CLOUDNATIVE SECURITYCON

NORTH AMERICA 2023

From the Cluster to the Cloud: Lateral Movements in Kubernetes

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Agenda

- Identity types in Kubernetes
- Inner-cluster lateral movement
- Cluster-to-cloud lateral movement: Azure, AWS and GCP
- Detections & mitigations
- Key takeaways

Identity types in Kubernetes

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Three main areas:

- How users (or applications) from outside the cluster authenticate with the cluster.
- How workloads in the cluster authenticate within the cluster.
- How workloads in the cluster authenticate with resources in the cloud outside the cluster.

Identity types in Kubernetes

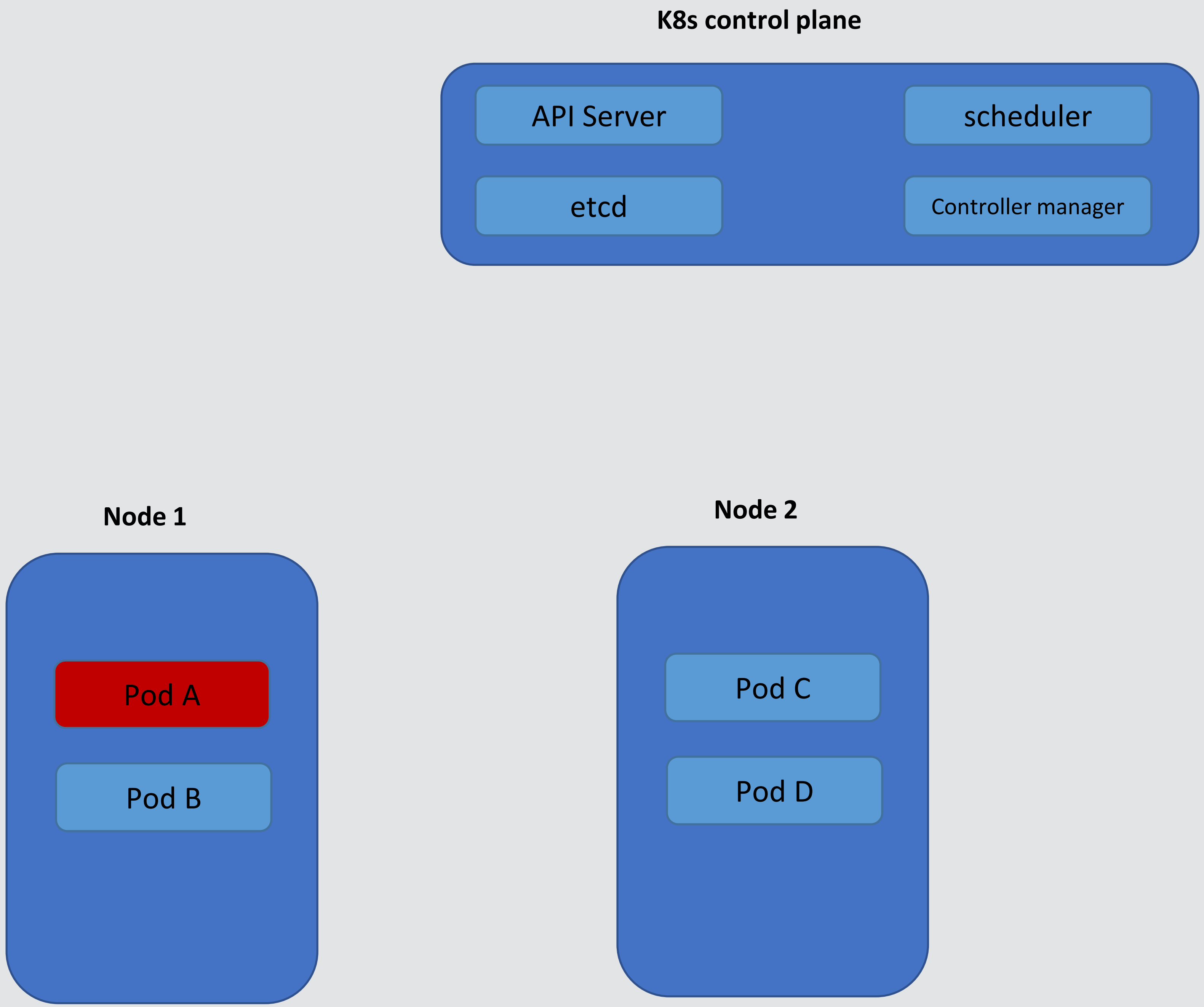
Three main areas:

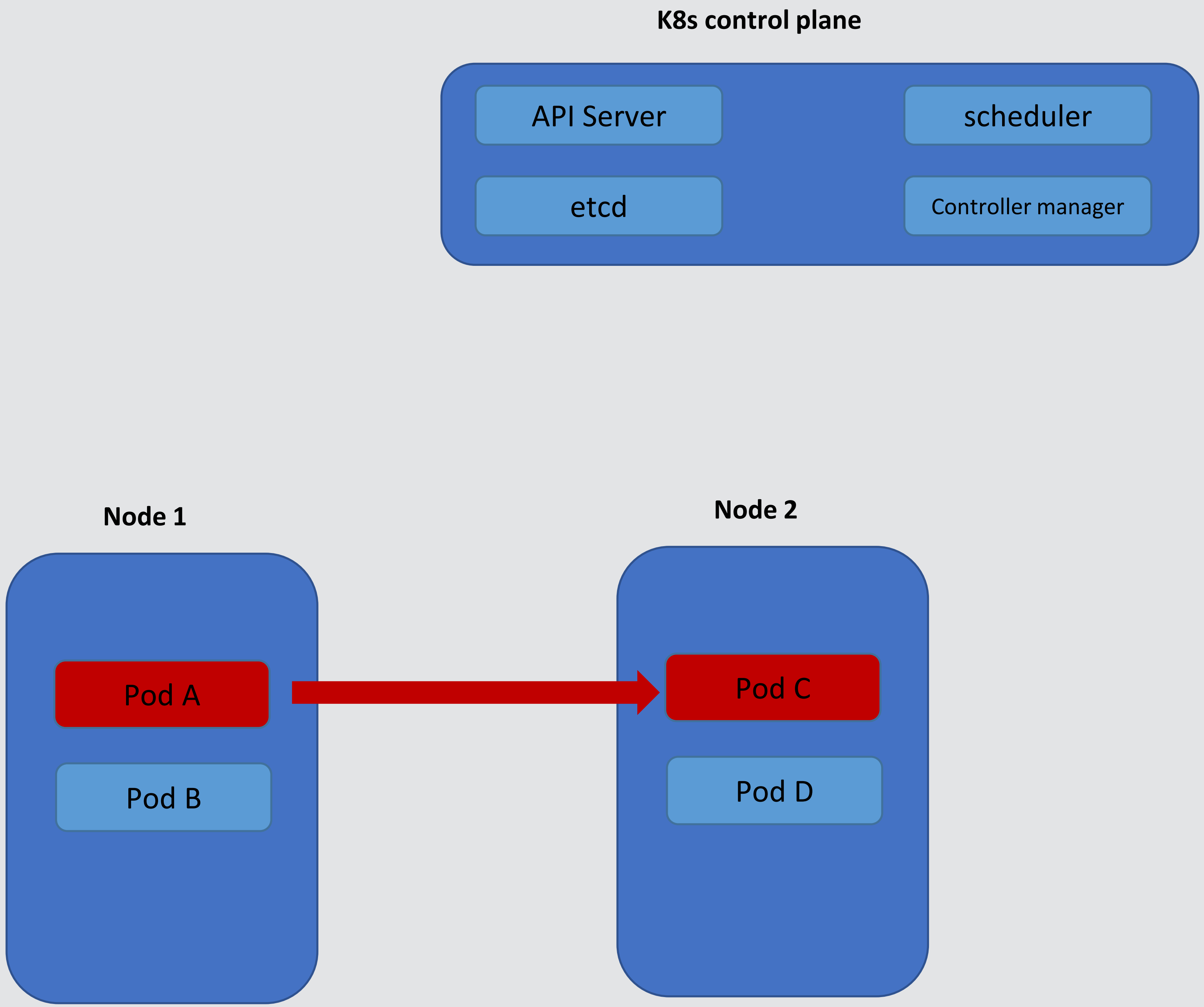
- How users (or applications) from outside the cluster authenticate with the cluster.
- **How workloads in the cluster authenticate within the cluster.**
  (Inner-cluster lateral movement)
- **How workloads in the cluster authenticate with resources in the cloud outside the cluster.**
  (Cluster-to-cloud lateral movement)

Inner-cluster lateral movement

Inner-cluster lateral movement

Let’s assume a pod is compromised


K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Pod A
Pod B
Node 2
Pod C
Pod D
Node 3
Pod E
Pod F



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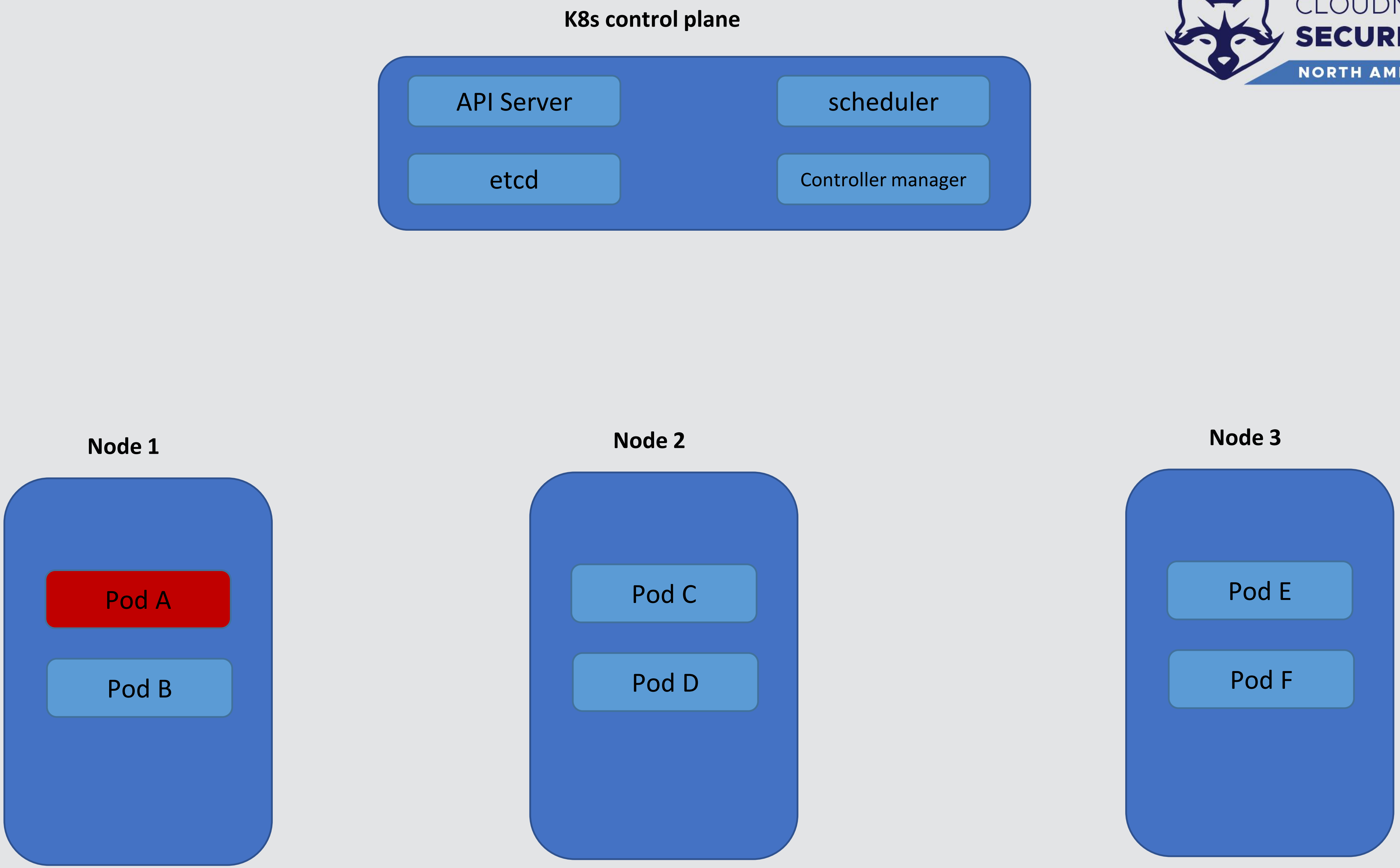
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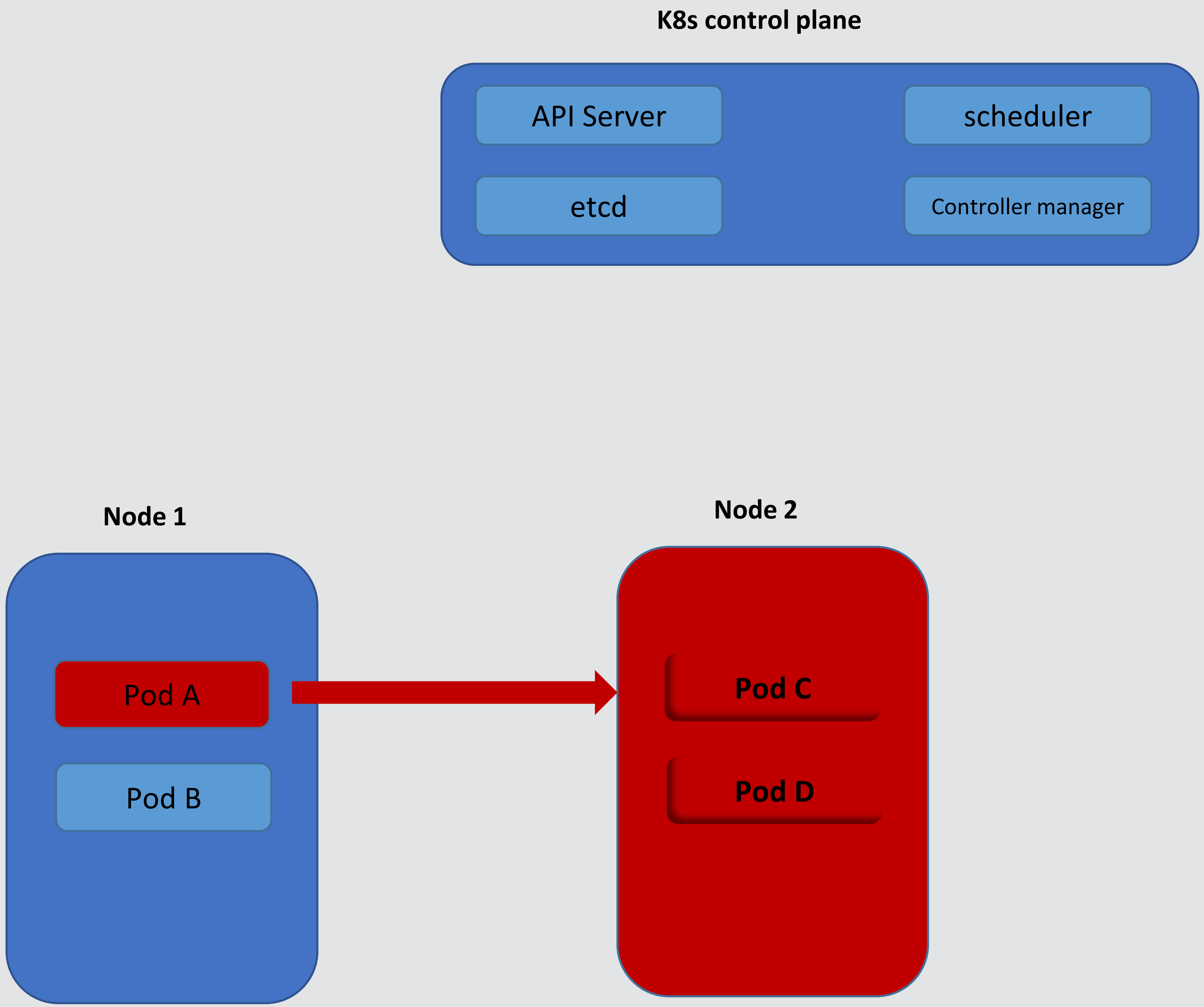
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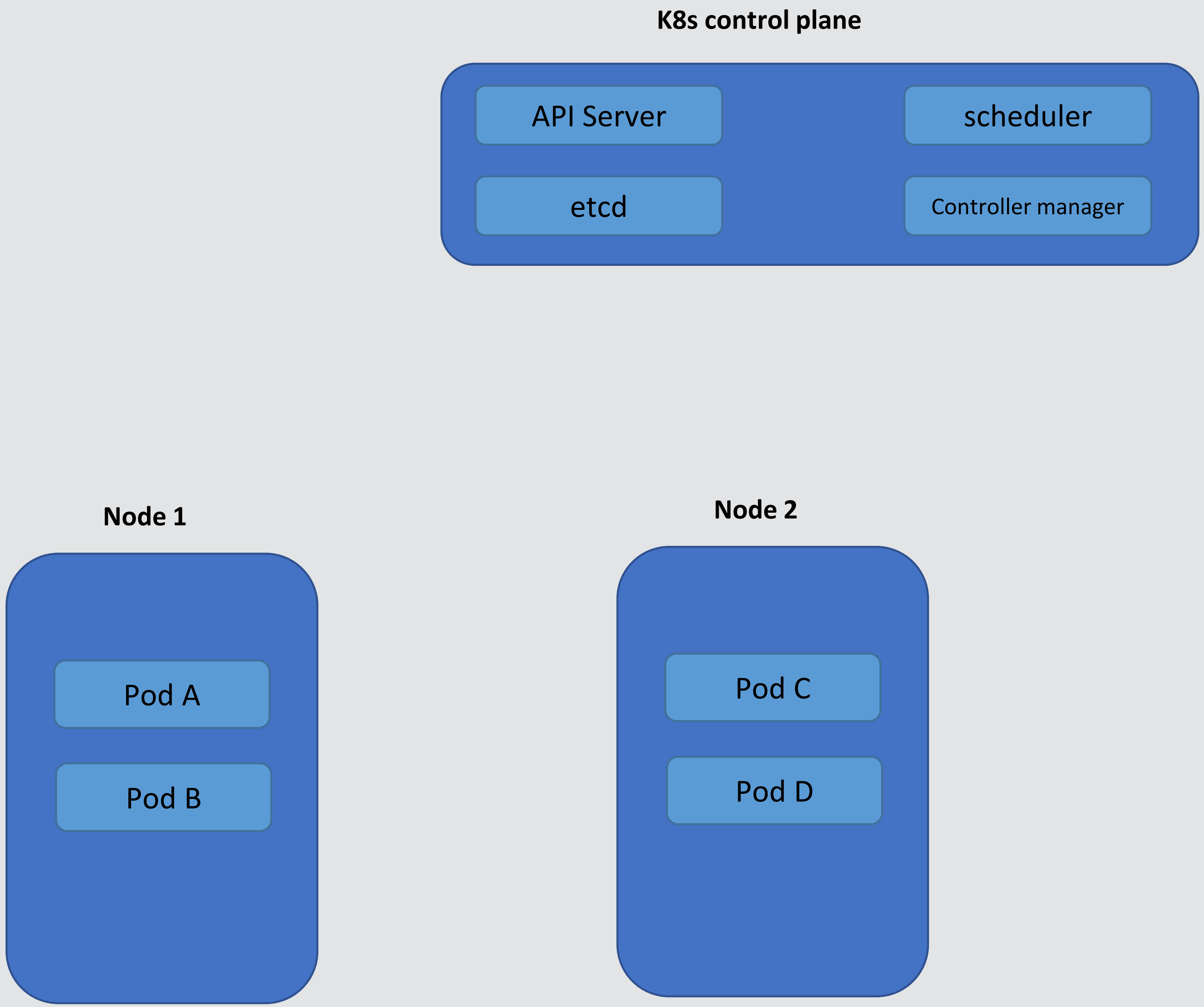
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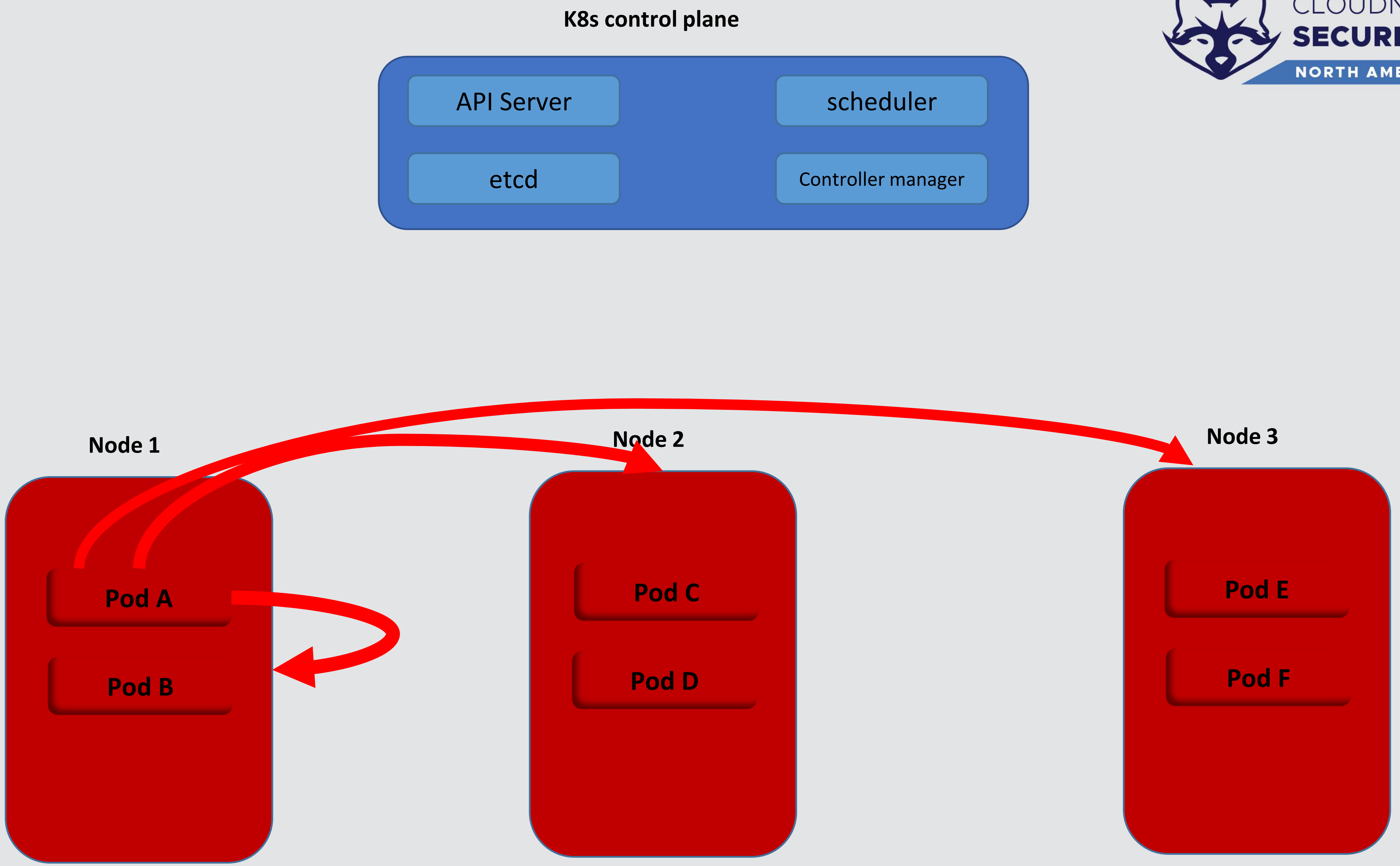
K8s control plane
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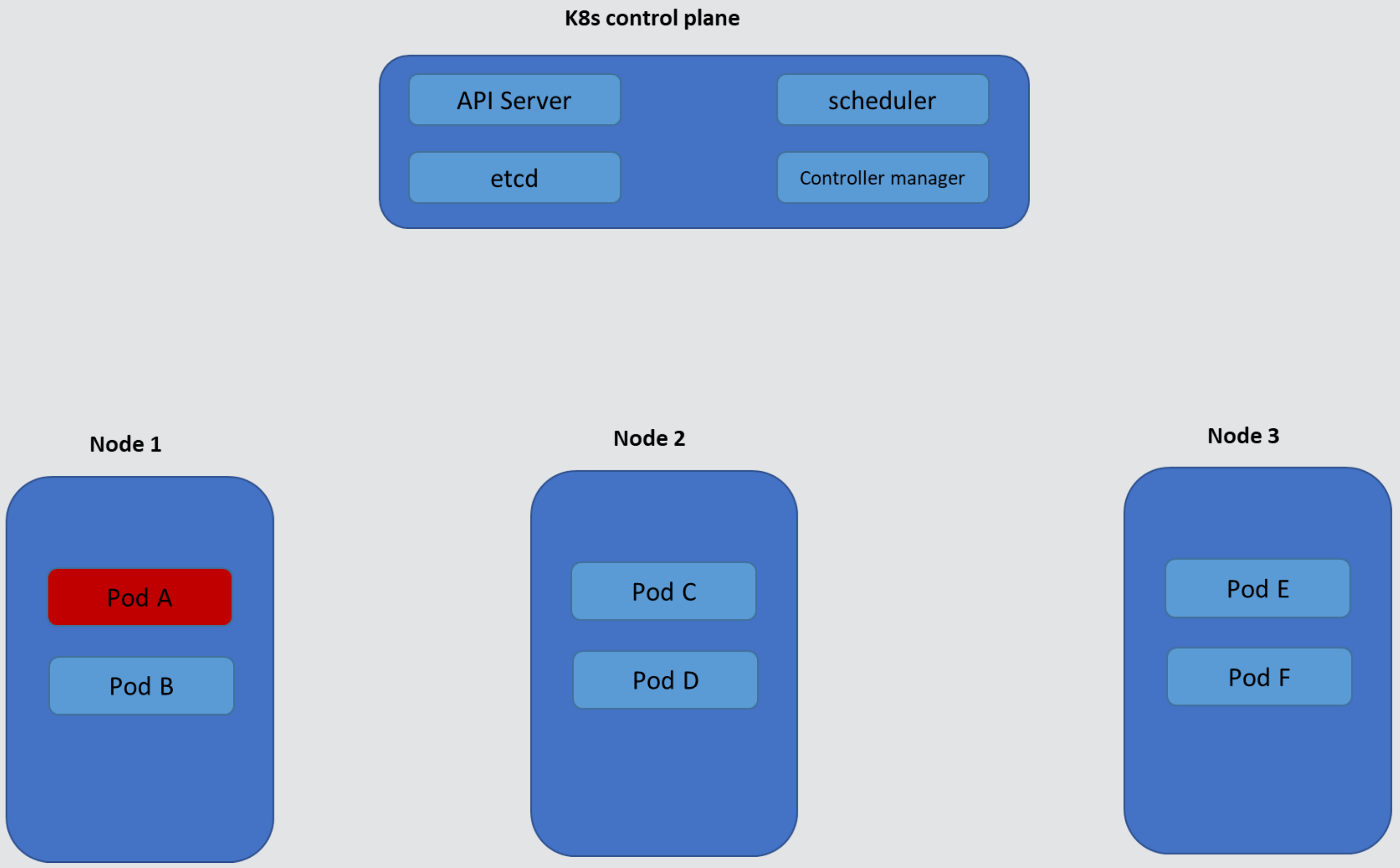
Inner-cluster lateral movement

How can attackers leverage a compromised pod for cluster takeover?



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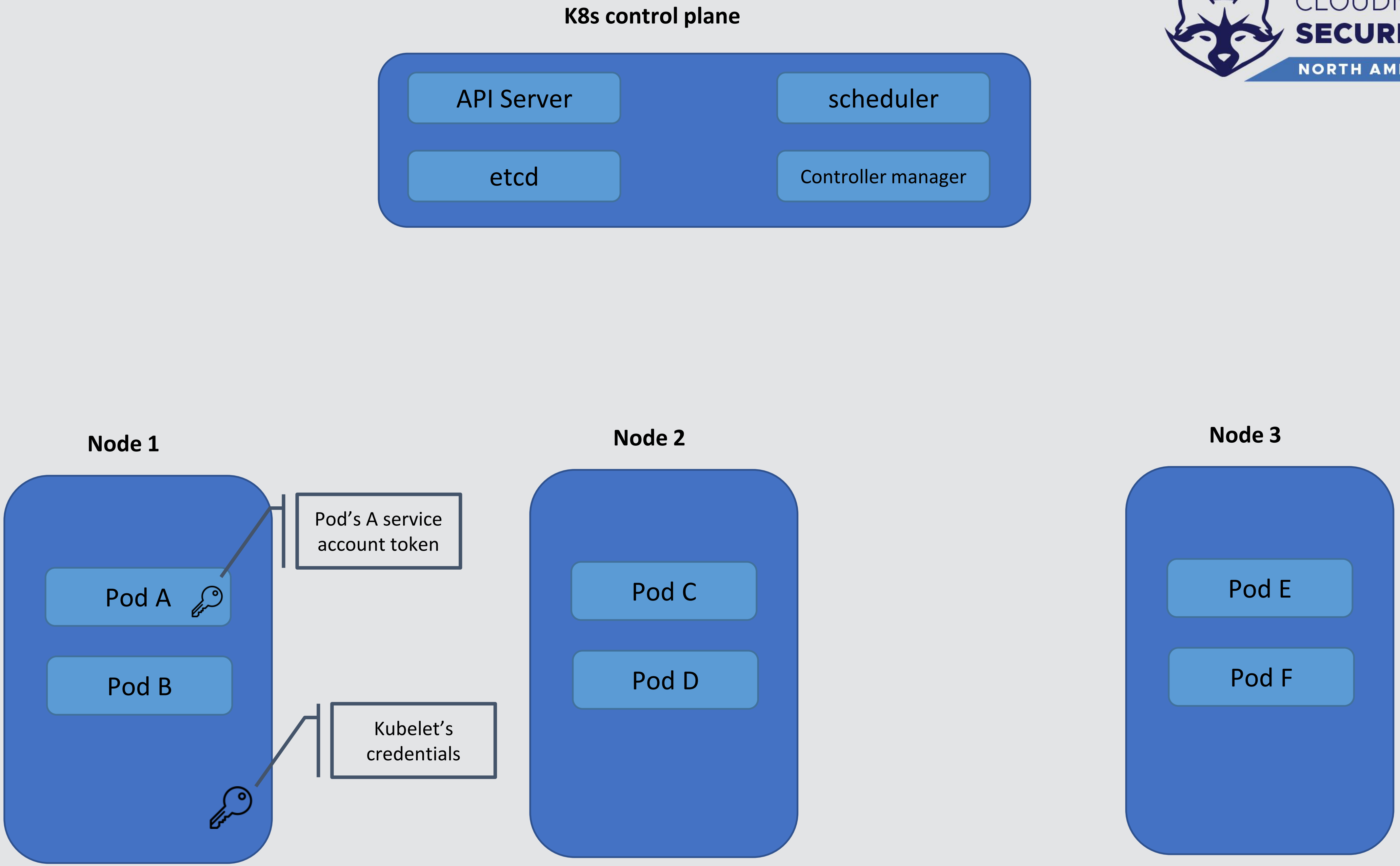

Inner-cluster lateral movement

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How can attackers leverage a compromised pod for cluster takeover?

Good news – it becomes more difficult:

- **Read secrets permission isn’t enough**
  - **Newer versions of K8s don’t create long-lived SA tokens as secret objects**

- **Node takeover ≠ cluster takeover**
  - **Node authorizer + NodeRestriction admission controller limit the permissions of the nodes’ identities**

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However, common misconfigurations still allow it.

Inner-cluster lateral movement

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- Node takeover ≠ cluster takeover
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However, common misconfigurations still allow it.

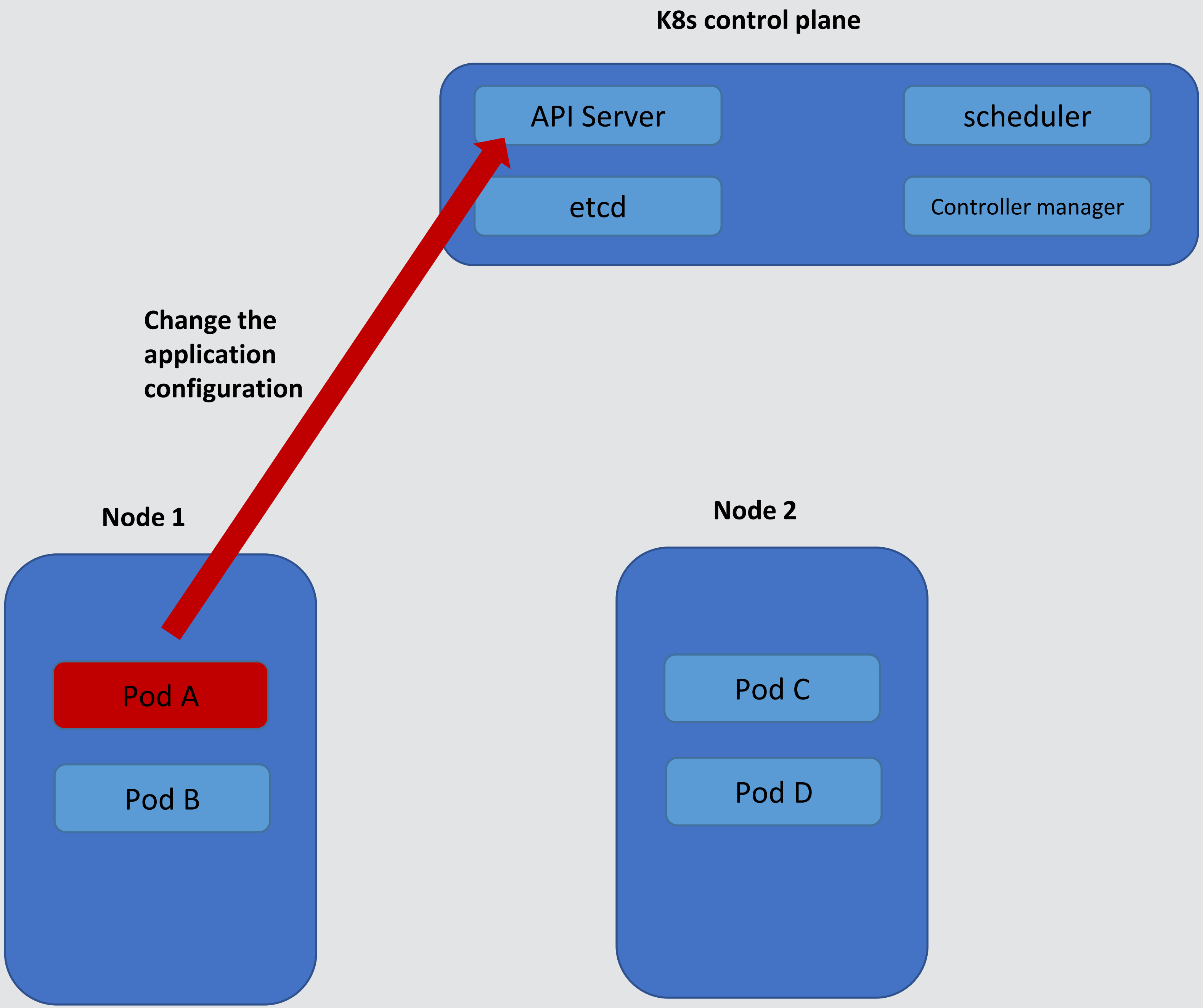
Let's see an example

Inner-cluster lateral movement

Example: Self-update permissions

```yaml
apiVersion: rbac.authorization.k8s.io/v1
kind: ClusterRole
metadata:
  name: app-update
rules:
- apiGroups:
  - 'apps'
  resources:
  - 'deployments'
  verbs:
  - 'update'
  resourceNames:
  - 'my-app'
```

- We've observed cases in which applications had permissions to update themselves.
- This allows the applications to change their own configuration. For example: update their configuration to be privileged, change their service account, schedule to specific node(s).
- Effectively, this can lead to cluster takeover


K8s control plane
API Server
scheduler
etcd
Controller manager
Change the application configuration
Node 1
Node 2
Node 3
Pod A
Pod B
Pod C
Pod D
Pod E
Pod F

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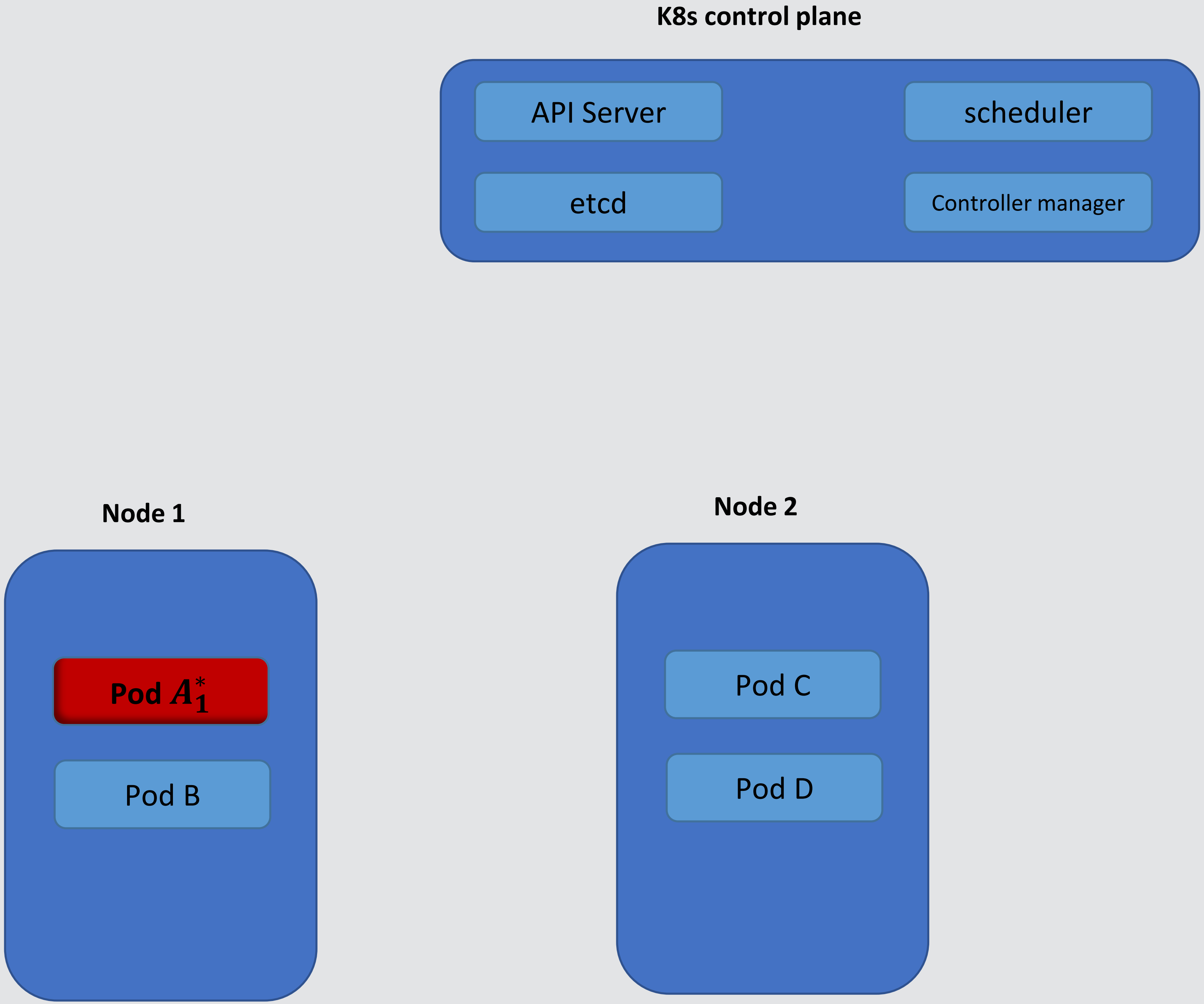
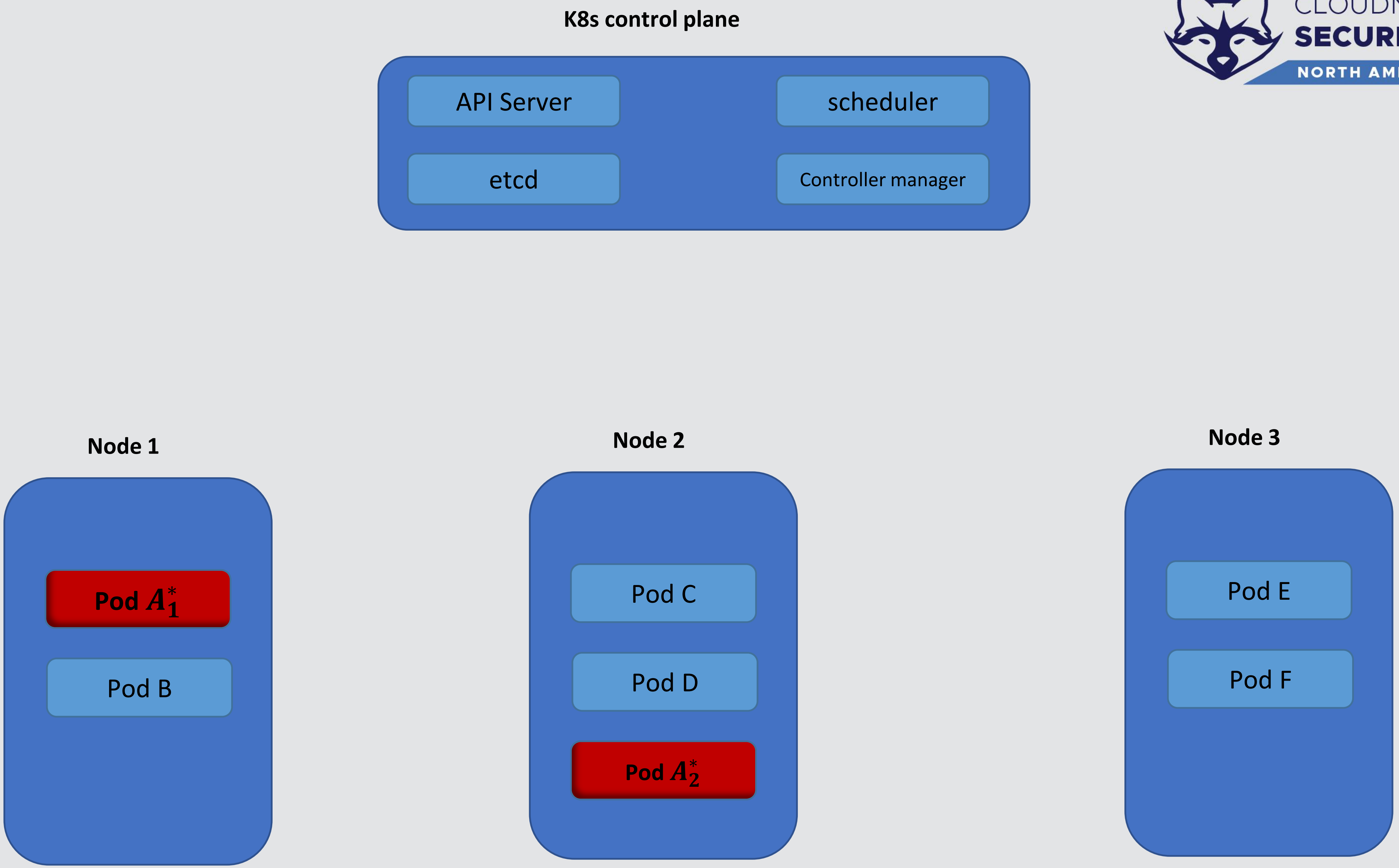
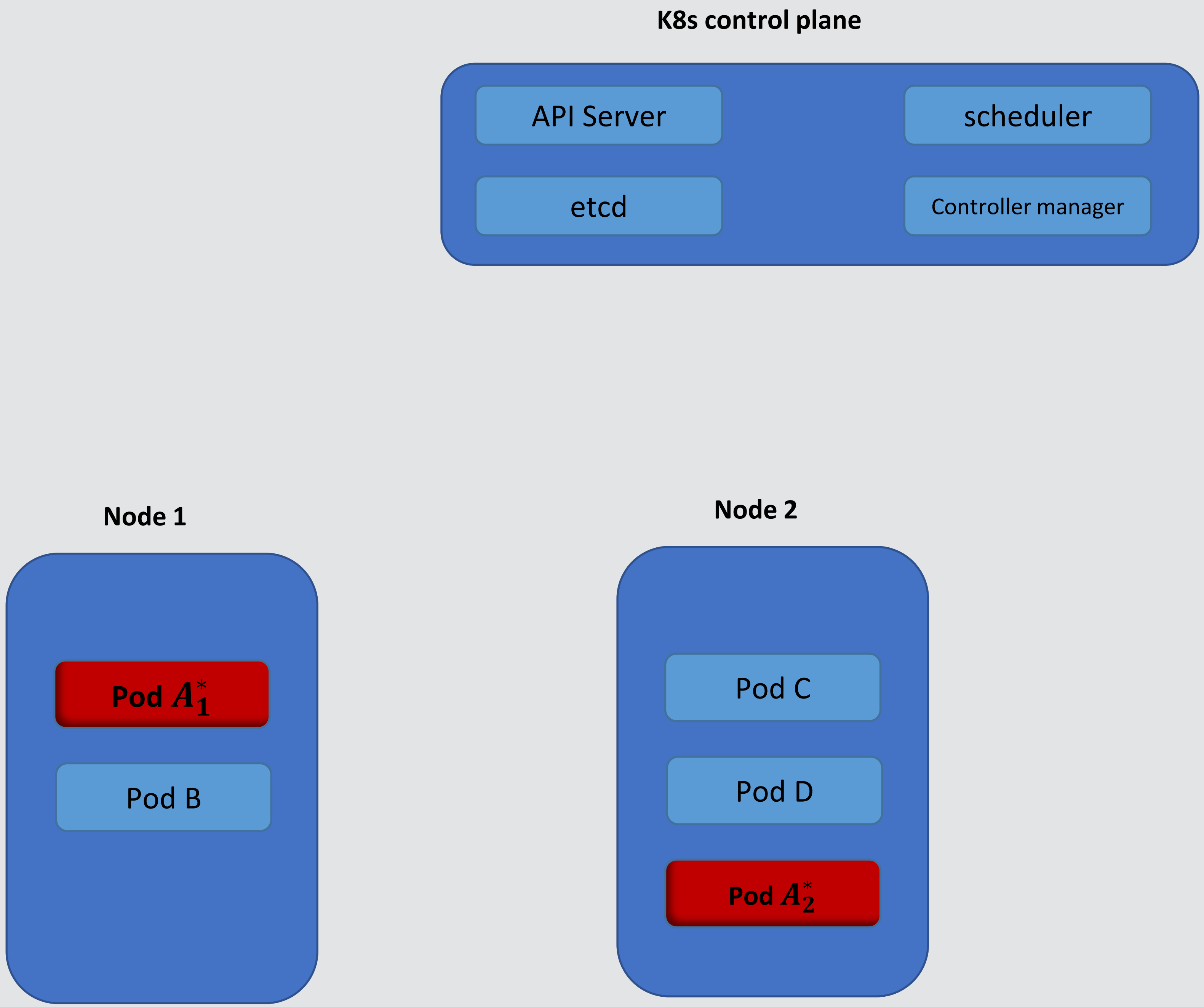
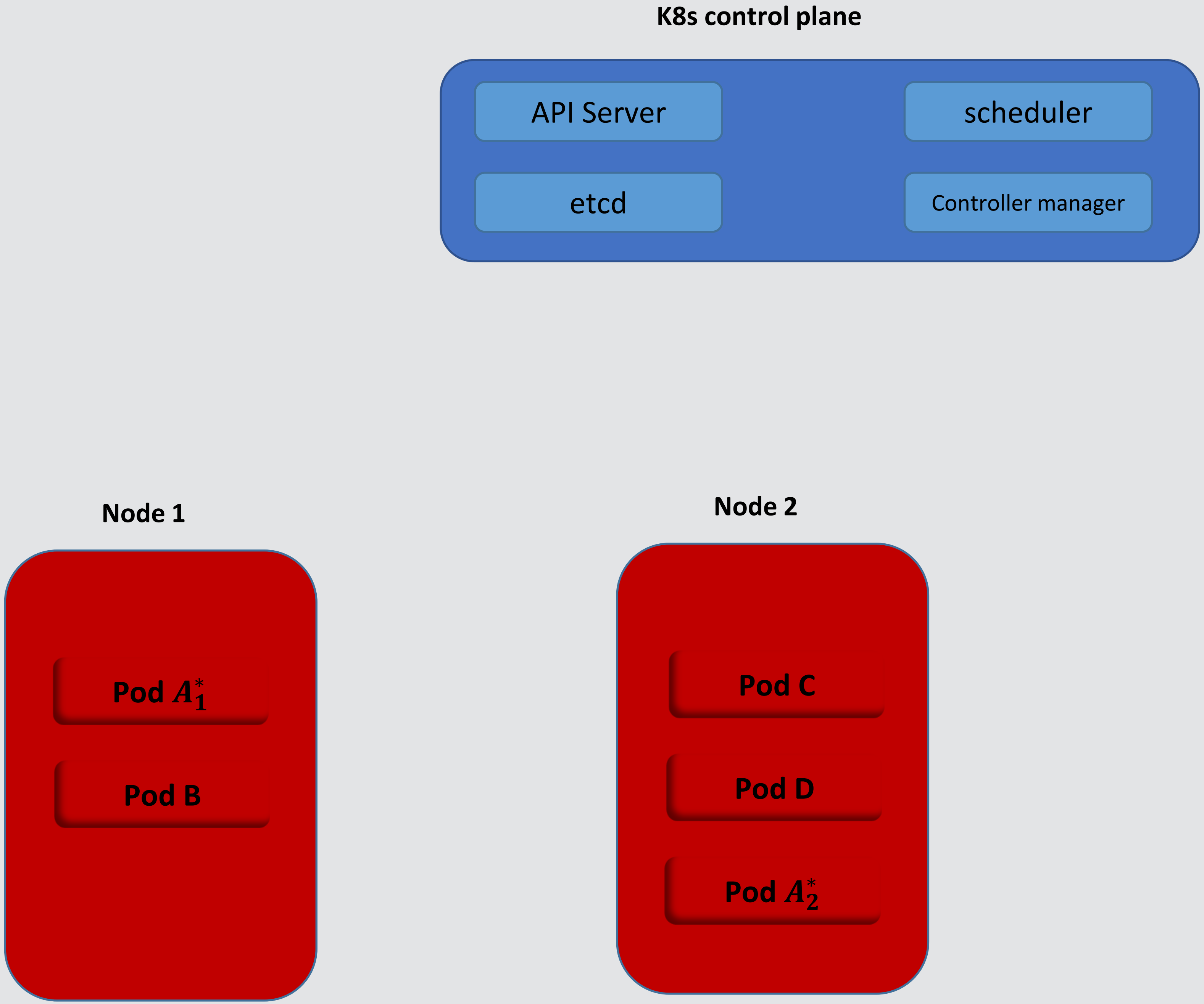



K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Pod A_1^*
Pod B
Node 2
Pod C
Pod D
Pod A_2^*
Node 3
Pod E
Pod F



K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Pod A_1^*
Pod B
Node 2
Pod C
Pod D
Pod A_2^*
Node 3
Pod E
Pod F
Pod A_3^*


K8s control plane
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Node 1
Pod A_1^*
Pod B
Node 2
Pod C
Pod D
Pod A_2^*
Node 3
Pod E
Pod F
Pod A_3^*

Inner-cluster lateral movement

Other sensitive permissions (partial list):

Permission	Allows to
Create pod\controllers	Use a privileged service account in a new pod
Update controller	Change the configuration to use a privileged service account
Create secrets & get\list secret	Create a new long-lived token for SA and read its value
Create serviceaccounts/token	Create a short-lived token for SA

Cluster-to-cloud lateral movement

Cluster-to-cloud lateral movement

How tightly coupled are Kubernetes clusters with their Cloud hosting environment?

1. Managed clusters use cloud services for their ongoing operation (e.g., VMs allocation)
2. Workloads in Kubernetes may need access to cloud resources (e.g., cloud storage, cloud secret store, etc.)

Cluster-to-cloud lateral movement

How do workloads in Kubernetes authenticate with the cloud?

We’ll go over the following authentication methods:

1. Storing cloud identity credential on the node
2. Direct access to IMDS
3. Indirect access to IMDS
4. Using OIDC (identity federation)

Cluster-to-cloud lateral movement

Storing cloud identity credential on the node

- Used to be the default authentication method in AKS in the past.
- In this method, each Kubernetes node stores a file with service principal (SPN) credentials. SPNs are Azure application identities.
- By default, this SPN has Contributor role for the node resource group.
- Users can bring their own SPN or grant more permissions to the SPN if their applications need access to more cloud resources. For example: add permissions to a cloud storage.

Cluster-to-cloud lateral movement

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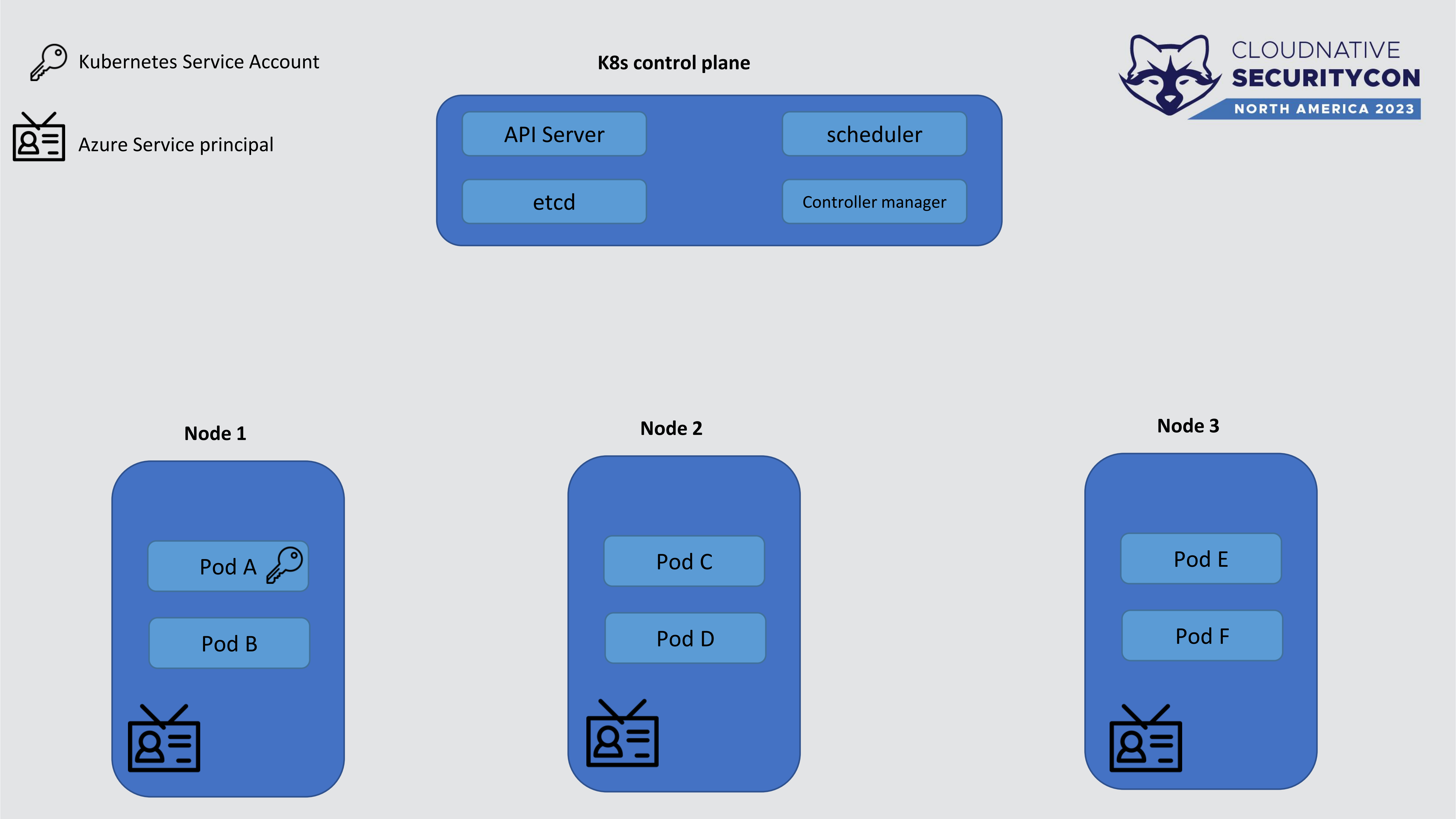
→ **Access to the node's File System meant elevation to Contributor Role on the K8s resource group**



Kubernetes Service Account
Azure Service principal
K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Pod A
Pod B
Node 2
Pod C
Pod D
Node 3
Pod E
Pod F
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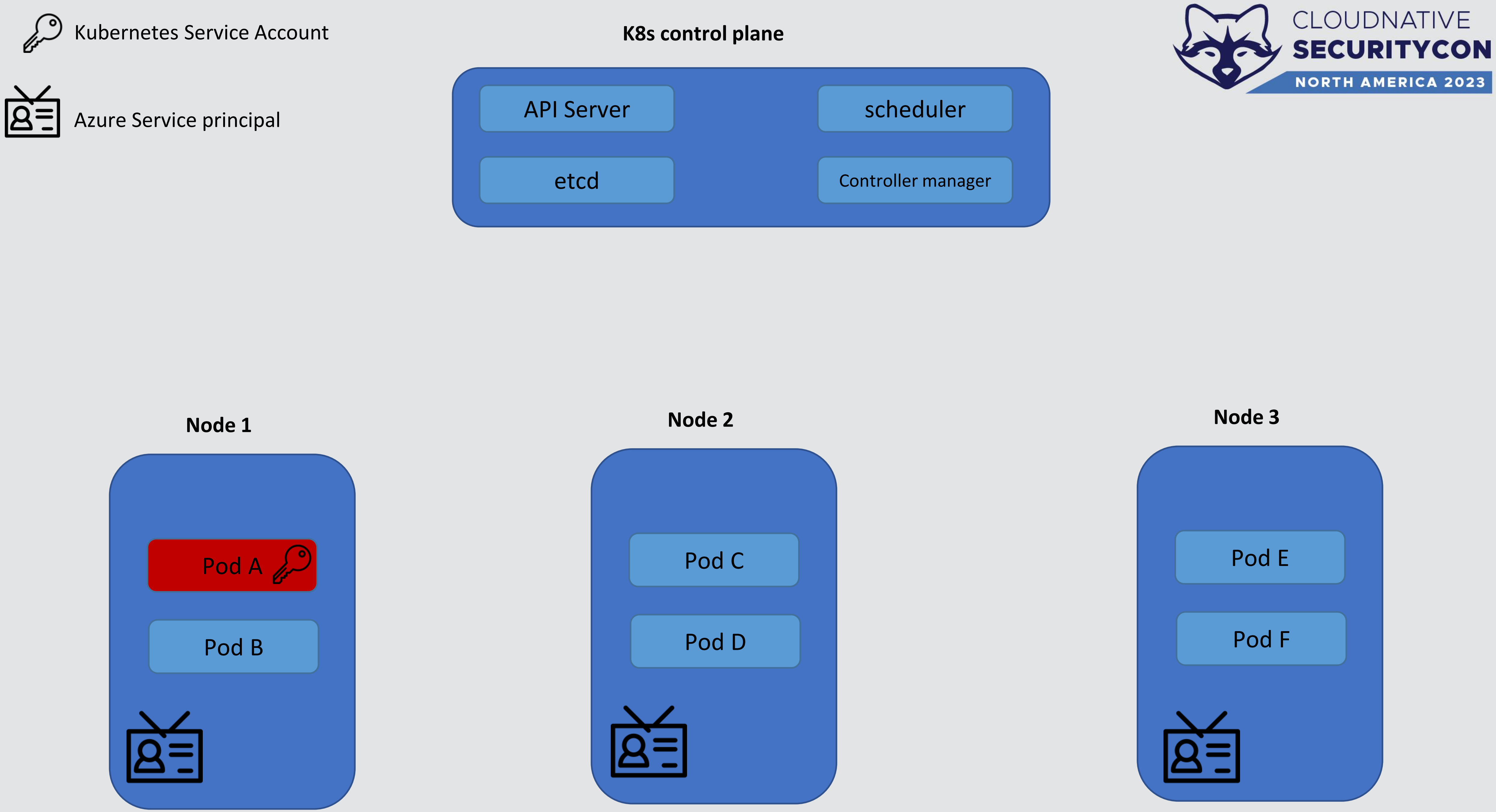
Kubernetes Service Account
Azure Service principal
K8s control plane
API Server
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Controller manager
CLOUDNATIVE SECURITYCON NORTH AMERICA 2023
Node 1
Pod A
Pod B
Node 2
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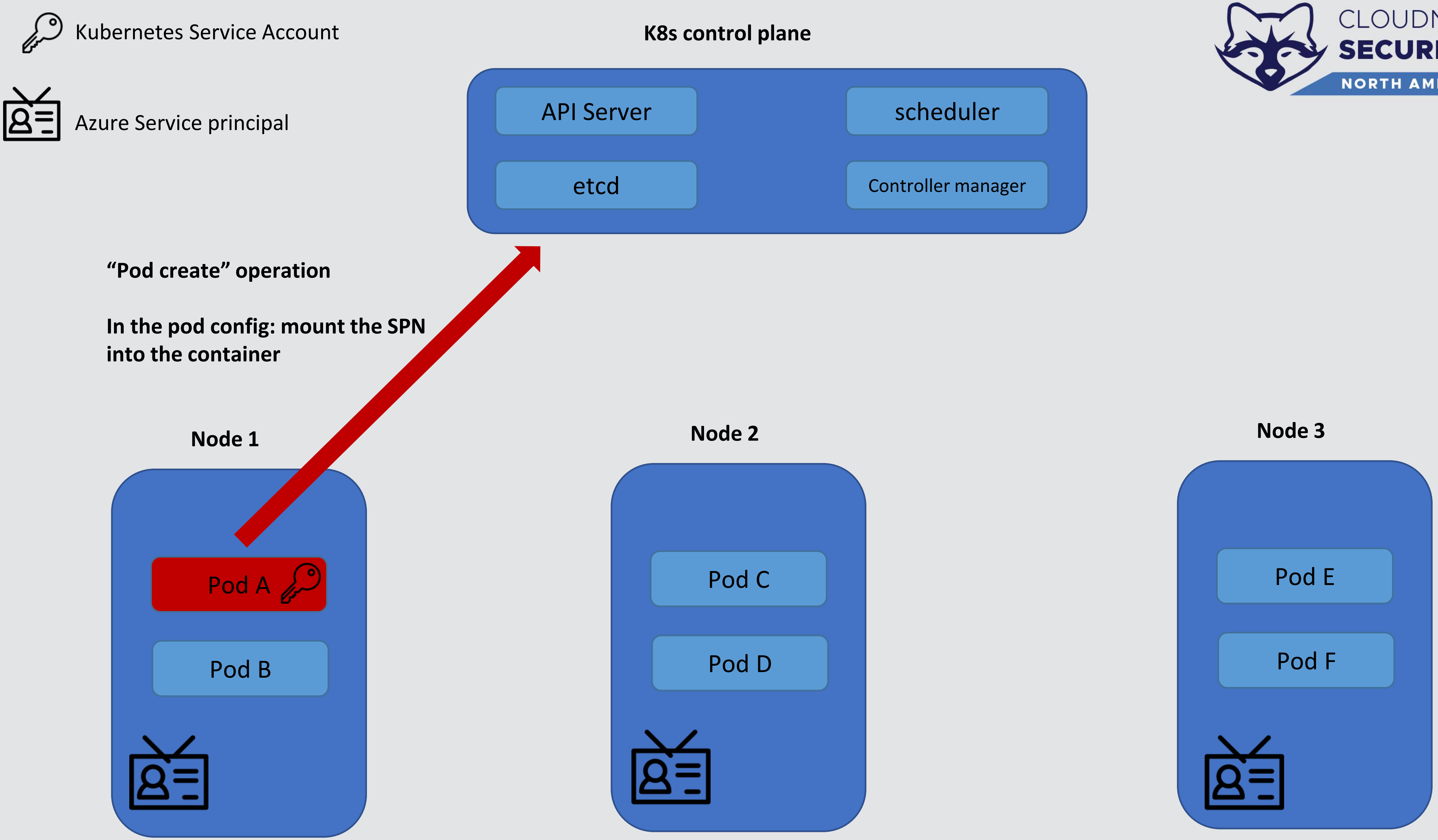
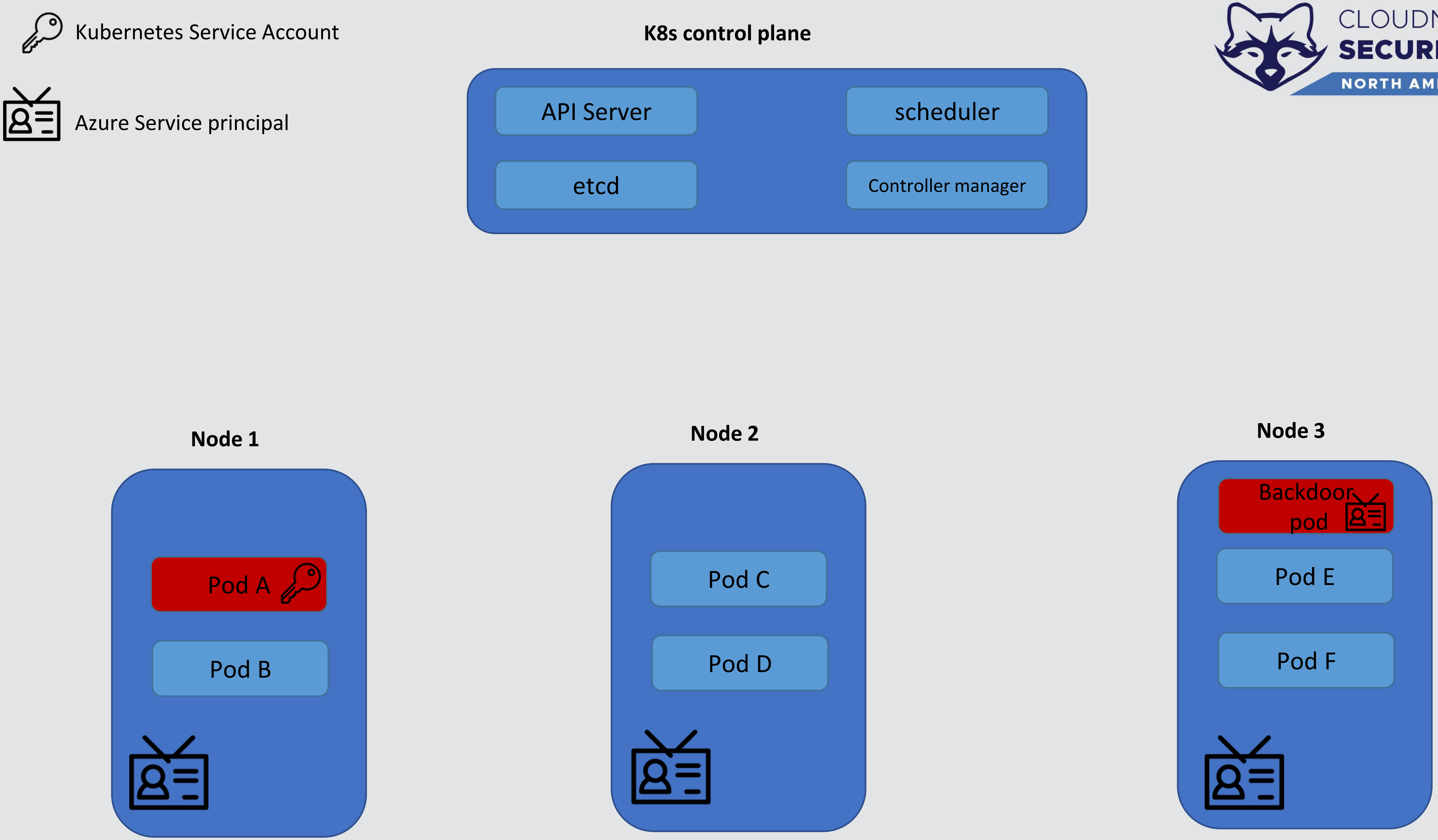
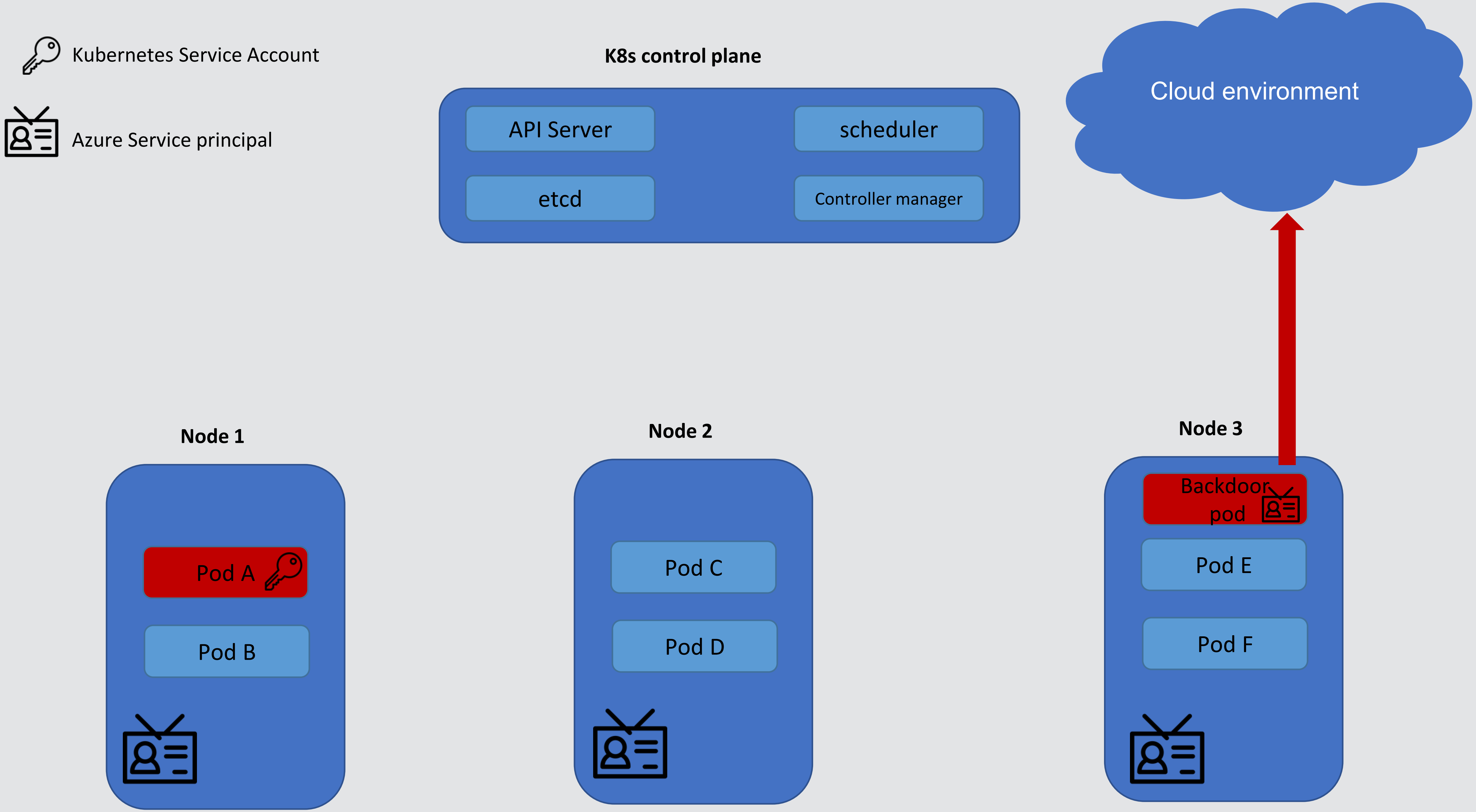
Node 3
Pod E
Pod F



Kubernetes Service Account
Azure Service principal
K8s control plane
API Server
scheduler
etcd
Controller manager
"Pod create" operation
In the pod config: mount the SPN into the container
Node 1
Pod A
Pod B
Node 2
Pod C
Pod D
Node 3
Pod E
Pod F


Kubernetes Service Account
Azure Service principal
K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Pod A
Pod B
Node 2
Pod C
Pod D
Node 3
Backdoor pod
Pod E
Pod F



Kubernetes Service Account
Azure Service principal
K8s control plane
API Server
scheduler
etcd
Controller manager
Cloud environment
Node 1
Pod A
Pod B
Node 2
Pod C
Pod D
Node 3
Backdoor pod
Pod E
Pod F

Cluster-to-cloud lateral movement

Direct access to IMDS

Cluster-to-cloud lateral movement

Direct access to IMDS

- The metadata service is a special endpoint that is accessible to VMs, allowing them to retrieve information about the VM.
- Implemented by all major cloud providers.
- Metadata service allows retrieving tokens for the cloud identity that is attached to the VM:
  - Azure: 169.254.169.254/metadata/identity/oauth2
  - AWS: 169.254.169.254/latest/meta-data/iam/security-credentials
  - GCP: metadata.google.internal/computeMetadata/v1/instance/service-accounts
- Querying the metadata service doesn't require any authentication.

Cluster-to-cloud lateral movement

Direct access to IMDS

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- In managed K8s clusters, the nodes are VMs which can access to their metadata service.
- By default, pods can access to the metadata service of their nodes.
- Thus, pods can acquire tokens of cloud identities attached to the nodes.
- The permissions of the identities depend on the cloud provider and the specific environment.

Cluster-to-cloud lateral movement

Direct access to IMDS - AKS

- AKS uses several managed identities to operate the cluster.

- Users can change the default permissions of those identities, or alternatively attach additional managed identities to the nodes.

Cluster-to-cloud lateral movement

Direct access to IMDS - AKS

Identity	Name	Use case	Default permissions	Bring your own identity
Control plane	AKS Cluster Name	Used by AKS control plane components to manage cluster resources including ingress load balancers and AKS managed public IPs, Cluster Autoscaler, Azure Disk & File CSI drivers	Contributor role for Node resource group	Supported
Kubelet	AKS Cluster Name-agentpool	Authentication with Azure Container Registry (ACR)	NA (for kubernetes v1.15+)	Supported
Add-on	AzureNPM	No identity required	NA	No
Add-on	AzureCNI network monitoring	No identity required	NA	No
Add-on	azure-policy (gatekeeper)	No identity required	NA	No
Add-on	azure-policy	No identity required	NA	No
Add-on	Calico	No identity required	NA	No
Add-on	Dashboard	No identity required	NA	No
Add-on	HTTPApplicationRouting	Manages required network resources	Reader role for node resource group, contributor role for DNS zone	No
Add-on	Ingress application gateway	Manages required network resources	Contributor role for node resource group	No
Add-on	omsagent	Used to send AKS metrics to Azure Monitor	Monitoring Metrics Publisher role	No
Add-on	Virtual-Node (ACIConnector)	Manages required network resources for Azure Container Instances (ACI)	Contributor role for node resource group	No
OSS project	aad-pod-identity	Enables applications to access cloud resources securely with Microsoft Azure Active Directory (Azure AD)	NA	Steps to grant permission at https://github.com/Azure/aad-pod-identity#role-assignment.

Cluster-to-cloud lateral movement

Direct access to IMDS - EKS

- EKS uses EC2 Roles for the Kubernetes nodes.

- By default, the EC2 Role has the following policies:
  - AmazonEC2ContainerRegistryReadOnly - Pull permissions to the container registry
  - AmazonEKSWorkerNodePolicy - Read permissions of the compute environment (EC2, VPC, etc.)
  - AmazonEKS_CNI_Policy – Attach network interfaces and IPs to VMs

- Users can add more policies, if their containers require access to cloud resources.

Cluster-to-cloud lateral movement

Direct access to IMDS - GKE

- GKE uses IAM service accounts to authenticate with the cloud.
- By default, all the VMs in a project, including the Kubernetes nodes, share a default SA.
- This SA has Editor role for the project.
- While the access scope limits the permissions, they are still powerful by default:

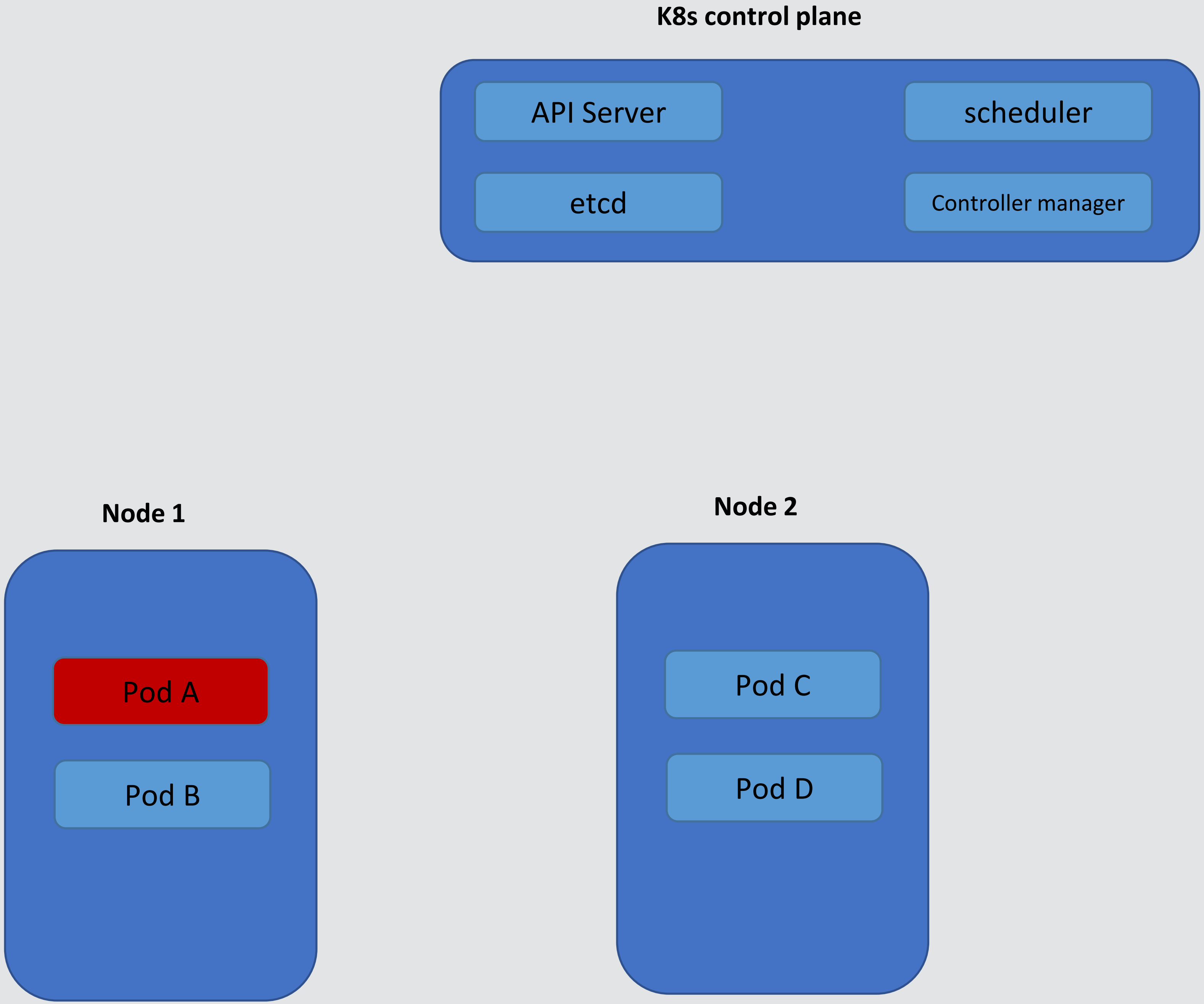
Security

Sandbox with gVisor	Disabled	
Service account	default	
Access scopes	Service Control	Enabled
	Service Management	Read Only
	Stackdriver Logging API	Write Only
	Stackdriver Monitoring API	Full
	Stackdriver Trace	Write Only
	Storage	Read Only
GKE Metadata Server	Disabled	
Integrity monitoring	Enabled	
Secure boot	Disabled	

Cluster-to-cloud lateral movement

Direct access to IMDS

How does lateral movement from the cluster to the cloud would look like?


K8s control plane
API Server
scheduler
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Node 1
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Pod B
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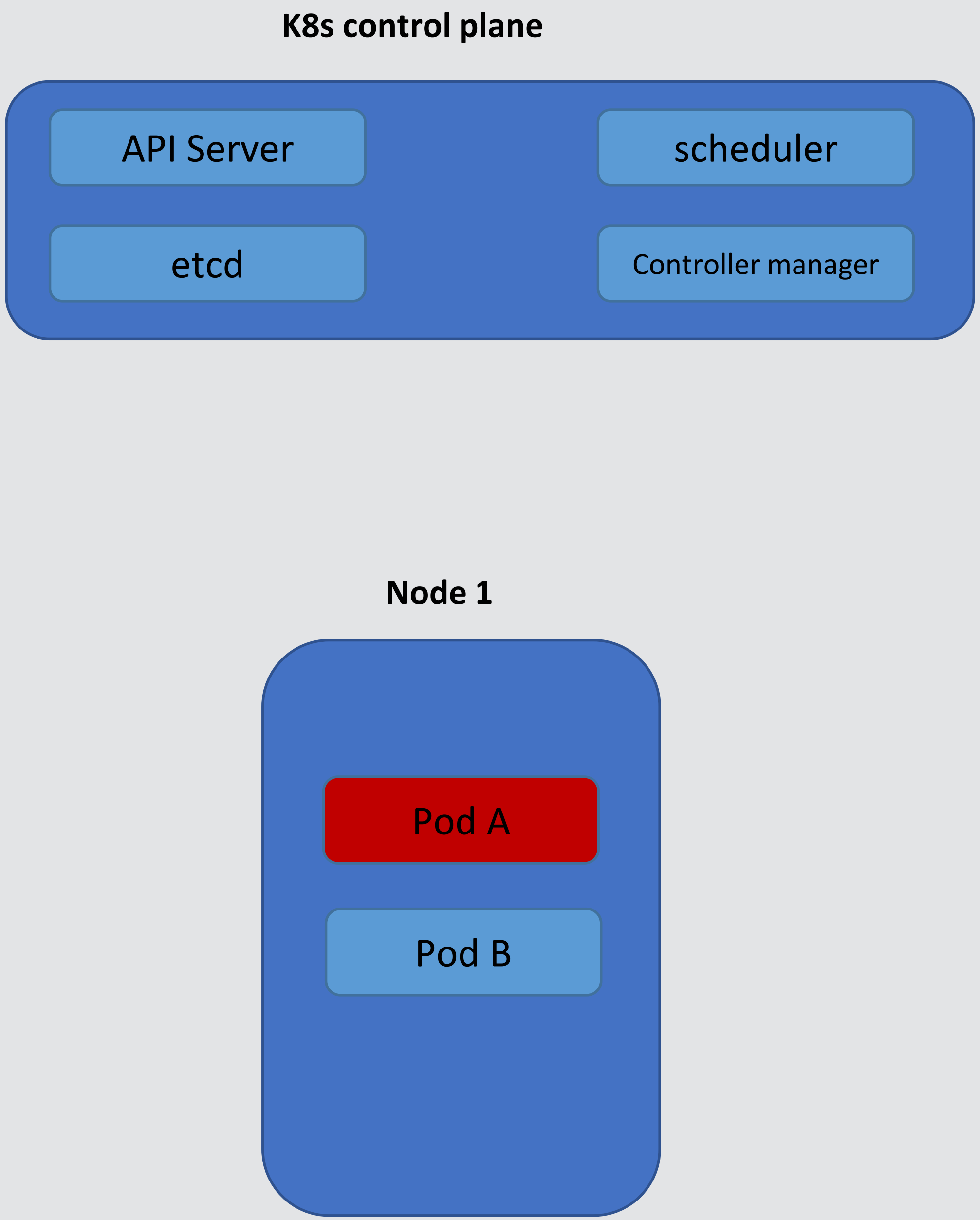
K8s control plane
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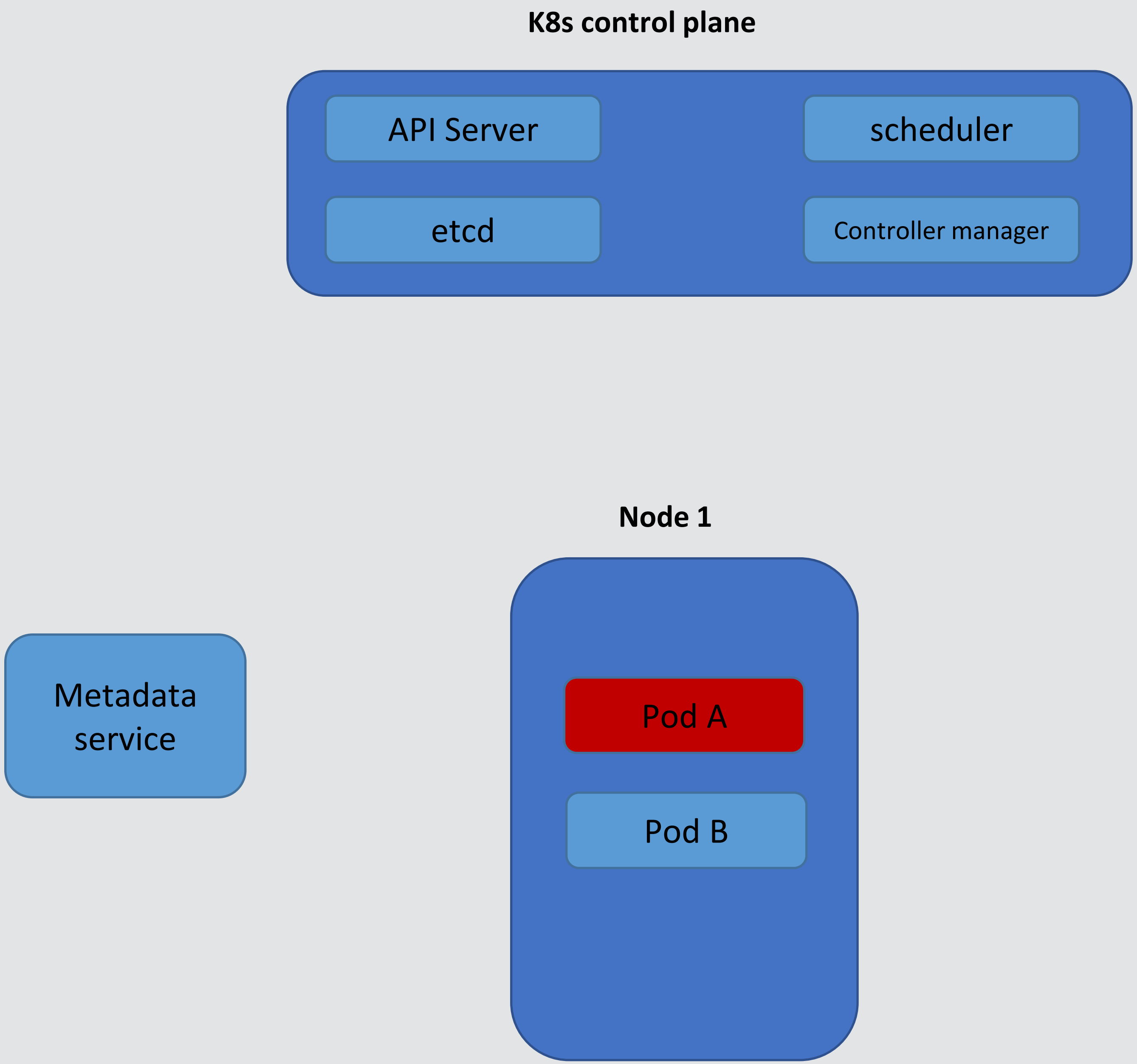
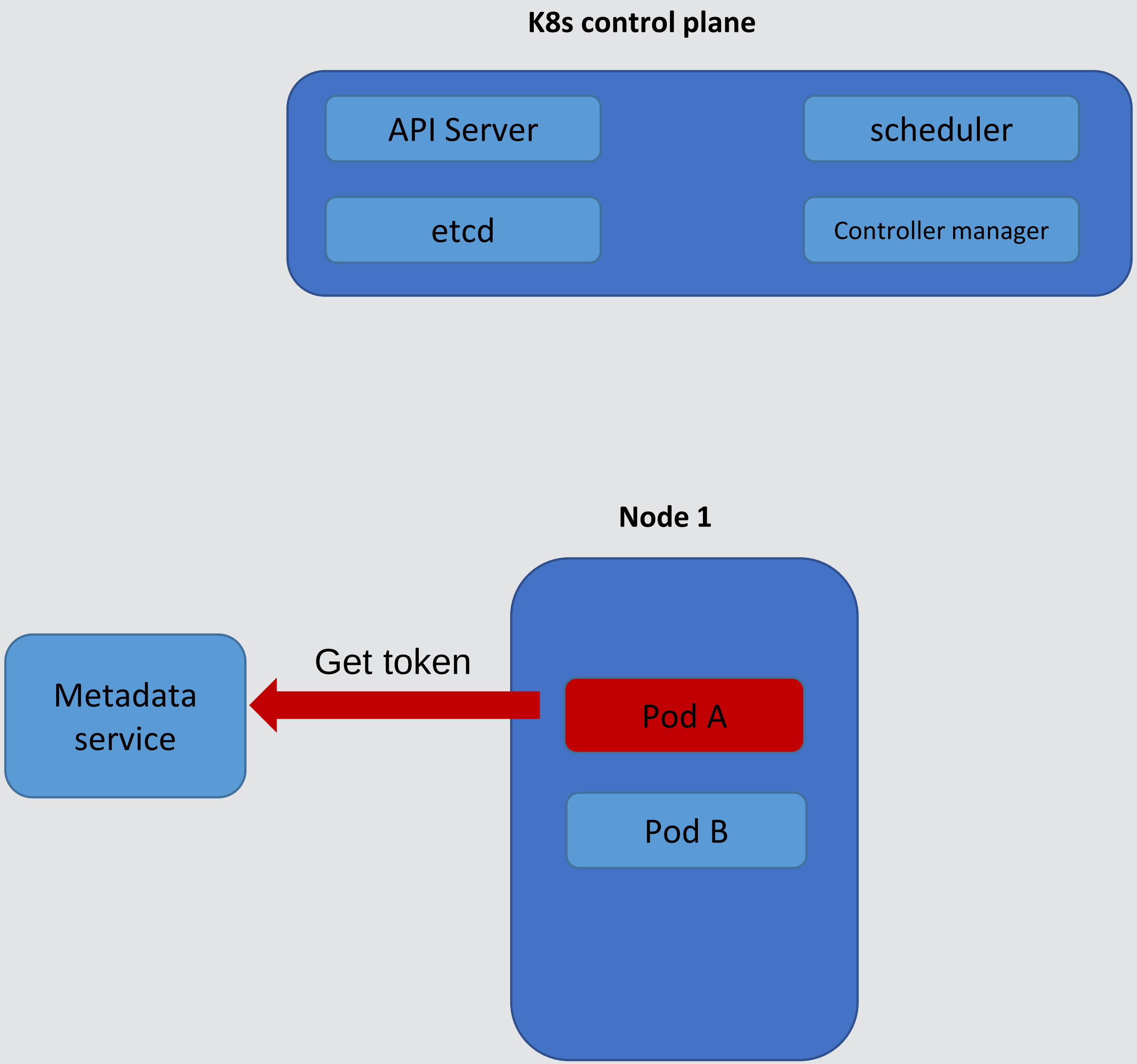
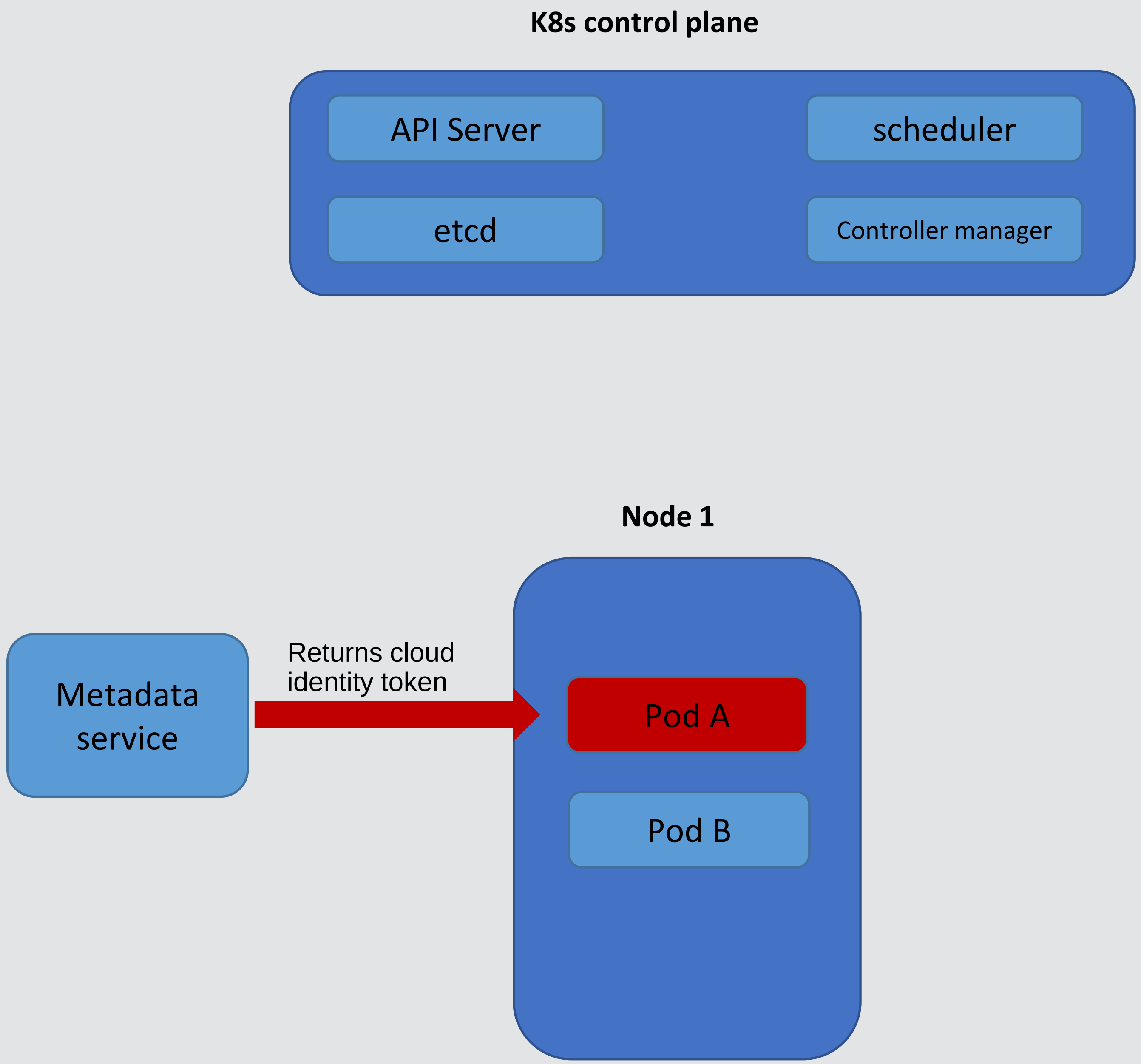
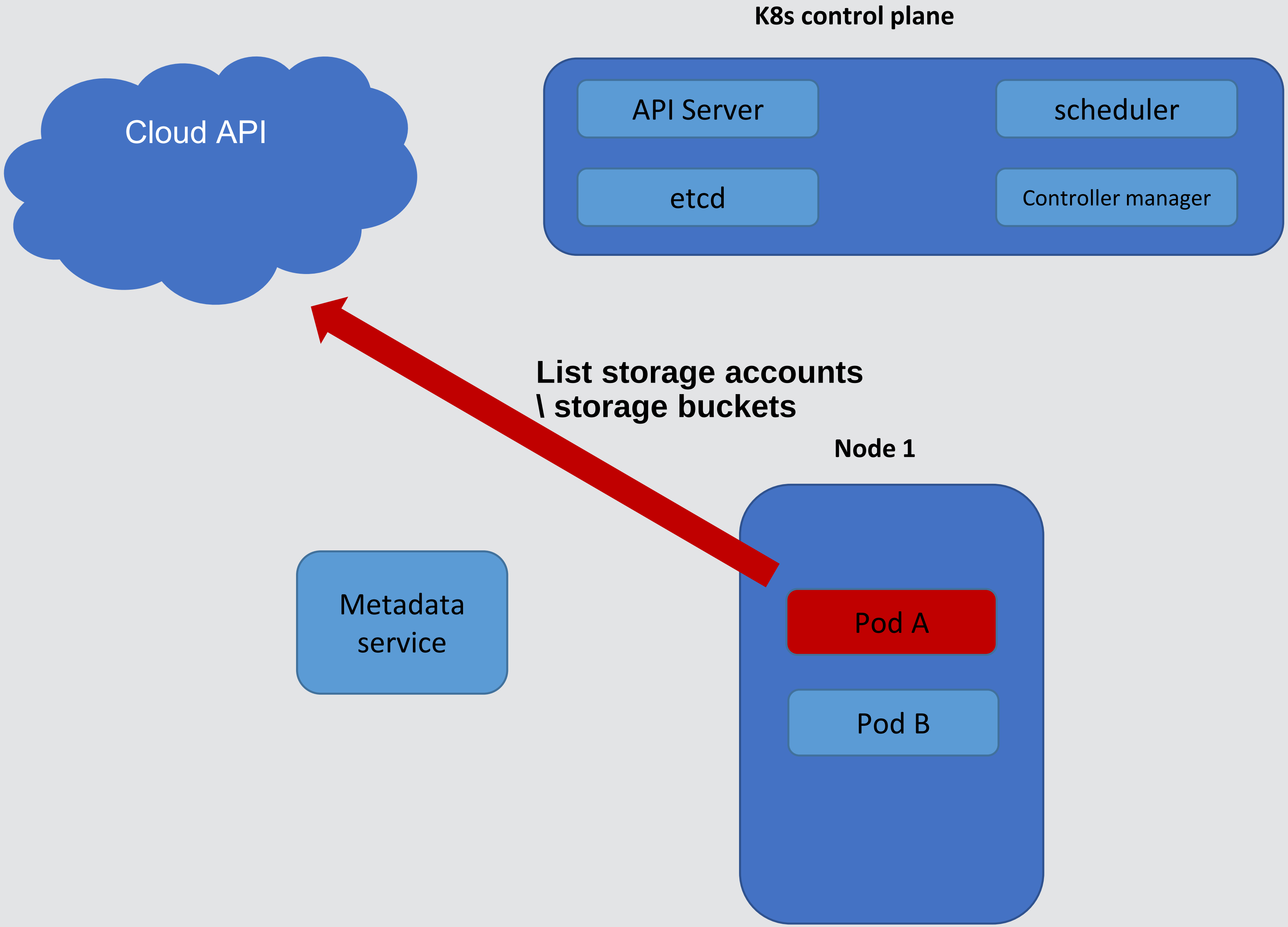
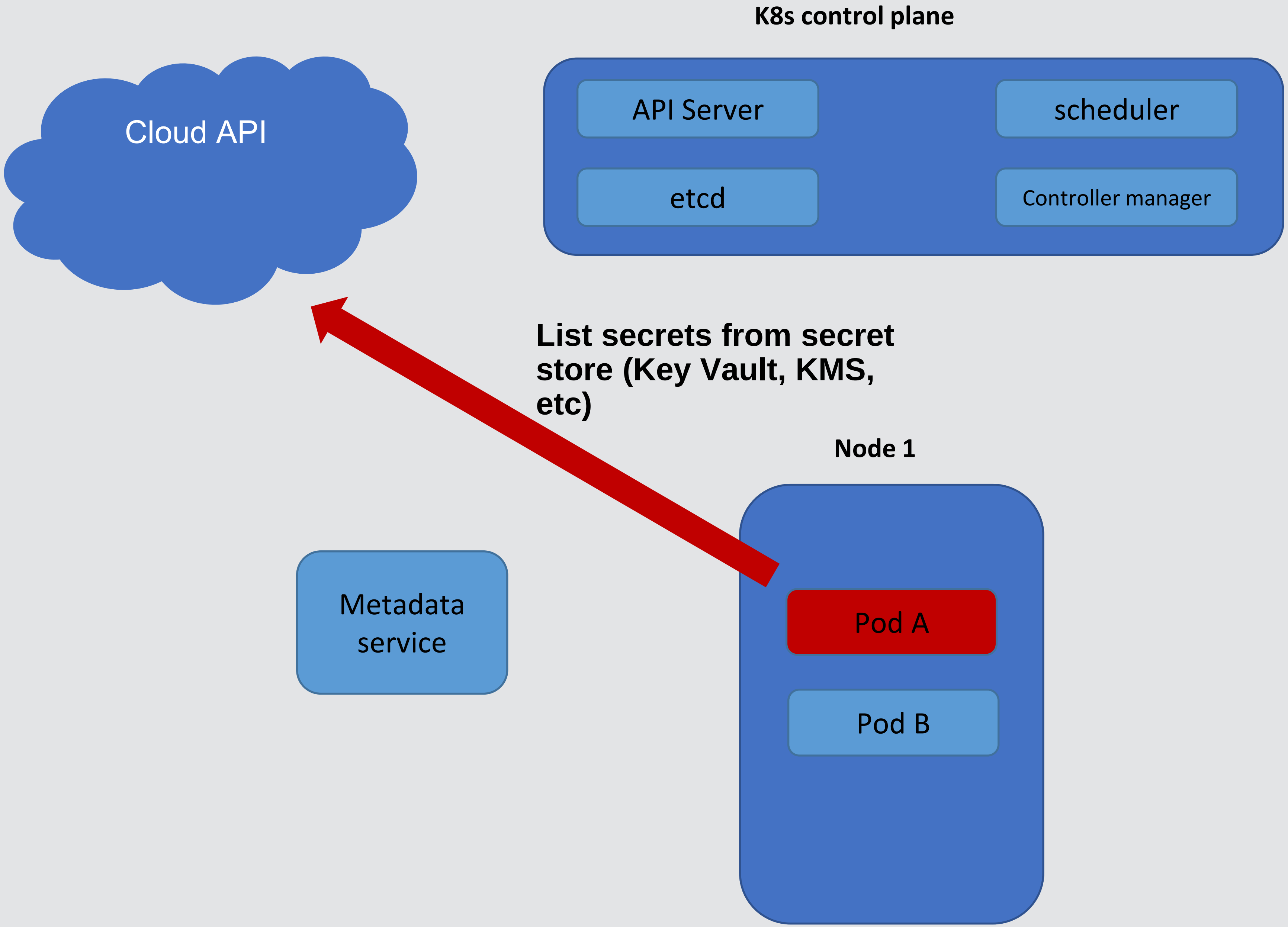
Controller manager
Node 1
Pod A
Pod B


K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Metadata service
Pod A
Pod B

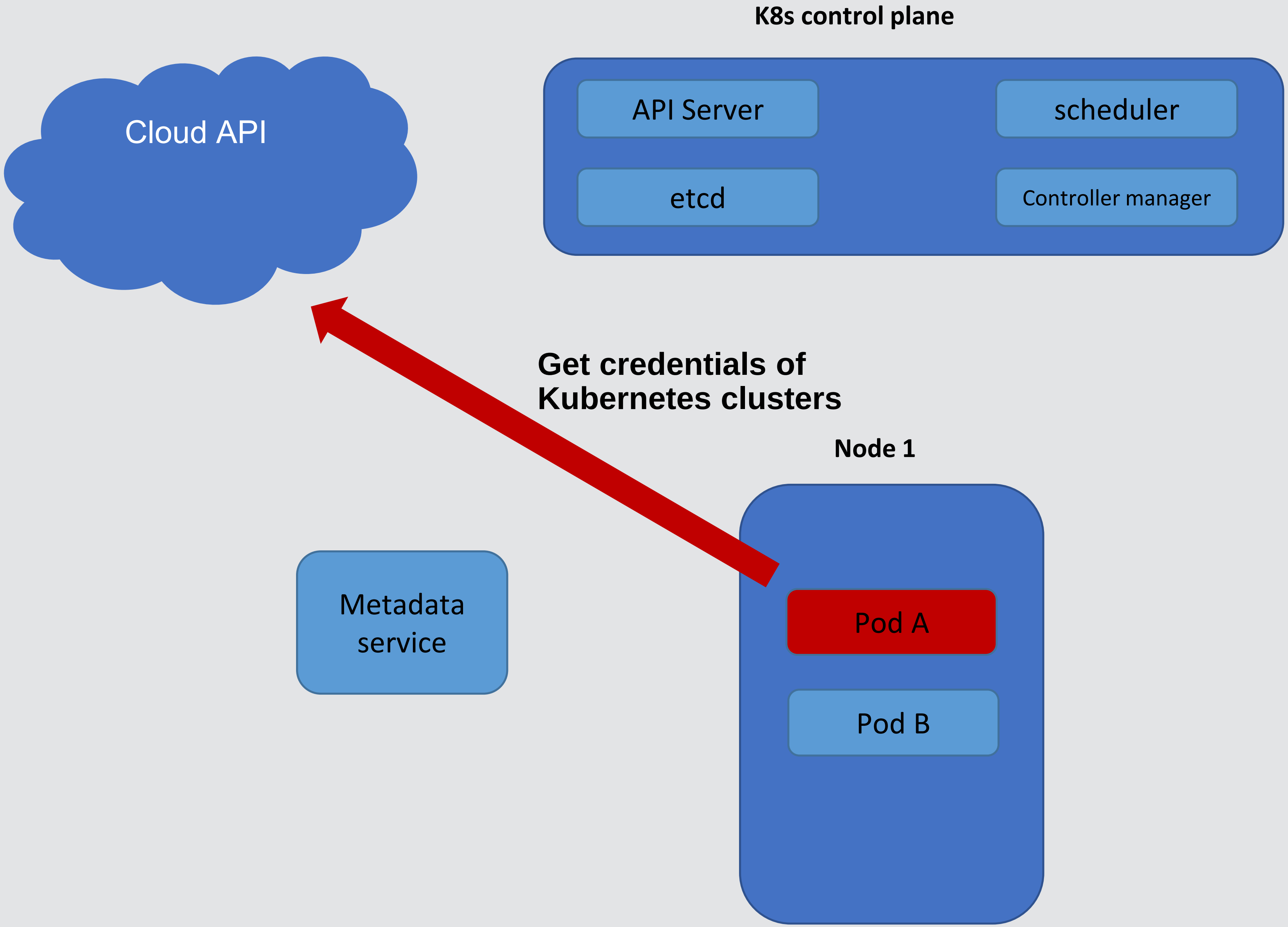

K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Metadata service
Get token
Pod A
Pod B


K8s control plane
API Server
scheduler
etcd
Controller manager
Node 1
Metadata service
Returns cloud identity token
Pod A
Pod B


K8s control plane
Cloud API
API Server
scheduler
etcd
Controller manager
List storage accounts
\ storage buckets
Node 1
Metadata service
Pod A
Pod B



K8s control plane
API Server
scheduler
etcd
Controller manager
Cloud API
List secrets from secret store (Key Vault, KMS, etc)
Node 1
Metadata service
Pod A
Pod B


K8s control plane
API Server
scheduler
etcd
Controller manager
Cloud API
Get credentials of
Kubernetes clusters
Node 1
Metadata
service
Pod A
Pod B

Cluster-to-cloud lateral movement

Direct access to IMDS

The problem

- Pods can freely access to their node's cloud identities.
- All pods share the same cloud identities (the node's identities).

What we want:

- Allocate a specific identity to each pod (that needs access to cloud resources) with the minimal needed permissions.
- Make sure pods can only acquire tokens for their own identities.

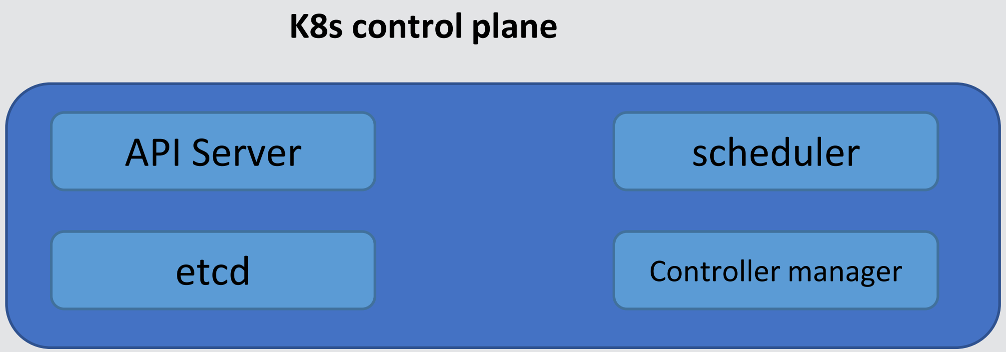
Cluster-to-cloud lateral movement

Indirect access to IMDS

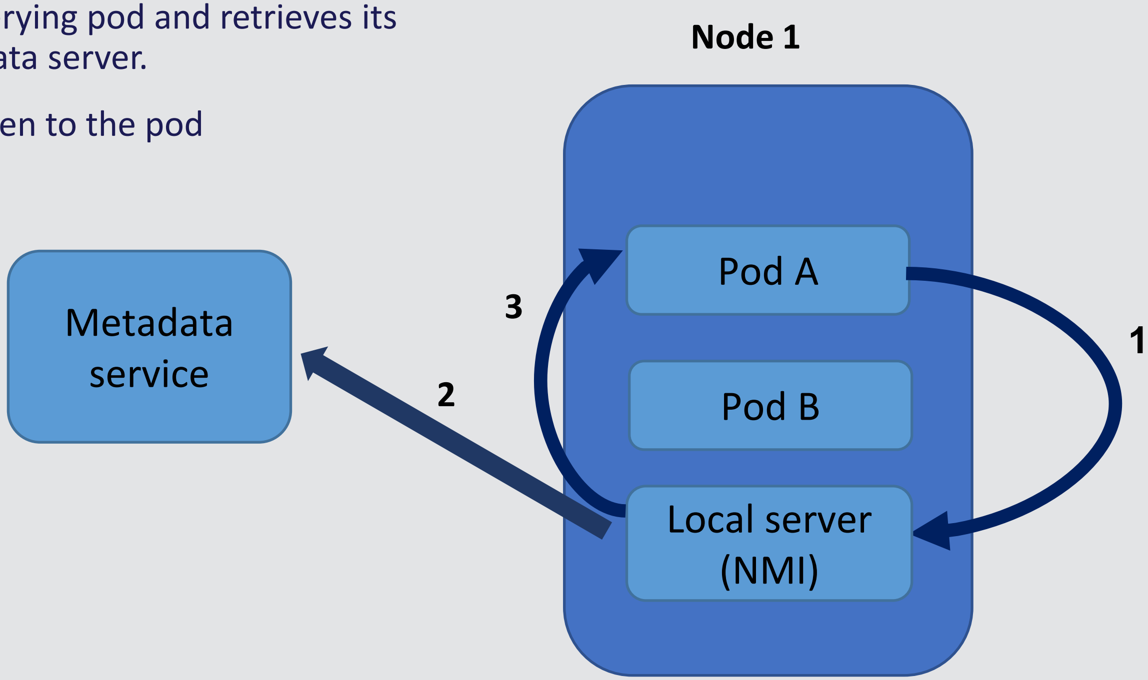
Cluster-to-cloud lateral movement

Indirect access to IMDS

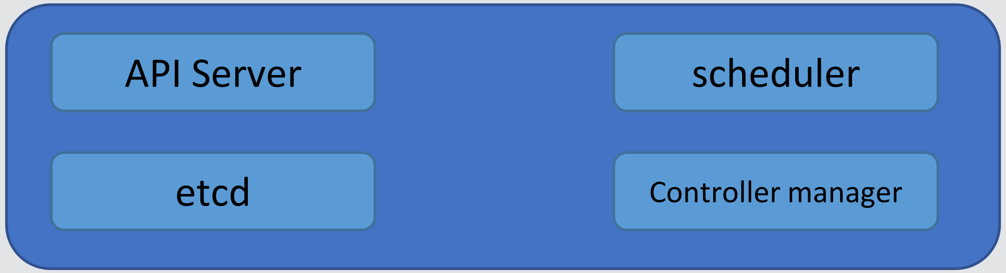
- Users allocate different identities to the various applications in the cluster.
- When pods query IMDS, the traffic is intercepted and redirected to a local server in the cluster.
- The local server is K8s-aware, thus can identify the querying pod.
- The local server queries IMDS on behalf of the pod and request the pod-specific identity.
- This concept was implemented in Azure by AAD Pod Identity [**in deprecation**].



1. Requests to the metadata server are intercepted and sent to the NMI pod (by modifying the IPTables of the node).
2. NMI recognize the querying pod and retrieves its token from the metadata server.
3. NMI send back the token to the pod



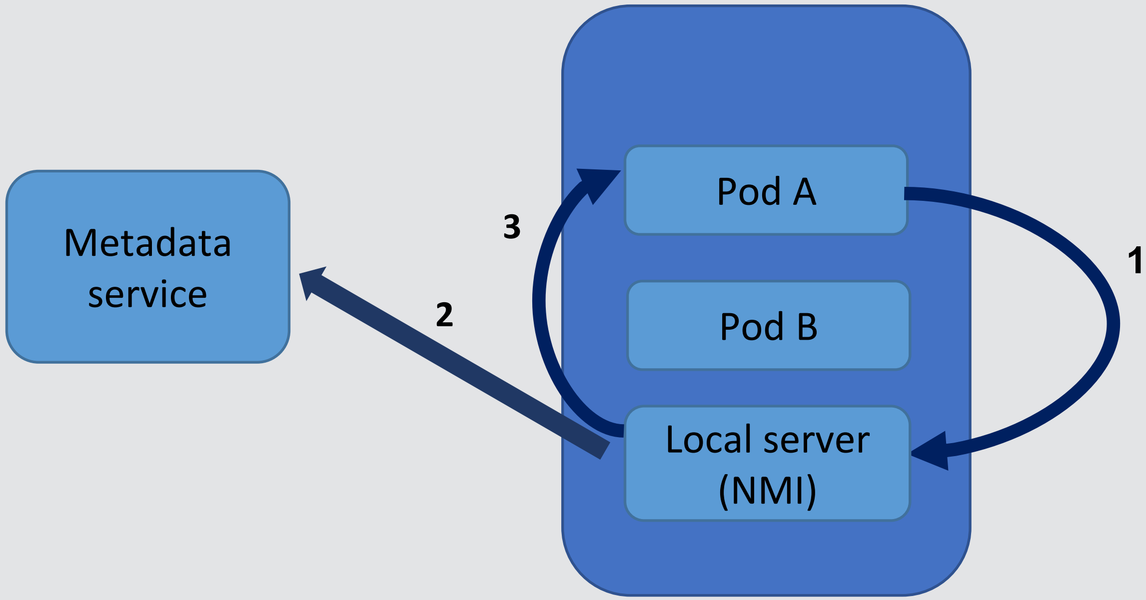
K8s control plane



Limitations

1. Works only for Linux containers (uses IPTables).
2. Not supported by all Kubernetes network configuration.

Node 1



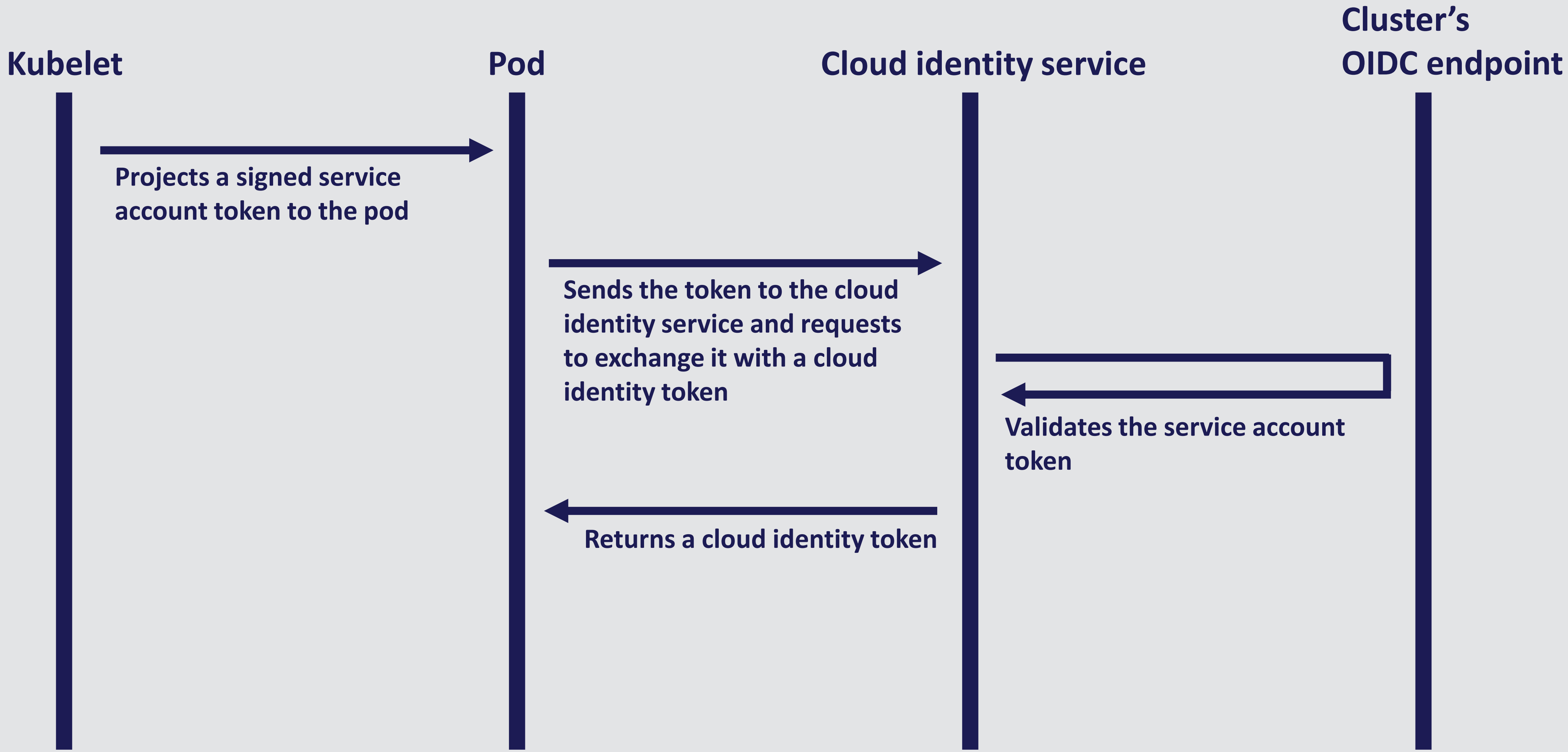
Cluster-to-cloud lateral movement

Using OIDC (identity federation)

- Implemented by all major cloud providers:
  - Azure: AAD workload identity
  - AWS: IAM roles for service accounts (IRSA)
  - GCP: Workload identity
- The Kubernetes cluster is used as an OIDC identity provider (IdP).
- Trust relation is created such as the cloud identity platform (AAD, AWS IAM, GCP IAM) trusts the service accounts issued by the K8s cluster.
- This trust relation allows applications in the cluster to exchange a K8s service account token with a cloud identity token.

Cluster-to-cloud lateral movement

Using OIDC (identity federation) – General flow



Cluster-to-cloud lateral movement

Using OIDC (identity federation)

Example: Azure

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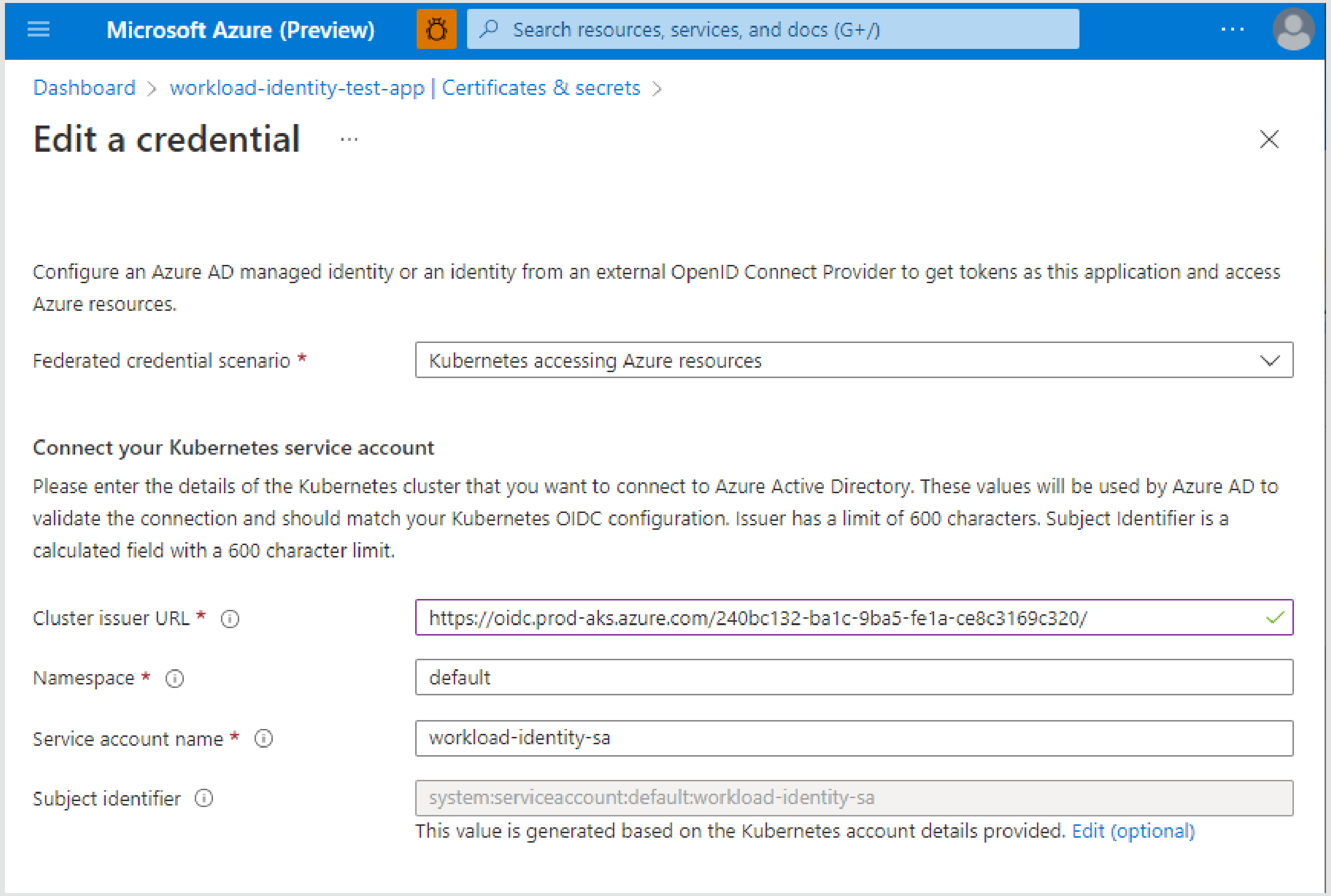
Binding of a Kubernetes service account to an AAD application (federation)

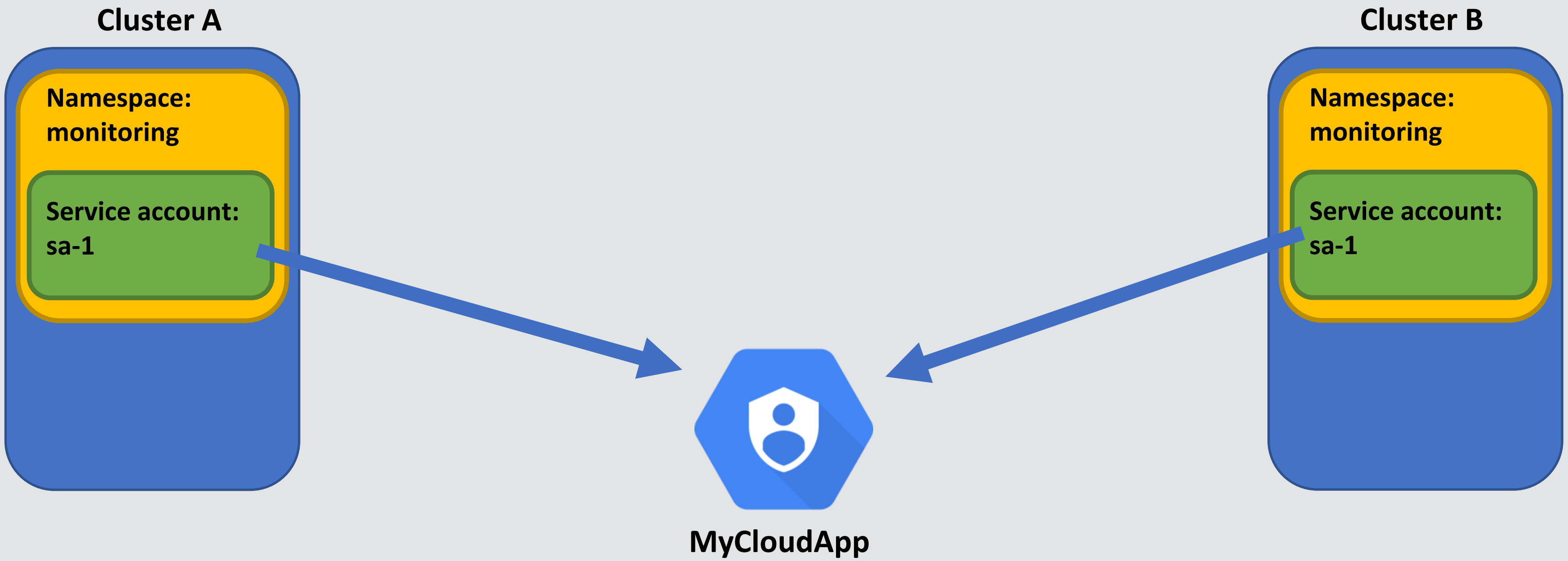


Cluster-to-cloud lateral movement

Using OIDC (identity federation)
GCP

- In GCP, there’s a unified identity pool for the entire project.

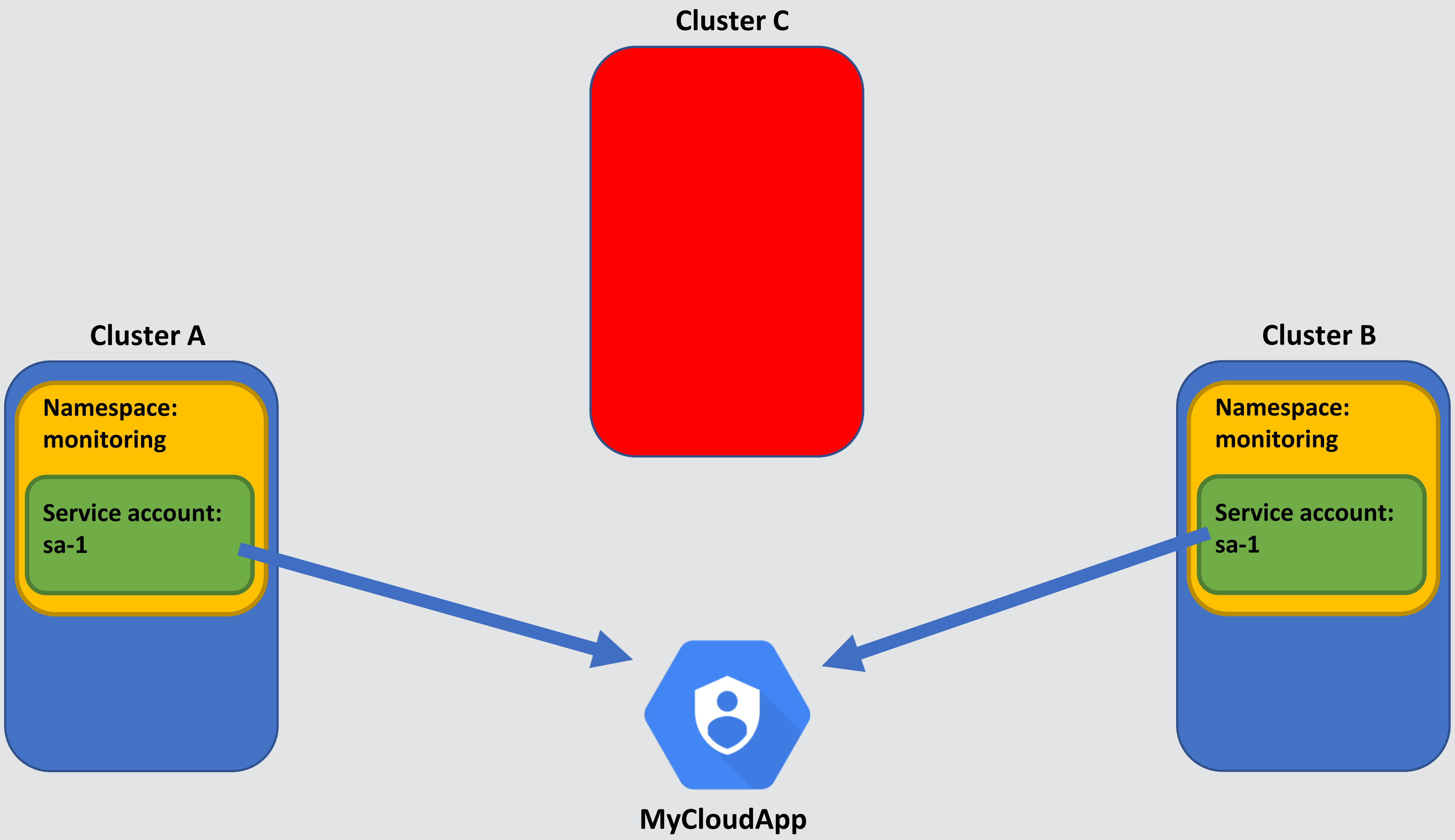
- Meaning, there’s a single binding of a K8s service account (namespace + SA name) to a cloud identity.




```
gcloud iam service-accounts add-iam-policy-binding MyCloudApp@My-GCP-Project.iam.gserviceaccount.com \
    --role roles/iam.workloadIdentityUser \
    --member "serviceAccount:My-GCP-Project.svc.id.goog[monitoring/sa-1]"
```

Cluster-to-cloud lateral movement

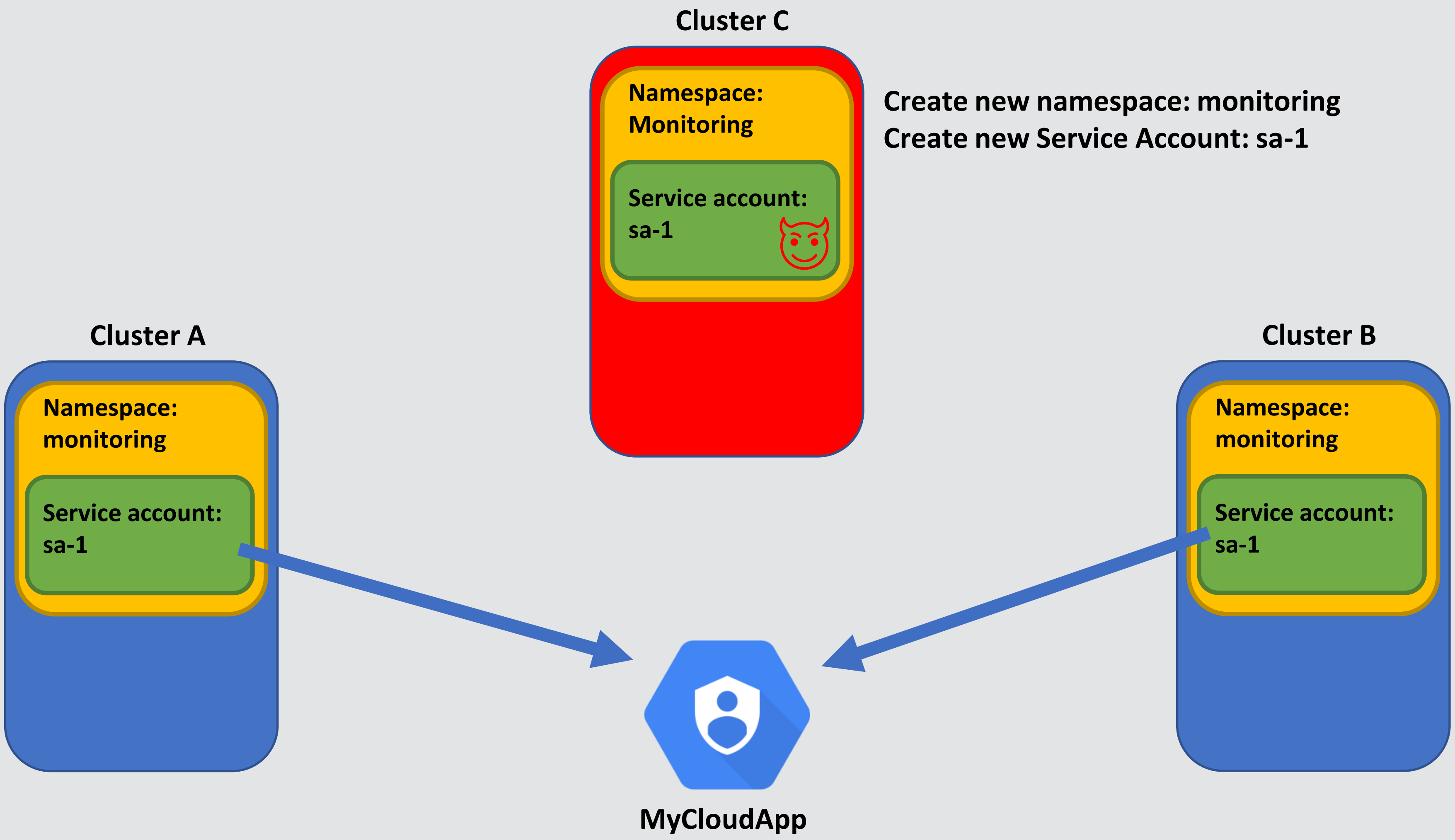
Using OIDC (identity federation)
GCP



Cluster-to-cloud lateral movement

Using OIDC (identity federation)

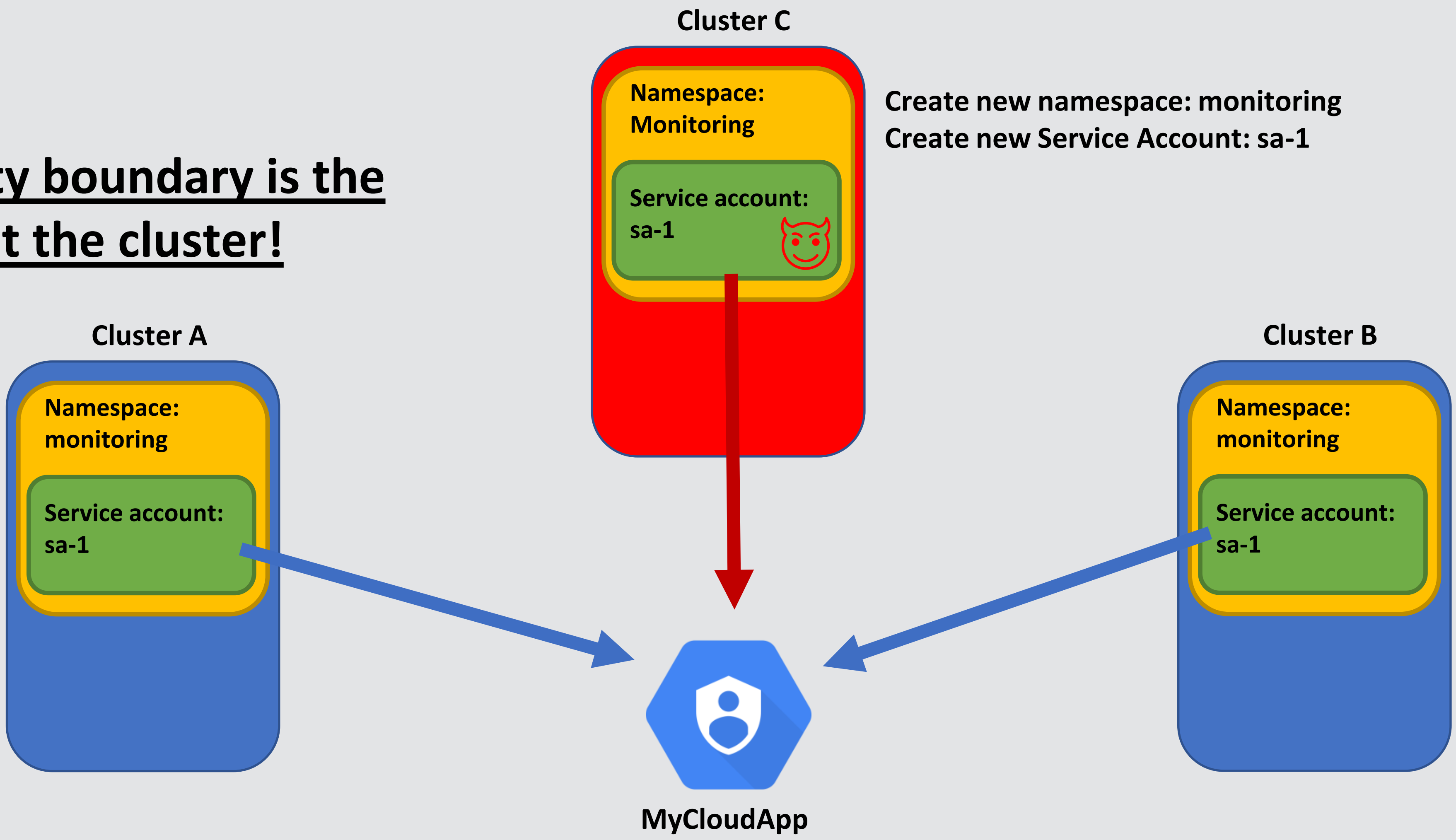
GCP



Cluster-to-cloud lateral movement

Using OIDC (identity federation)
GCP

<u>The security boundary is the project, not the cluster!</u>



Cluster-to-cloud lateral movement

What have we seen so far?

- Inner-cluster lateral movement
  - Example: Self-update permissions that lead to cluster-takeover
  - Additional permissions can lean to cluster takeover (partial list)

- Cluster-to-cloud lateral movement:
  - Storing cloud identity credential on the node
  - Direct access to IMDS
  - Indirect access to IMDS
  - Using OIDC (identity federation)

Detections & mitigations

Detections & mitigations

Detections & mitigations

Kubernetes control plane

Monitor suspicious activity in the cluster using K8s audit log (kube-audit). Examples:

1. Deployment of abnormal images
2. Pods with suspicious configurations (sensitive volume mounts, privileged etc.)
3. Reconnaissance activity (for example: SelfSubjectRulesReview API call).
4. Sensitive API calls, such as "get secret"

Cloud provider control plane

Monitor suspicious activity of cloud identities used by K8s workloads\nodes. Examples:

1. Abnormal behavior of cloud identities. Usually, the cloud identities used by the workloads have a consistent behavior.
2. Suspicious access to sensitive cloud services (e.g. storage, secret store etc.)

Detections & mitigations

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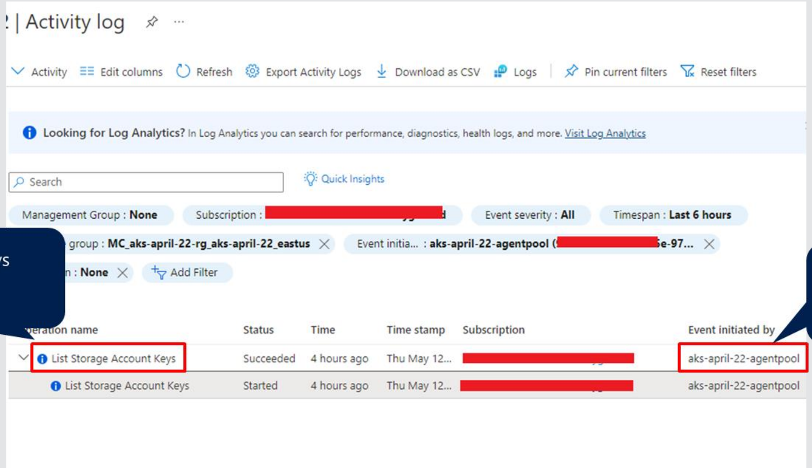
Azure: Activity Log

AWS: CloudTrail

GCP: Cloud Audit Logs

List storage keys



Managed identity used by Kubernetes node

Detections & mitigations

- In December, a new version of the Threat Matrix for Kubernetes was released (v3).
- The new version now includes mitigation techniques.
- **http://aka.ms/KubernetesThreatMatrix**

Detections & mitigations

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Tactics

Initial Access	Execution	Persistence	Privilege Escalation	Defense Evasion	Credential Access	Discovery	Lateral Movement	Collection	Impact
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Kubeconfig file	New container	Kubernetes CronJob	hostPath mount	Pod / container name similarity	Container service account	Network mapping	Cluster internal networking		Denial of service
Application vulnerability	Application exploit (RCE)	Malicious admission controller	Access cloud resources	Connect from proxy server	Application credentials in configuration files	Exposed sensitive interfaces	Application credentials in configuration files		
Exposed sensitive interfaces	SSH server running inside container	Container service account			Access managed identity credentials	Instance Metadata API	Writable hostPath mount		
	Sidecar injection	Static pods			Malicious admission controller		CoreDNS poisoning		
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Detections & mitigations

Access cloud resources

If the Kubernetes cluster is deployed in the cloud, in some cases attackers can leverage their access to a single container to get access to other cloud resources outside the cluster. For example, AKS uses several managed identities that are attached to the nodes, for the cluster operation. Similar identities exist also in EKS and GKE (EC2 roles and IAM service accounts, respectively). By default, running pods can retrieve the identities which in some configurations have privileged permissions. Therefore, if attackers gain access to a running pod in the cluster, they can leverage the identities to access external cloud resources.

Also, AKS has an option to authenticate with Azure using a service principal. When this option is enabled, each node stores service principal credentials that are located in /etc/kubernetes/azure.json. AKS uses this service principal to create and manage Azure resources that are needed for the cluster operation. By default, the service principal has contributor permissions in the cluster's Resource Group. Attackers who get access to this service principal file (by hostPath mount, for example) can use its credentials to access or modify the cloud resources.

Info

ID: MS-TA9020
Tactic: Privilege Escalation, Lateral Movement
MITRE technique: T1078.004

Mitigations

ID	Mitigation	Description
MS-M9003	Adhere to least-privilege principle	Grant only necessary permission to the cloud identities.
MS-M9018	Restrict the access of pods to IMDS	Restrict the access of pods to IMDS to restrict pods from getting access to cloud identities.
MS-M9019	Allocate specific identities to pods	Use dedicated allocated identities to pods
MS-M9013	Restrict over permissive containers	Block mounting volumes with access to cloud credentials.

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Detections & mitigations

Allocate specific identities to pods

When needed, allocate dedicated cloud identity per pod with minimal permissions, instead of inheriting the node's cloud identity. This prevents other pods from accessing cloud identities that are not necessary for their operation. The features that implement this separation are: Azure AD Pod Identity (AKS), Azure AD Workload identity (AKS), IRSA (EKS) and GCP Workload Identity (GCP).

Info

ID: MS-M9019
MITRE mitigation: -

Techniques Addressed by Mitigation

ID	Name	Use
MS-TA9020	Access cloud resources	Use dedicated allocated identities to pods
MS-TA9028	Access Managed Identity credentials	Allocate specific identities to pods.

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Container service account

Service account (SA) represents an application identity in Kubernetes. By default, a Service Account access token is mounted to every created pod in the cluster and containers in the pod can send requests to the Kubernetes API server using the Service Account credentials. Attackers who get access to a pod can access the Service Account token (located in `/var/run/secrets/kubernetes.io/serviceaccount/token`) and perform actions in the cluster, according to the Service Account permissions. If RBAC is not enabled, the Service Account has unlimited permissions in the cluster. If RBAC is enabled, its permissions are determined by the RoleBindings \ ClusterRoleBindings that are associated with it.

An attacker which get access to the Service Account token can also authenticate and access the Kubernetes API server from outside the cluster and maintain access to the cluster.

Info

ID: MS-TA9016
Tactic: Credential Access, Lateral Movement, Persistence
MITRE technique: T1528

Mitigations

ID	Mitigation	Description
MS-M9025	Disable Service Account Auto Mount	Disable service account auto mount.
MS-M9003	Adhere to least-privilege principle	Configure the Kubernetes RBAC such that each service account will have the minimal necessary permissions for the application's functionality.

Detections & mitigations

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Mitigations

- Multi-factor authentication
- Restrict access to the API server using IP firewall
- Adhere to least-privilege principle
- Secure CI/CD environment
- Image assurance policy
- Enable Just In Time access to API server
- Network intrusion prevention
- Limit access to services over network
- Require strong authentication to services
- Restrict exec commands on pods
- Restrict container runtime using LSM
- Remove tools from container images
- Restrict over permissive containers
- Network segmentation
- Avoid running management interface on containers
- Restrict file and directory permissions
- Ensure that pods meet defined Pod Security Standards
- Restricting cloud metadata API access
- Allocate specific identities to

Disable service account auto mount

By default, a service account is mounted to every pod. If the application doesn't require access to the Kubernetes API, disable the service account auto-mount by specifying `automountServiceAccountToken: false` in the pod configuration.

Info

ID: MS-M9025

MITRE mitigation: -

Techniques Addressed by Mitigation

ID	Name	Use
MS-TA9016	Container service account	Disable service account auto mount.

Threat Matrix for Kubernetes

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    a. MITRE ATT&CK framework became the standard for EDR evaluations
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3. v3 – December 2022
   a. New attack TTPs
   b. Introducing Mitigation

Key takeaways

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1. Implement a holistic strategy for K8s security by considering both the cluster and the cloud levels.

2. Identities are a key aspect of K8s security: monitor their activity using auditing tools.

3. Adhere to the least-privilege principle.

4. Use mitigation measures to prevent potential attacks.

Thank You!

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Ram Pliskin — rampliskin