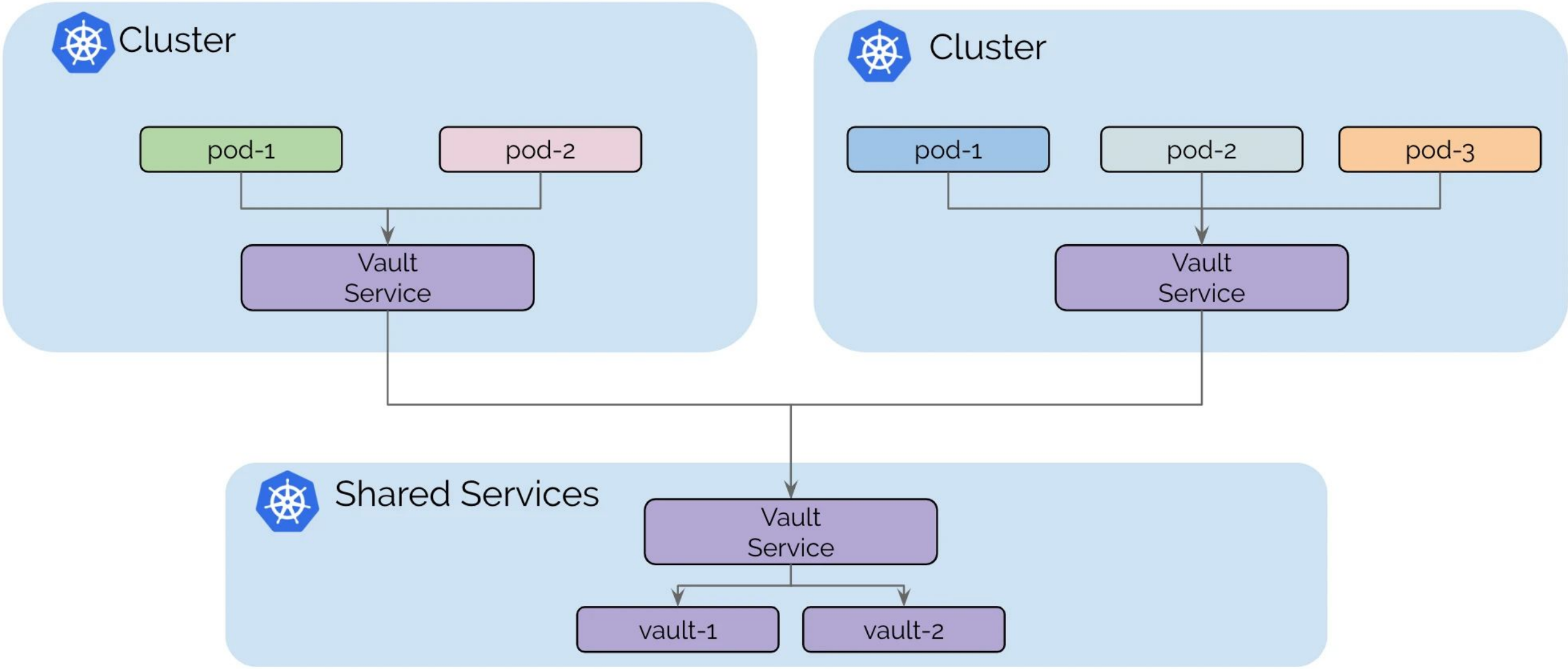
Clustermesh provides:

- Cross-cluster connectivity for your workloads
- Transparent service discovery with standard Kubernetes services and coredns/kube-dns
- Network policy enforcement spanning multiple clusters.
- Transparent encryption for all communication between nodes in the local cluster as well as across cluster boundaries.

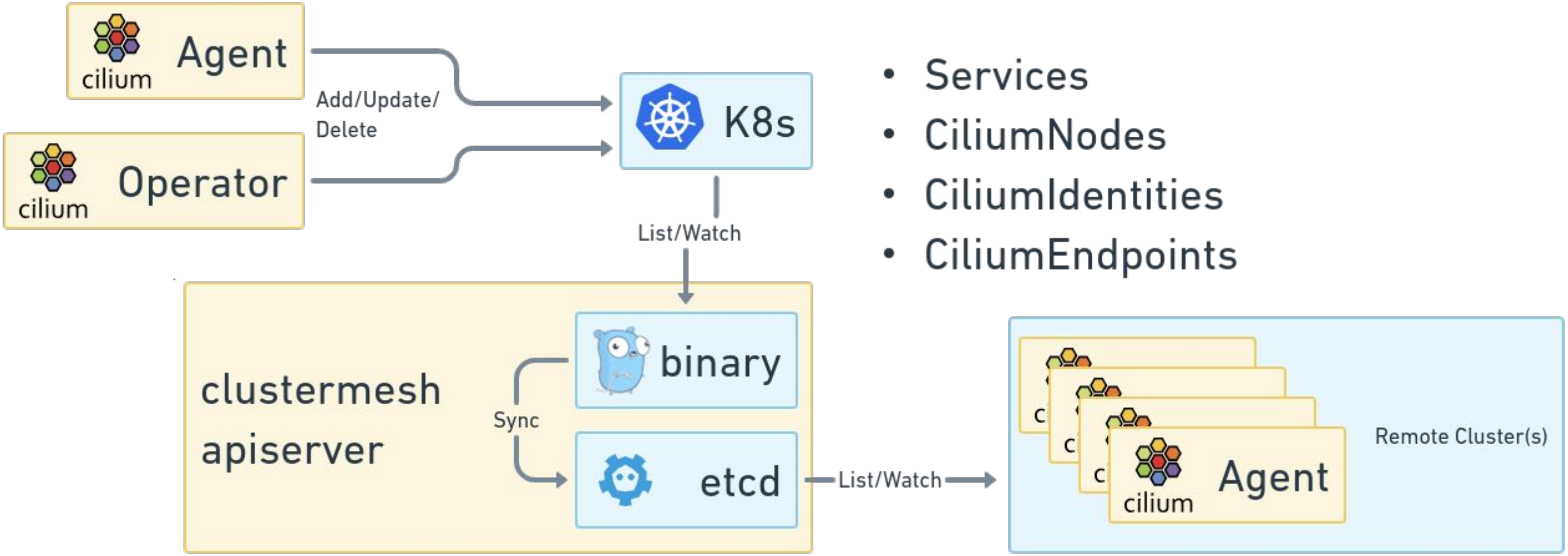
Use case: High availability



Use case: Shared services



Initial architecture

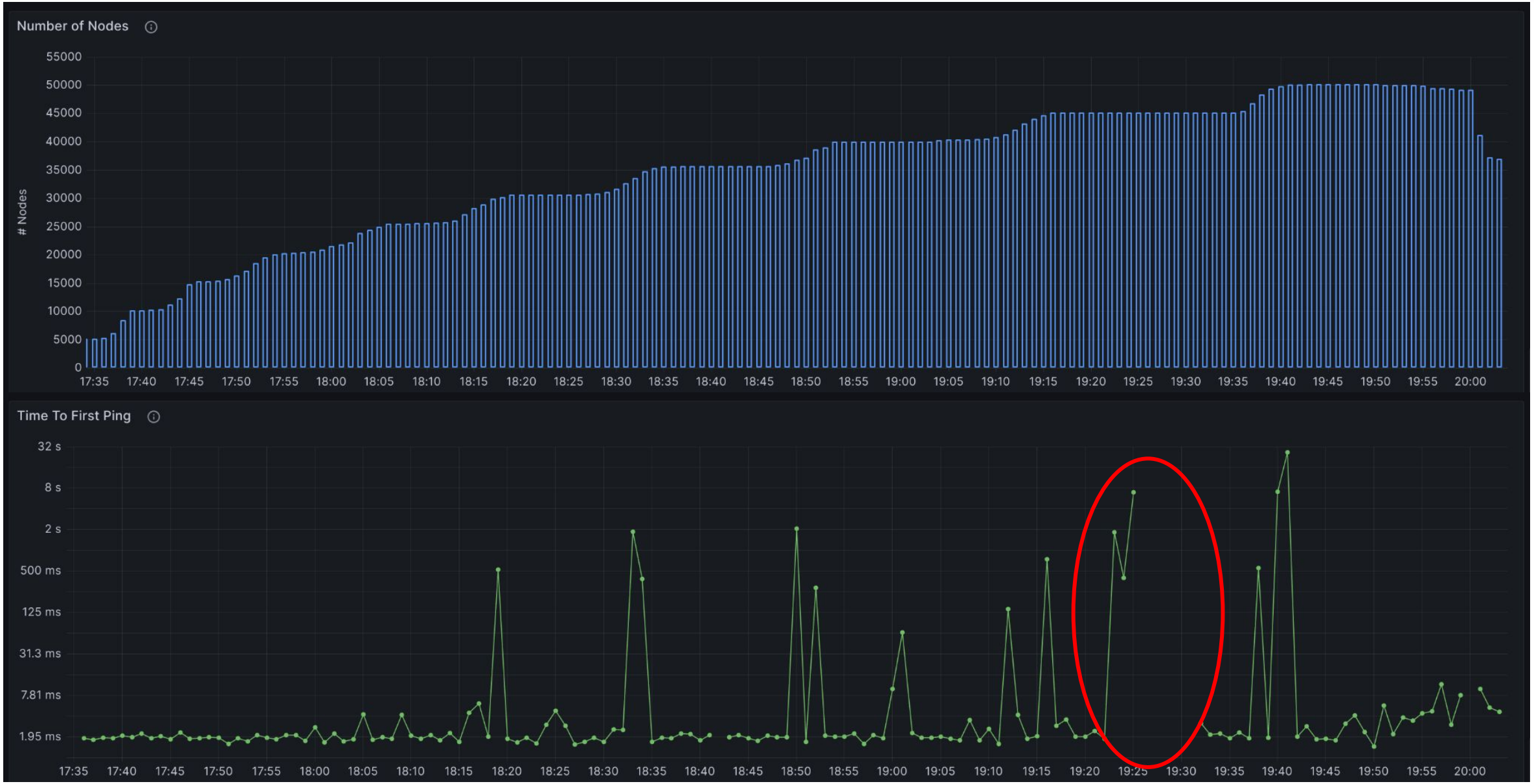


- Services
- CiliumNodes
- CiliumIdentities
- CiliumEndpoints

Clustermesh target scale

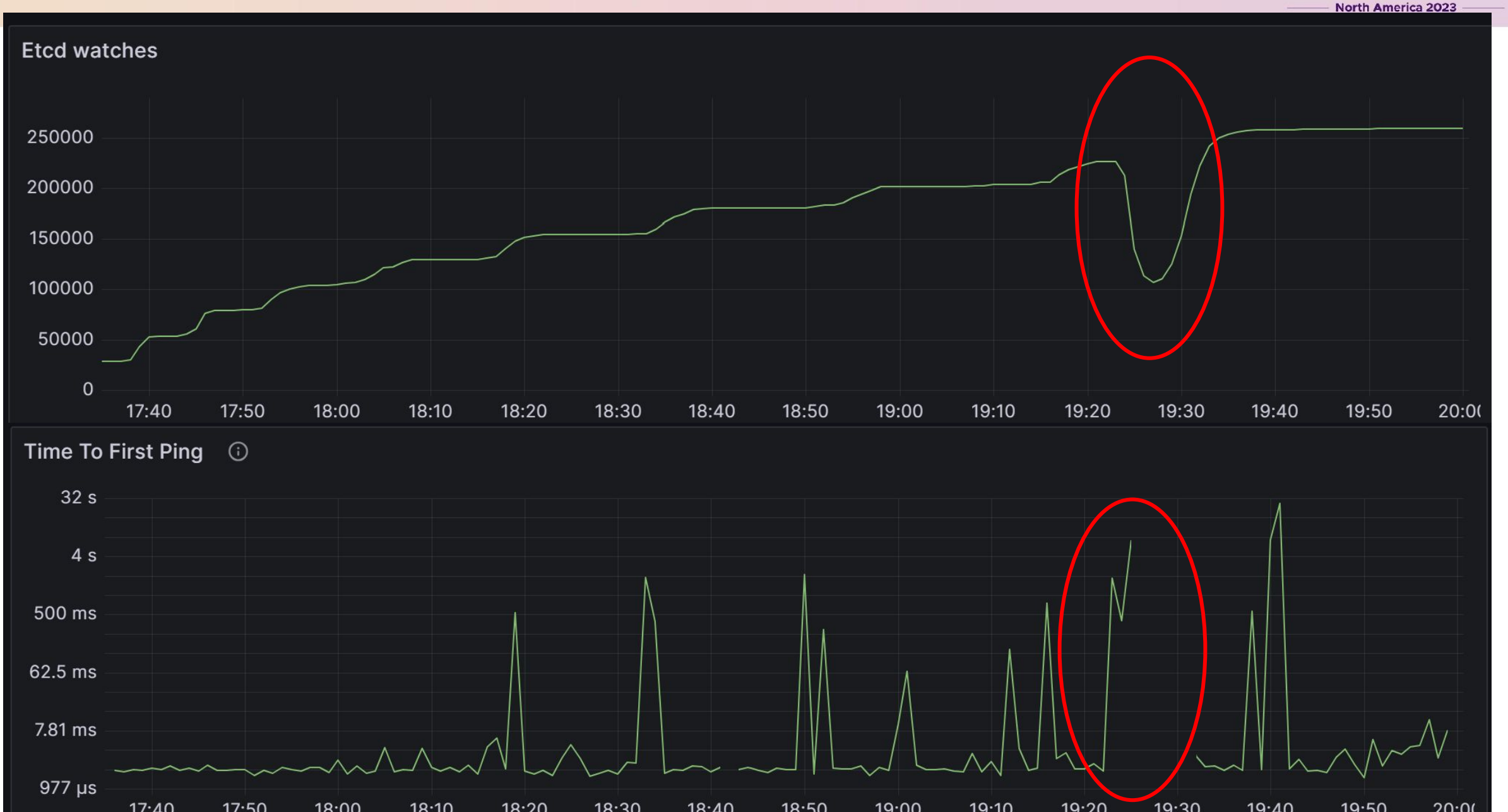
Scalability dimension	Limit
# Clusters	255
# Nodes	50k
Node churn	<50 nodes per second
Endpoint propagation rate	100 per second
# Pods in total	500k

Scale test results

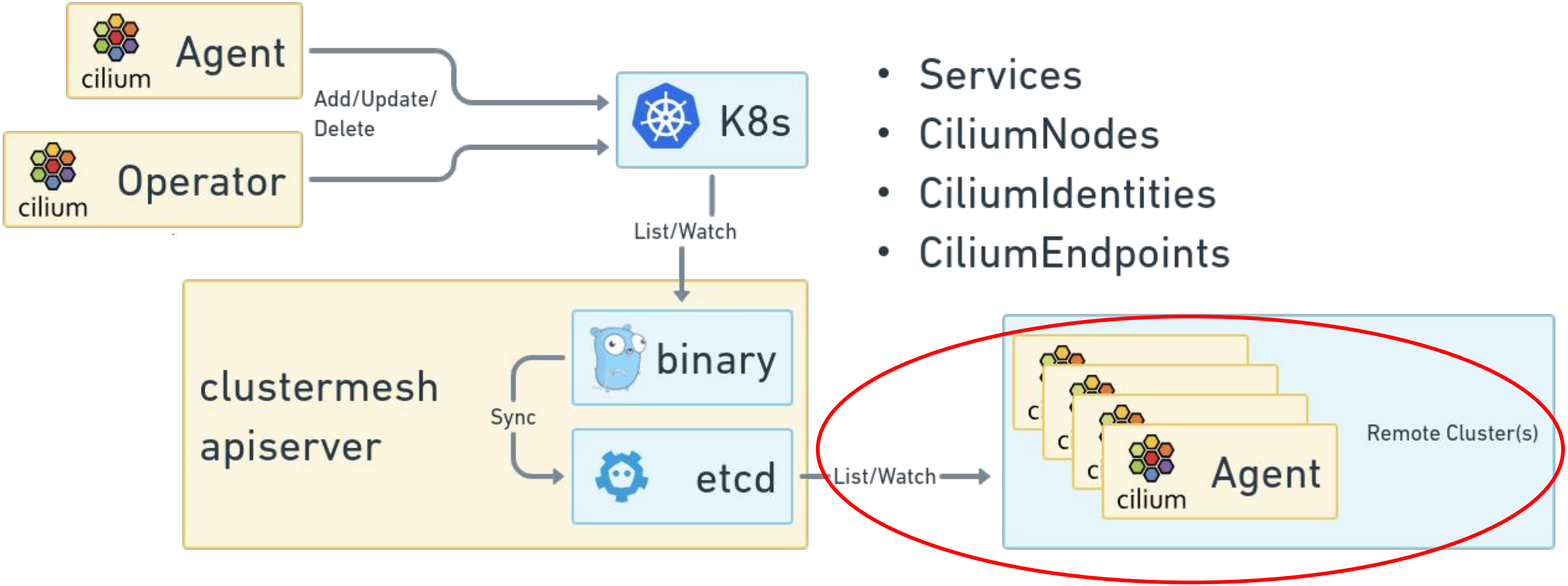


Scale test results

Scale test results

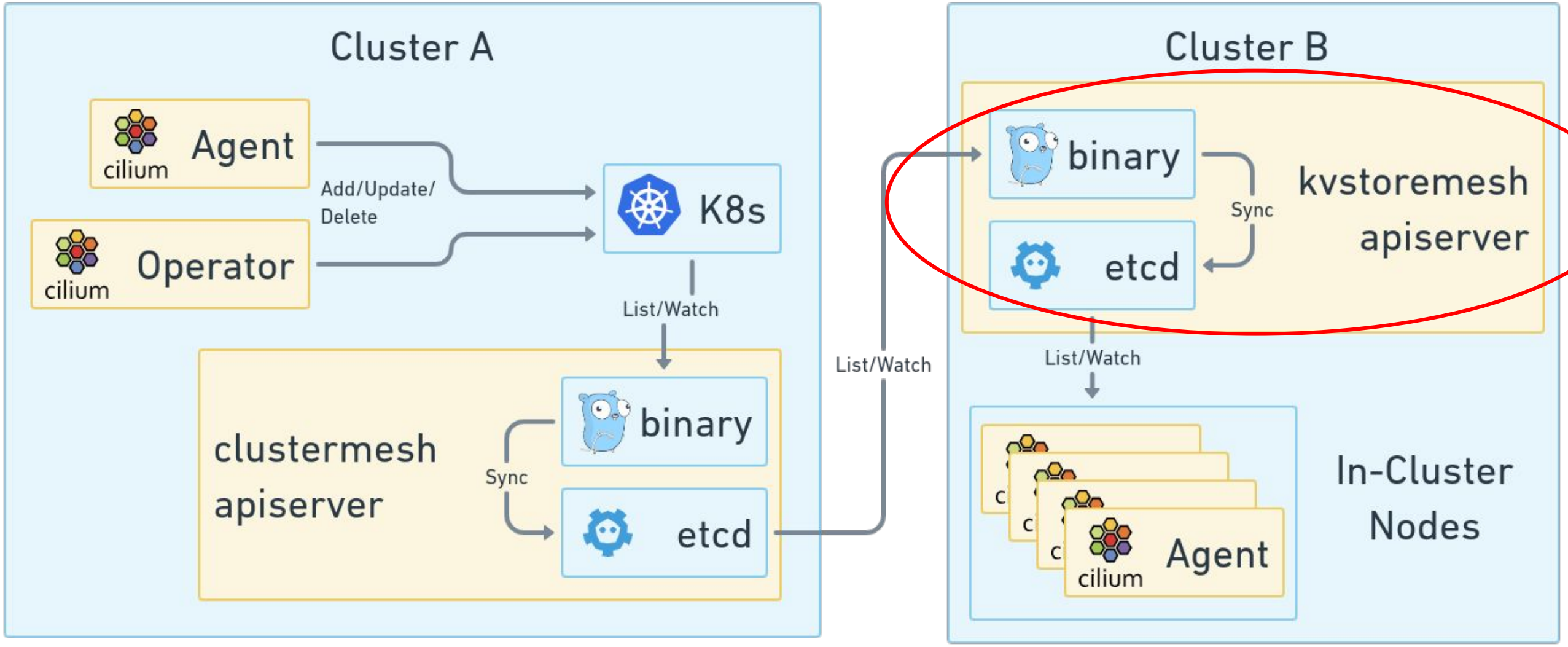


Bottleneck in initial architecture

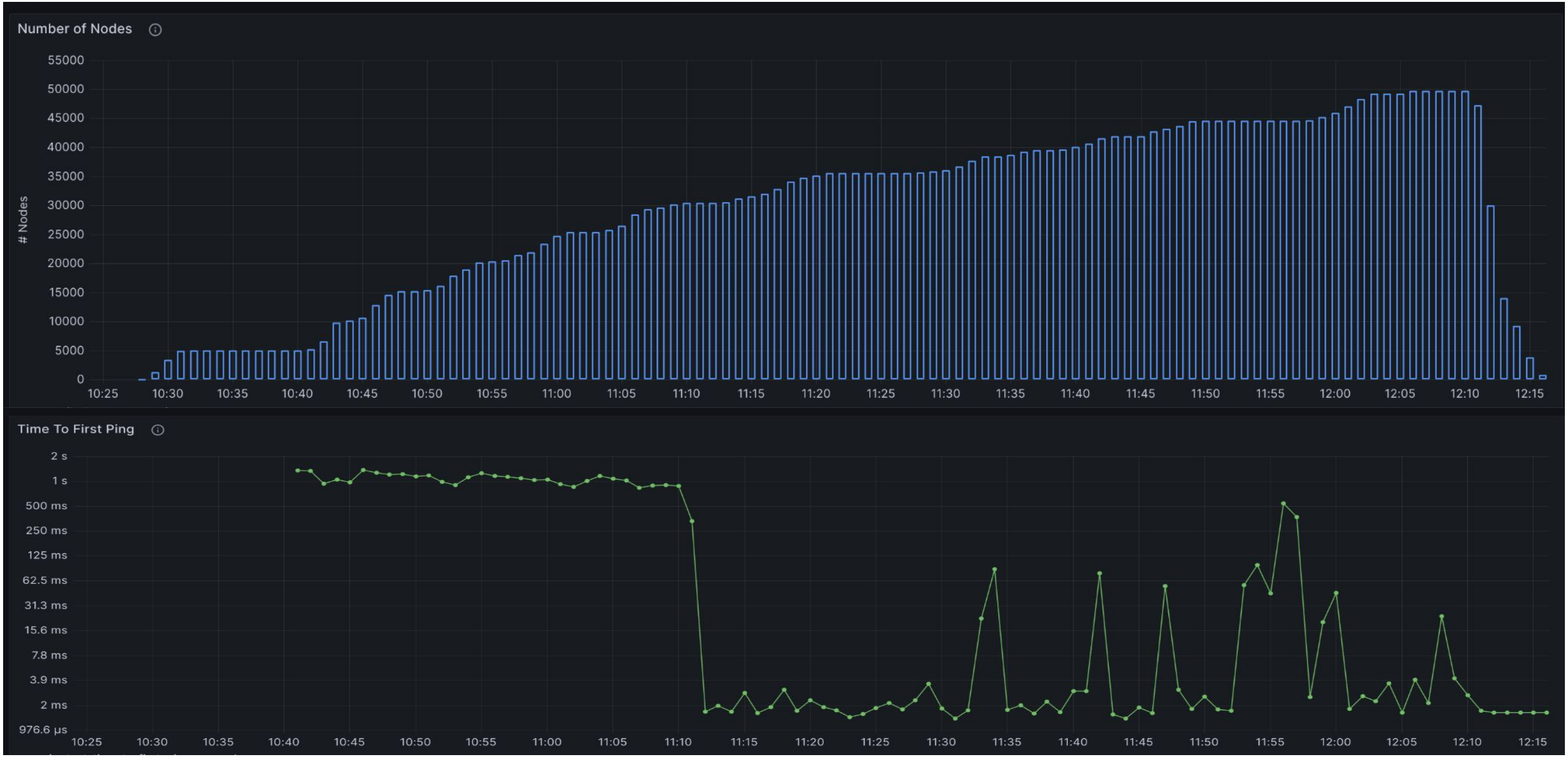


- Services
- CiliumNodes
- CiliumIdentities
- CiliumEndpoints

KVStoreMesh architecture



KVStoreMesh scale test results



KVStoreMesh scale test results

Future KVStoreMesh improvements

- Support for 511 clusters in clustermesh
- Increase propagation rate of endpoints to 500/s
- Reduce initialization time of Clustermesh control plane

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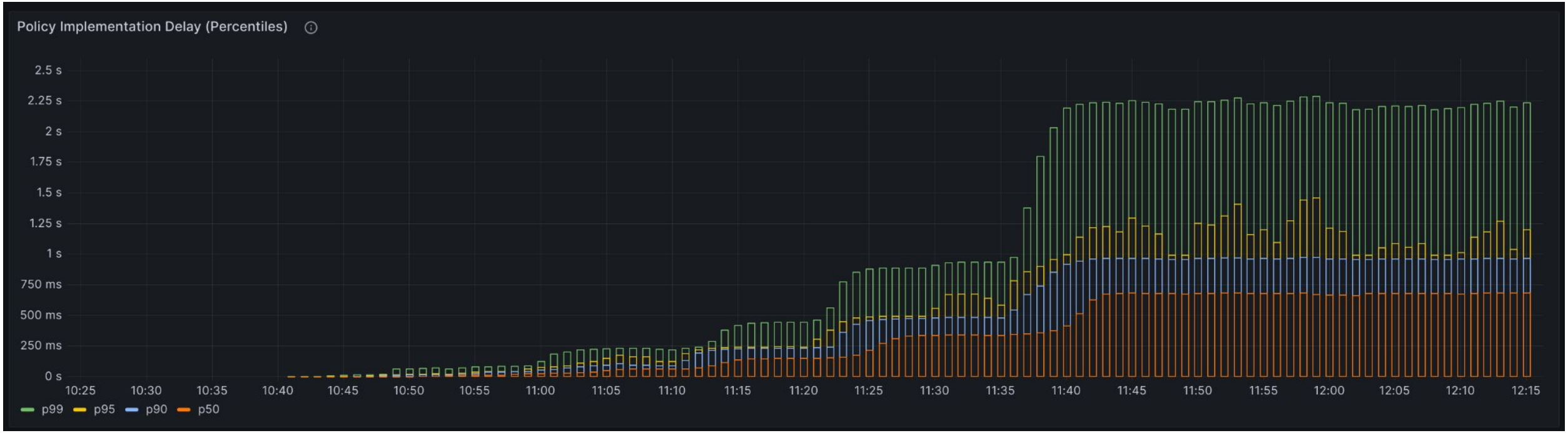
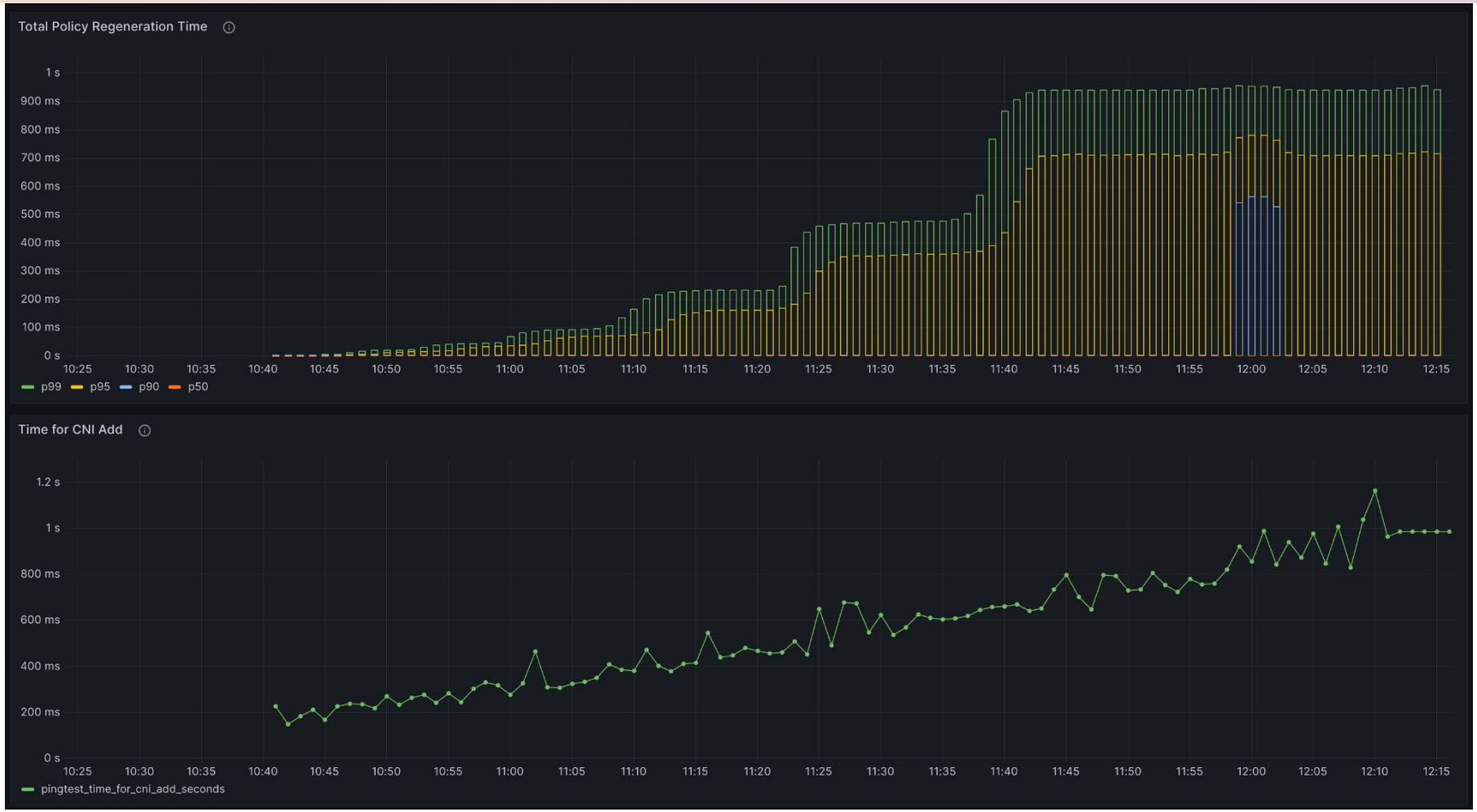
to leave feedback on this session

KVStoreMesh



KVStoreMesh



Latency measurement