

02 K8s ReplicaSets 101

Kubernetes ReplicaSets

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Introduction and Purpose

A **ReplicaSet** is a Kubernetes workload resource responsible for maintaining a stable set of replica Pods running at any given time. Its primary function is to ensure that a specified number of identical Pod instances are always available in the cluster, providing reliability and high availability for applications.

Key Responsibilities

- **Availability Assurance:** Maintains the desired number of Pod replicas continuously
- **Self-Healing:** Automatically replaces failed or deleted Pods
- **Scaling:** Manages horizontal scaling by creating or terminating Pods as needed
- **Load Distribution:** Enables multiple instances of an application to handle increased traffic

Use Cases

ReplicaSets are ideal for:

- Stateless applications requiring multiple instances
 - Web servers and API services
 - Microservices architectures
 - Server-type applications that must remain continuously operational
-

Core Concepts

The Management Hierarchy

In production Kubernetes environments, resources follow a hierarchical management pattern:

Deployment → ReplicaSet → Pod

- **Deployment** (highest level): Manages ReplicaSets, handles updates and rollbacks
- **ReplicaSet** (middle level): Manages Pods, ensures replica count
- **Pod** (lowest level): Contains one or more containers

Important: ReplicaSets are considered lower-level resources. In production environments, Deployments should be used instead, as they provide additional capabilities while managing ReplicaSets automatically behind the scenes.

Restart Policy

Pods managed by ReplicaSets implicitly have their restart policy set to **Always**. This is non-configurable and ensures that:

- Containers are automatically restarted if they fail
- The application remains running continuously
- The system maintains the desired availability level

Architecture and Components

Controller Manager

The ReplicaSet functionality is implemented through a controller running within the Kubernetes Controller Manager. This controller:

1. **Monitors** the cluster state continuously
2. **Compares** the actual state with the desired state
3. **Reconciles** differences by creating or deleting Pods
4. **Responds** to node failures and Pod terminations

How ReplicaSets Handle Node Failures

Consider a scenario with four nginx instances distributed across multiple nodes:

Node 1: [Pod A] [Pod B]
Node 2: [Pod C]
Node 3: [Pod D]

If Node 2 becomes unreachable or fails:

1. The Controller Manager detects the node failure
2. Recognizes that only 3 Pods remain (desired: 4)
3. Schedules a new Pod on an available node
4. Maintains the desired replica count

Contrast with Standalone Pods: If Pods were created manually without a ReplicaSet:

- Node failure would permanently lose those Pods
- No automatic recovery mechanism exists
- Kubelet restart would not help (as Kubelet runs on the failed node)
- Manual intervention required to restore service

ReplicaSet Specification

YAML Structure

A ReplicaSet manifest consists of four main sections:

```
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 3
  template:
    metadata:
      labels:
        app: my-app
    spec:
      containers:
        - name: nginx
          image: nginx
```

YAML

Component Breakdown

1. API Version and Kind

```
apiVersion: apps/v1
kind: ReplicaSet
```

YAML

- **apiVersion:** Specifies the API group and version (**apps/v1**)

- **kind:** Declares this resource as a ReplicaSet

2. Metadata

```
metadata:
  name: my-rs
```

YAML

- **name:** Unique identifier for the ReplicaSet within its namespace
- Can include additional metadata like labels and annotations

3. Specification (spec)

The spec section contains three critical fields:

a. Selector

```
selector:
  matchLabels:
    app: my-app
```

YAML

Defines which Pods the ReplicaSet should manage based on labels.

b. Replicas

```
replicas: 3
```

YAML

Specifies the desired number of Pod instances.

c. Template

```
template:
  metadata:
    labels:
      app: my-app
  spec:
    containers:
      - name: nginx
        image: nginx
```

YAML

Provides the Pod template used to create new Pods when needed.

Label Selection Mechanism

Understanding Labels and Selectors

Labels are key-value pairs attached to Kubernetes objects. The ReplicaSet uses selectors to identify which Pods it should manage.

How Selection Works

```
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 3
  template:
    metadata:
      labels:
        app: my-app
```

YAML

The ReplicaSet logic:

1. Searches for all Pods with label `app: my-app`
2. Counts matching Pods
3. Takes action based on the count:
 - **Count = 3**: No action needed (desired state achieved)
 - **Count > 3**: Terminates excess Pods immediately
 - **Count < 3**: Creates new Pods using the template

Critical Label Consistency Rule

Mandatory Requirement: Labels in `spec.selector.matchLabels` must exist in `spec.template.metadata.labels`.

Invalid Configuration:

```
spec:
  selector:
    matchLabels:
      app: my-app # Selector looking for this label
  template:
    metadata:
      labels:
        app: my-app-one # Template creates Pods with different label
```

YAML

This will result in a validation error because the ReplicaSet cannot manage Pods it creates.

Valid Configuration:

```
spec:
  selector:
    matchLabels:
      app: my-app
  template:
    metadata:
      labels:
        app: my-app
        version: v1.0
        tier: frontend
```

YAML

The template can have additional labels beyond those in the selector, but must include all selector labels.

Multiple ReplicaSets and Label Isolation

When multiple ReplicaSets exist with identical label selectors:

```
# ReplicaSet 1
metadata:
  name: my-rs-1
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 2
---
# ReplicaSet 2
metadata:
  name: my-rs-2
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 2
```

YAML

Behavior:

- Each ReplicaSet manages its own set of Pods independently
- ReplicaSets do not claim Pods managed by other controllers
- Each maintains its own replica count
- No conflicts occur despite identical selectors

Key Principle: A Pod can only be managed by one controller at a time. ReplicaSets will only adopt unmanaged Pods that match their selector.

Pod Management Lifecycle

Pod Creation Process

When a ReplicaSet needs to create Pods:

1. **Template Application:** Uses the pod template from `spec.template`
2. **Name Generation:** Creates unique names by appending random suffixes to the ReplicaSet name
 - Pattern: `<replicaset-name>-<random-string>`
 - Example: `my-rs-8k7d2`, `my-rs-j4p9w`
3. **Label Attachment:** Applies labels from `template.metadata.labels`
4. **Owner Reference:** Sets the ReplicaSet as the Pod's owner

Note: The `name` field in the Pod template (if specified) is ignored because multiple Pods cannot share the same name.

Pod Adoption

ReplicaSets can adopt existing Pods under specific conditions:

Scenario: Creating a ReplicaSet when matching Pods already exist

YAML

```
# Existing Pods created manually
```

```
---
```

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-1
  labels:
    team: team-a
```

```
---
```

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-2
  labels:
    team: team-a
```

```
---
```

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-3
  labels:
    team: team-a
```

YAML

```
# ReplicaSet configured to manage 2 replicas
```

```
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs
spec:
  selector:
    matchLabels:
      team: team-a
  replicas: 2
  template:
    metadata:
      labels:
        team: team-a
    spec:
      containers:
        - name: nginx
          image: nginx
```

When the ReplicaSet is created:

1. Finds 3 existing Pods with label `team: team-a`
2. Desired state is 2 replicas
3. Adopts 2 of the existing Pods
4. Terminates 1 Pod immediately to match desired count

Adoption Requirements:

- Pods must have matching labels
- Pods must NOT be managed by another controller
- Pods must not have an existing owner reference

Self-Healing Behavior

Automatic Recovery: When a Pod is deleted, the ReplicaSet immediately creates a replacement.

Demonstration:

```
# Initial state: 3 Pods running
kubectl get pods

# NAME                READY   STATUS    RESTARTS   AGE
# my-rs-8k7d2         1/1     Running   0           2m
# my-rs-j4p9w         1/1     Running   0           2m
# my-rs-m3k5n         1/1     Running   0           2m

# Delete one Pod
kubectl delete pod my-rs-8k7d2

# Immediate observation: New Pod created
kubectl get pods

# NAME                READY   STATUS    RESTARTS   AGE
# my-rs-j4p9w         1/1     Running   0           2m
# my-rs-m3k5n         1/1     Running   0           2m
# my-rs-x9r4t         1/1     Running   0           3s # New Pod
```

SHELL

Bulk Deletion: Deleting all Pods results in the ReplicaSet creating an entirely new set to maintain the desired count.

ReplicaSet Deletion

When a ReplicaSet is deleted:

```
kubectl delete -f replicaset.yaml
```

SHELL

Result:

- The ReplicaSet resource is removed

- All Pods managed by the ReplicaSet are terminated
- Cascading deletion occurs automatically

Practical Examples

Example 1: Basic ReplicaSet

File: 01-simple-rs.yaml

YAML

```
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 3
  template:
    metadata:
      name: my-pod
      labels:
        app: my-app
    spec:
      containers:
        - name: nginx
          image: nginx
```

Deployment:

SHELL

```
# Create the ReplicaSet
kubectl create -f 01-simple-rs.yaml

# Verify creation
kubectl get replicaset

# NAME      DESIRED   CURRENT   READY   AGE
# my-rs     3         3         3       10s

kubectl get pods --show-labels

# NAME                READY   STATUS    RESTARTS   AGE   LABELS
# my-rs-8k7d2         1/1     Running   0           10s   app=my-app
# my-rs-j4p9w         1/1     Running   0           10s   app=my-app
# my-rs-m3k5n         1/1     Running   0           10s   app=my-app
```

Example 2: Managing Existing Pods

File: 02-multiple-pods.yaml

YAML

```
apiVersion: v1
kind: Pod
metadata:
  name: pod-1
  labels:
    team: team-a
spec:
  containers:
  - name: nginx
    image: nginx
---
apiVersion: v1
kind: Pod
metadata:
  name: pod-2
  labels:
    team: team-a
spec:
  containers:
  - name: nginx
    image: nginx
---
apiVersion: v1
kind: Pod
metadata:
  name: pod-3
  labels:
    team: team-a
spec:
  containers:
  - name: nginx
    image: nginx
```

File: 03-existing-pod-manager.yaml

YAML

```

apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs
spec:
  selector:
    matchLabels:
      team: team-a
  replicas: 2
  template:
    metadata:
      labels:
        team: team-a
    spec:
      containers:
      - name: nginx
        image: nginx

```

Execution Sequence:

SHELL

```

# Step 1: Create the standalone Pods
kubectl create -f 02-multiple-pods.yaml

# Verify Pods exist
kubectl get pods
# NAME      READY   STATUS    RESTARTS   AGE
# pod-1     1/1     Running   0           5s
# pod-2     1/1     Running   0           5s
# pod-3     1/1     Running   0           5s

# Step 2: Create ReplicaSet to manage 2 replicas
kubectl create -f 03-existing-pod-manager.yaml

# Observation: ReplicaSet adopts 2 Pods, terminates 1
kubectl get pods
# NAME      READY   STATUS    RESTARTS   AGE
# pod-1     1/1     Running   0           30s
# pod-2     1/1     Running   0           30s
# pod-3     0/1     Terminating   0           30s # Being deleted

```

Example 3: Multiple ReplicaSets with Same Labels**File: 04-multiple-rs.yaml**

```
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs-1
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 2
  template:
    metadata:
      labels:
        app: my-app
    spec:
      containers:
      - name: nginx
        image: nginx
---
apiVersion: apps/v1
kind: ReplicaSet
metadata:
  name: my-rs-2
spec:
  selector:
    matchLabels:
      app: my-app
  replicas: 2
  template:
    metadata:
      labels:
        app: my-app
    spec:
      containers:
      - name: nginx
        image: nginx
```

Deployment:

SHELL

```
kubectl create -f 04-multiple-rs.yaml
```

```
# Verification
```

```
kubectl get replicaset
```

```
# NAME          DESIRED   CURRENT   READY   AGE
# my-rs-1       2         2         2       15s
# my-rs-2       2         2         2       15s
```

```
kubectl get pods
```

```
# NAME              READY   STATUS    RESTARTS   AGE
# my-rs-1-a7b2c     1/1     Running   0           15s
# my-rs-1-d3e4f     1/1     Running   0           15s
# my-rs-2-g5h6i     1/1     Running   0           15s
# my-rs-2-j7k8l     1/1     Running   0           15s
```

Key Observation: Each ReplicaSet manages its own independent set of Pods despite identical label selectors.

Advanced Topics

Describing Resources

The `kubectl describe` command provides detailed information about ReplicaSets:

SHELL

```
kubectl describe replicaset my-rs
```

Output includes:

- **Metadata:** Name, namespace, labels, annotations
- **Selector:** Label selector configuration
- **Replicas:** Desired vs current vs ready counts
- **Pod Template:** Complete Pod specification
- **Events:** Recent actions taken by the controller

Sample Events:

```
Events:
```

| Type | Reason | Age | From | Message |
|--------|------------------|-----|-----------------------|--------------------------|
| Normal | SuccessfulCreate | 5m | replicaset-controller | Created pod: my-rs-8k7d2 |
| Normal | SuccessfulCreate | 5m | replicaset-controller | Created pod: my-rs-j4p9w |
| Normal | SuccessfulCreate | 3m | replicaset-controller | Created pod: my-rs-x9r4t |

Advanced Label Selection: matchExpressions

Beyond `matchLabels`, ReplicaSets support more complex selection criteria using `matchExpressions`:

```
spec:
  selector:
    matchExpressions:
      - key: team
        operator: In
        values:
          - team-a
          - team-b
```

YAML

Available Operators:

- **In:** Label value must be in the specified list
- **NotIn:** Label value must not be in the specified list
- **Exists:** Label key must exist (value ignored)
- **DoesNotExist:** Label key must not exist

Example with NotIn:

```
spec:
  selector:
    matchExpressions:
      - key: team
        operator: NotIn
        values:
          - team-a
          - team-b
  replicas: 3
  template:
    metadata:
      labels:
        team: team-c
    spec:
      containers:
        - name: nginx
          image: nginx
```

YAML

This ReplicaSet will manage Pods where the `team` label is neither `team-a` nor `team-b`.

Note: While `matchExpressions` provides powerful selection capabilities, `matchLabels` is sufficient for most production use cases. The complex syntax is primarily useful for specialized scenarios or certification exam requirements.

Useful kubectl Commands

SHELL

```
# List all ReplicaSets
kubectl get replicaset
kubectl get rs # Shorthand

# List all resources (Pods, ReplicaSets, Services, etc.)
kubectl get all

# Show labels on Pods
kubectl get pods --show-labels

# Watch resources in real-time
watch -d -t -n 2 kubectl get all

# Delete a specific Pod
kubectl delete pod <pod-name>

# Delete all resources from a manifest
kubectl delete -f manifest.yaml

# Describe a ReplicaSet for detailed information
kubectl describe rs <replicaset-name>
```

Best Practices

Production Guidelines

1. Use Deployments, Not ReplicaSets Directly

- ReplicaSets are lower-level resources
- Deployments provide additional features (rolling updates, rollbacks)
- Deployments automatically manage ReplicaSets

2. Label Strategy

- Use meaningful, descriptive labels
- Maintain consistency across resources
- Avoid generic labels that might cause conflicts
- Example: `app: product-service`, `version: v1.2.3`, `tier: backend`

3. Unique Labels for Different Applications

- Each application should have distinct label sets
- Prevents accidental cross-application management
- Facilitates proper resource isolation

4. Appropriate Replica Counts

- Set replicas based on actual load requirements
- Consider resource availability in the cluster
- Plan for high availability (minimum 2-3 replicas)

5. Resource Management

- Always define resource requests and limits in Pod templates
- Ensures proper scheduling and prevents resource exhaustion
- Example:

```
spec:
  containers:
  - name: nginx
    image: nginx
    resources:
      requests:
        memory: "64Mi"
        cpu: "250m"
      limits:
        memory: "128Mi"
        cpu: "500m"
```

YAML

Operational Considerations

1. Monitoring

- Track ReplicaSet health and Pod status
- Monitor replica counts (desired vs actual)
- Set up alerts for discrepancies

2. Scaling Operations

- Use `kubectl scale` for manual scaling
- Consider Horizontal Pod Autoscaler for automatic scaling
- Plan capacity for peak loads

3. Troubleshooting

- Use `kubectl describe` to investigate issues
- Check events for creation/deletion patterns
- Verify label selectors match Pod labels

4. Cleanup

- Delete ReplicaSets when no longer needed
- Understand cascading deletion behavior
- Use `--cascade=false` if Pods should remain

Summary

ReplicaSets are fundamental Kubernetes resources that ensure application availability and reliability through automated Pod management. Key takeaways:

- **Purpose:** Maintain a specified number of identical Pod replicas
- **Self-Healing:** Automatically replace failed Pods
- **Label-Based Management:** Use selectors to identify managed Pods
- **Controller Pattern:** Continuously reconcile desired state with actual state
- **Production Usage:** Managed indirectly through Deployments
- **Restart Policy:** Implicitly set to **Always** for server-type applications

While ReplicaSets provide essential functionality, they represent an intermediate abstraction layer. In production environments, Deployments should be used to manage ReplicaSets automatically, providing additional capabilities like declarative updates and version control.

Understanding ReplicaSets is crucial for comprehending Kubernetes' self-healing mechanisms and the foundation upon which higher-level resources like Deployments are built. This knowledge enables effective troubleshooting, optimization, and architectural decision-making in Kubernetes environments.