Kubernetes IP Hash Set For Managing Addresses in IP-Tables

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Abstract

Kubernetes is a platform for automating the deployment, scaling, and management of containerized applications. Kubernetes automates the orchestration of containers, enabling seamless scaling, load balancing, and fault tolerance in a highly dynamic environment. In Kubernetes, iptables is commonly used to support networking functionalities like kube-proxy, Manages networking rules to route traffic to the appropriate backend pods. Service discovery and load balancing. Kubernetes uses iptables rules to direct requests for a service to the correct pod(s) based on IPs. Network policies,

IP Tables plays a key role in how networking is managed, particularly in terms of routing traffic to Pods and Services. Kubernetes uses IPTables in several key components to ensure smooth communication within the cluster and to external systems. When you create a Service, Kubernetes sets up IPTables rules to route traffic to the correct set of Pods. IP Tables use Hash Table to store rules and connections for fast lookups. Linked lists to manage chains of rules and connections, trees to optimize rule matching and bitmaps for compactly store flags and options.

IP Hashset is commonly used to optimize IPTables performance, especially in large-scale environments with extensive IP filtering needs, like Kubernetes clusters. When dealing with numerous IP addresses or IP ranges, the hashset data structure allows more efficient storage and quicker lookups than a list, especially with large datasets. Hashsets are typically implemented through ipset in Linux, which works in conjunction with iptables. Single IP hash sets in iptables can lead to significant challenges, especially as cluster sizes and network complexity grow. A single IP hash set can struggle to handle the scale in large Kubernetes clusters, where thousands of IP addresses are stored. It becomes more memory-intensive and slower in lookups due to higher collision rates in the hash set. As the hash set grows, search and update operations slow down, creating latency in packet processing. This affects cluster performance, as any latency in the network layer impacts the efficiency of service communication. In this paper we will address all these issues by using multi IP hash set.

Keywords: **Kubernetes (K8S), Cluster, Nodes, Deployments, Pods, ReplicaSets, Statefulsets, Service, Service Abstraction, IP-Tables, HashTable, IP Hash Set, Single IP Hash Set, Multiple IP Hash Set.**

INTRODUCTION

Kubernetes consists of several components that work together to manage containerized applications. Master Node: This controls the overall cluster, handling scheduling and task coordination.API Server: Frontend that exposes Kubernetes functionalities through RESTful APIs. Scheduler: Distributes work across the nodes based on workload requirements..Controller Manager: Ensures that the current state matches the desired state by managing the cluster's control loops.etcd: Kube-proxy: Manages network communication within and outside the cluster.

Pod is the smallest deployable unit in Kubernetes, encapsulating one or more containers [1] with shared storage and network resources. All containers in a pod run on the same node. Namespace, these are used to create isolated environments within a cluster. They allow teams to share the same cluster resources without conflicting with each other. Deployment: A higher-level abstraction that manages the creation and scaling of Pods. It also allows for updates, rollbacks, and scaling of applications. ReplicaSet [2] ensures a specified number of replicas (identical copies) of a Pod are running at any given time. StatefulSet: Designed to manage stateful applications, where each Pod has a unique identity and persistent storage, such as databases. DaemonSet, ensures that a copy of a Pod is running on all (or some) nodes. This is useful for deploying system services like log collectors or monitoring agents. Job, A Kubernetes resource that runs a task until completion. Unlike Deployments or Pods, a Job does not need to run indefinitely. CronJob runs Jobs at specified intervals, similar to cron jobs in Linux.

LITERATURE REVIEW

Kubernetes Cluster

A **cluster** [3] refers to the set of machines (physical or virtual) that work together to run containerized applications. A cluster is made up of one or more **master nodes** (control plane) and **worker nodes**, and it provides a platform for deploying, managing, and scaling containerized workloads.

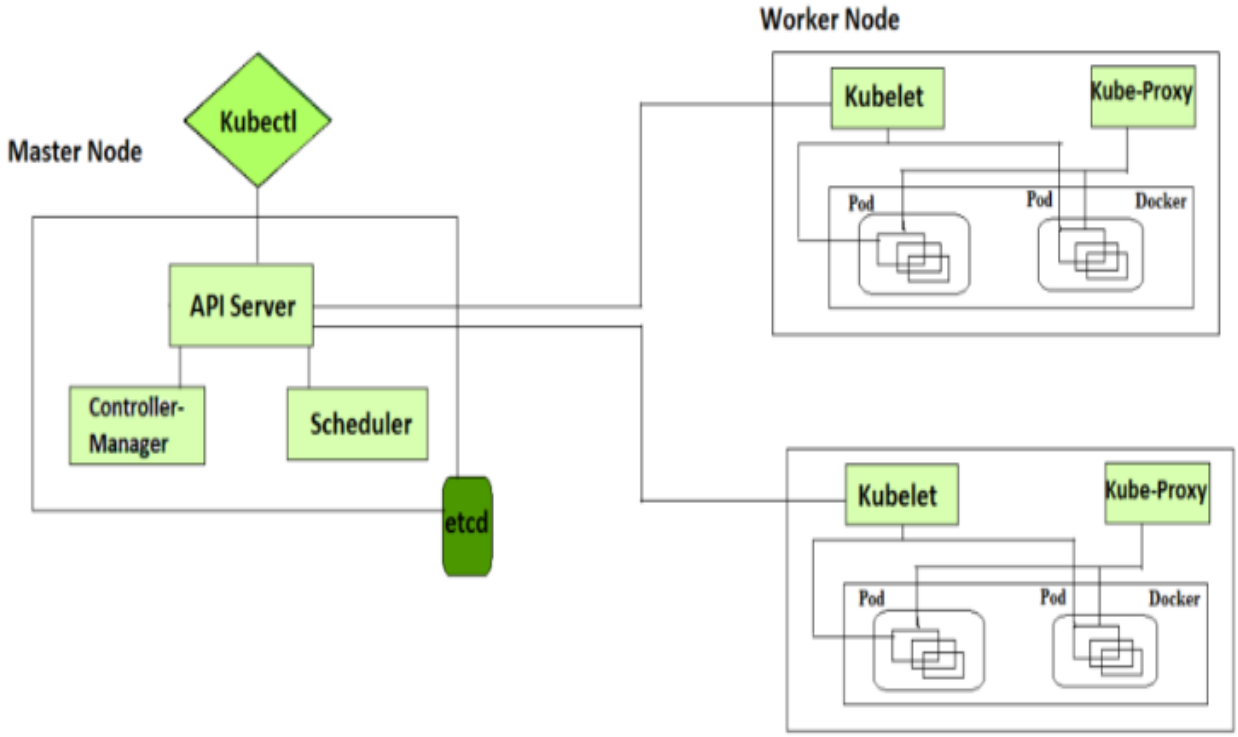


Fig 1. Kubernetes cluster Architecture

Client kubectl will connect to API server [4] (part of Master Node) to interact with Kubernetes resources like pods, services, deployment etc. Client will be authenticated through API server having different stages like authentication and authorization. Once the client is succeeded though authentication [5] and authorization (RBAC plugin) it will connect with corresponding resources to proceed with further operations. Etcd [6] is the storage location for all the kubernetes resources. Scheduler will select the appropriate node for scheduling the pods unless you have mentioned node affinity (this is the provision to

specify the particular node for accommodating the pod). Kubelet is the process which is running on all nodes of the kubernetes cluster and it will manage the mediation between api server and corresponding node. Communication between any entity with master node is going to happen only through api server.

Key Components of a Kubernetes Cluster:

Control Plane (Master Node):

API Server exposes Kubernetes APIs. All interactions with the cluster (e.g., deploying applications, scaling, etc.) go through the API server.
Etcd is a distributed key-value store [7] that holds the state and configuration of the cluster, including information about pods, services, secrets, and configurations.
Controller Manager ensures that the cluster's desired state matches its actual state, by managing different controllers (like deployment, replication, etc.).
Scheduler is the one which Assigns workloads to worker nodes based on resource availability, scheduling policies, and requirements.

Worker Nodes:
Kubelet is the agent running on each node that ensures containers are running in Pods as specified by the control plane.
Container Runtime [8] is the software responsible for running containers (e.g., Docker, containerd).
Kube-proxy manages network traffic between pods and services, handling routing, load balancing, and network rules.

How a Kubernetes Cluster Works:
Pods: The smallest deployable units in Kubernetes, consisting of one or more containers. They run on worker nodes and are managed by the control plane.
Nodes: Physical or virtual machines in the cluster that host Pods and execute application workloads.
Services: Provide stable networking and load balancing for Pods within a cluster.

Cluster Operations:

Kubernetes clusters can automatically scale up or down by adding/removing nodes or pods.
Resilience: Clusters are designed for high availability and can automatically restart failed pods or reschedule them on healthy nodes.

Kubernetes ensures traffic is evenly distributed across Pods within a Service.
Self-Healing: The control plane continuously monitors the state of the cluster and acts to correct failures or discrepancies between the desired and current state.

Service Abstraction:

Service Abstraction [9] in Kubernetes provides a way to define a logical set of Pods and a policy by which to access them. This abstraction enables communication between different application components without needing to know the underlying details of each component's location or state.

Stable Network Identity: Services provide a stable IP address and DNS name that can be used to reach Pods, which may be dynamically created or destroyed.

Load Balancing: Kubernetes services automatically distribute traffic to the available Pods, providing a load balancing mechanism. When a Pod fails, the service can route traffic to other healthy Pods.

Service Types: Kubernetes supports different types of services:

ClusterIP: The default type, which exposes the service on a cluster-internal IP. Only accessible from within the cluster.

NodePort: Exposes the service on each Node's IP at a static port (the NodePort). This way, the service can be accessed externally.

Kubernetes automatically provisions a load balancer for the service when running on cloud providers.

ExternalName maps the service to the contents of the externalName field (e.g., an external DNS name).

Iptables Coordination:

Iptables [10] is a user-space utility program that allows a system administrator to configure the IP packet filter rules of the Linux kernel firewall. In the context of Kubernetes, iptables is used to manage the networking rules that govern how traffic is routed to the various services.

SNo	IP Address	Port
1	10.3.4.3, 10.3.4.5,10.3.4.7	8125
2	10.3.5.3, 10.3.5.5,10.3.5.7	8081
3	10.3.6.3, 10.3.6.5,10.3.6.7	8080
4	10.3.2.3, 10.3.2.5,10.3.2.7	5432
5	10.3.7.3, 10.3.7.5,10.3.7.7	6212
6	10.3.8.3, 10.3.8.5,10.3.8.7	6515

Table 1: IP Tables Storage Structure

Key Functions:

Traffic Routing: Iptables rules direct incoming traffic to the correct service IP based on the defined service configurations.

NAT (Network Address Translation): Iptables can be configured to rewrite the source or destination IP addresses of packets as they pass through, which is crucial for services that need to expose Pods to external traffic.

Connection Tracking: Iptables tracks active connections and ensures that replies to requests are sent back to the correct Pod.

Service and IP Table:

Service Request: A request is sent to the service's stable IP address.

Kubernetes Networking [11] uses iptables to manage the routing of this request. It sets up rules to map the service IP to the IP addresses of the underlying Pods.

Load Balancing: Ip tables distributes incoming traffic among the Pods that match the service's selector, ensuring load balancing. Return Traffic: When a Pod responds, iptables ensures that the response goes back through the same network path, maintaining connection tracking.

Service abstraction in Kubernetes provides a simplified and stable interface for accessing application components, while iptables coordination ensures that the network traffic is efficiently routed to the right Pods. Together, they form a robust networking framework that is fundamental to the operation of Kubernetes clusters.

Three node , four node , five node , six node , seven node , eight node , nine node and ten node clusters have been configured with 32 CPU, 64 GB and 500GB for master node and 24 CPU , 32 GB and 350 GB for all worker nodes. The existing IP table has been implemented using IP Hash set, it is a data structure typically used in networking and firewall applications to store IP addresses using a hash table [12][13][24][25][26]. We have collected different samples for performance , scaling , network policy enforcement parameters.

```yaml
apiVersion: apps/v1
kind: DaemonSet
metadata:
  name: single-iphashset-metrics
  namespace: kube-system
spec:
  selector:
    matchLabels:
      app: single-iphashset-metrics
  template:
    metadata:
      labels:
        app: single-iphashset-metrics
    spec:
      containers:
      - name: single-iphashset-metrics
        image: busybox
        securityContext:
          privileged: true
        command: ["/bin/sh", "-c"]
        args:
          - |
            # Create a single IP hash set
            ipset create single_iphashset hash:ip -exist

            # Time Insertion
            start_insertion=$(date +%s%3N)
            ipset add single_iphashset 192.168.1.10 -exist
            end_insertion=$(date +%s%3N)
            insertion_time=$((end_insertion - start_insertion))
            echo "Insertion Time: $insertion_time ms" >> /metrics/single_iphash_metrics.log

            # Time Lookup
            start_lookup=$(date +%s%3N)
            ipset test single_iphashset 192.168.1.10
            end_lookup=$(date +%s%3N)
            lookup_time=$((end_lookup - start_lookup))
            echo "Lookup Time: $lookup_time ms" >> /metrics/single_iphash_metrics.log

            # Time Deletion
            start_deletion=$(date +%s%3N)
            ipset del single_iphashset 192.168.1.10
            end_deletion=$(date +%s%3N)
            deletion_time=$((end_deletion - start_deletion))
            echo "Deletion Time: $deletion_time ms" >> /metrics/single_iphash_metrics.log
```

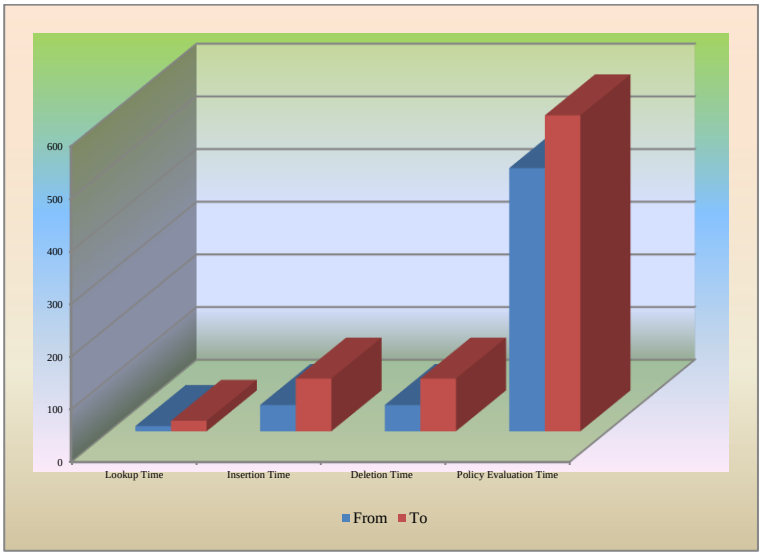
```
        # Time Policy Evaluation (using iptables)
        start_policy=$(date +%s%3N)
        iptables -C INPUT -m set --match-set single_iphashset src -j ACCEPT -exist
        end_policy=$(date +%s%3N)
        policy_time=$((end_policy - start_policy))
        echo "Policy Evaluation Time: $policy_time ms" >> /metrics/single_iphash_metrics.log

        # Keep the container running for ongoing logging
        sleep infinity
    volumeMounts:
      - name: metrics-volume
        mountPath: /metrics
    resources:
      requests:
        cpu: 100m
        memory: 50Mi
    volumeMounts:
    - mountPath: /lib/modules
      name: modules
      readOnly: true
  volumes:
  - name: metrics-volume
    emptyDir: {}
  - name: modules
    hostPath:
      path: /lib/modules
  hostNetwork: true
  hostPID: true
```

We have deployed daemon set at kube-system namespace, it is getting accommodated at all nodes in the cluster. It doesn't matter about dynamic increase or decrease of the number of nodes. We have taken the busybox image and ran the commands inside the docker container and invoking the single IPHash set and collected start insertion and end insertion, difference of the same. End lookup and start lookup and difference of the same,, end deletion , start deletion , difference of the same, end policy , start policy and difference of the same. Like we have found lookup time, insertion , deletion times and policy evaluation time. These parameters are getting at all machines in the corresponding log files.

Metric	From	To
Lookup Time	10	20
Insertion Time	50	100
Deletion Time	50	100
Policy Evaluation Time	500	1000

Table 2: Single IP Hash Set-1

Table 2 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 10 micro seconds to 20 micro seconds. Insertion time is from the range 50 micro seconds to 100 micro seconds. Deletion time is from the range 50 micro seconds to 100 micro seconds and Policy evaluation time is from the range 500 micro seconds to 1000 micro seconds.

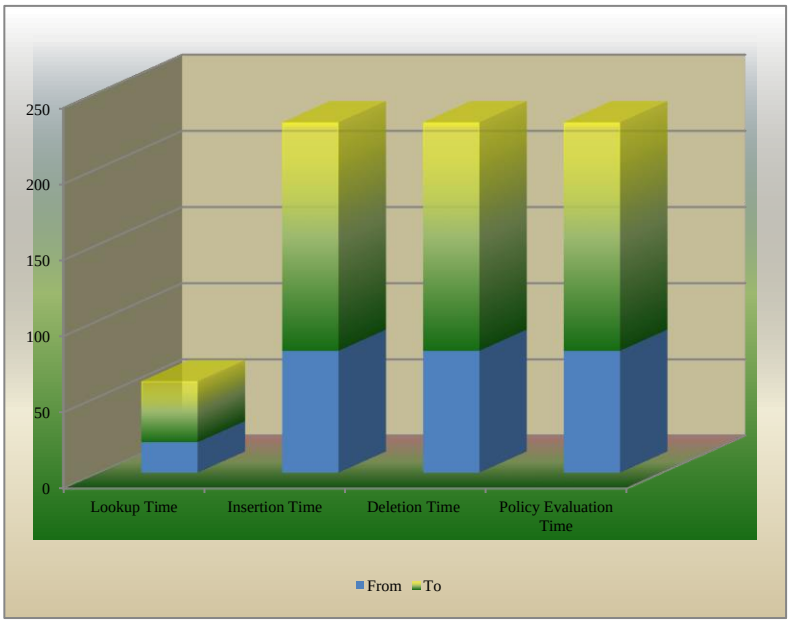


Graph 1: Single IP Hash Set-1

Metric	From	To
Lookup Time	20	40
Insertion Time	80	150
Deletion Time	80	150
Policy Evaluation Time	80	150

Table 3: Single IP Hash Set-2

Table 3 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 20 micro seconds to 40 micro seconds. Insertion time is from the range 80 micro seconds to 150 micro seconds. Deletion time is from the range 80 micro seconds to 150 micro seconds and Policy evaluation time is from the range 80 micro seconds to 150 micro seconds.

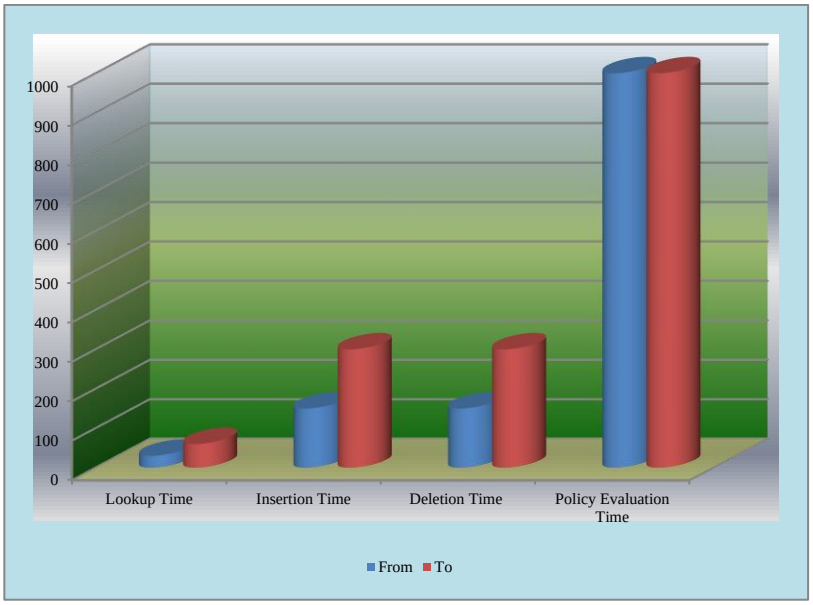


Graph 2: Single IP Hash Set-2

Metric	From	To
Lookup Time	30	60
Insertion Time	150	300
Deletion Time	150	300
Policy Evaluation Time	2000	4000

Table 4: Single IP Hash Set-3

Table 4 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 30 micro seconds to 60 micro seconds. Insertion time is from the range 150 micro seconds to 300 micro seconds. Deletion time is from the range 150 micro seconds to 300 micro seconds and Policy evaluation time is from the range 2000 micro seconds to 4000 micro seconds.

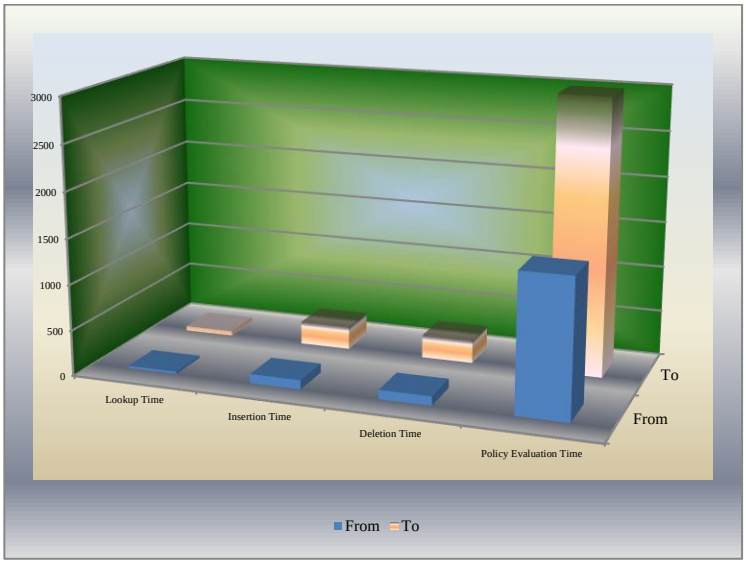


Graph 3: Single IP Hash Set-3

Metric	From	To
Lookup Time	25	50
Insertion Time	100	250
Deletion Time	100	250
Policy Evaluation Time	1500	3000

Table 5: Single IP Hash Set-4

Table 5 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 25 micro seconds to 50 micro seconds. Insertion time is from the range 100 micro seconds to 250 micro seconds. Deletion time is from the range 100 micro seconds to 250 micro seconds and Policy evaluation time is from the range 1500 micro seconds to 3000 micro seconds.

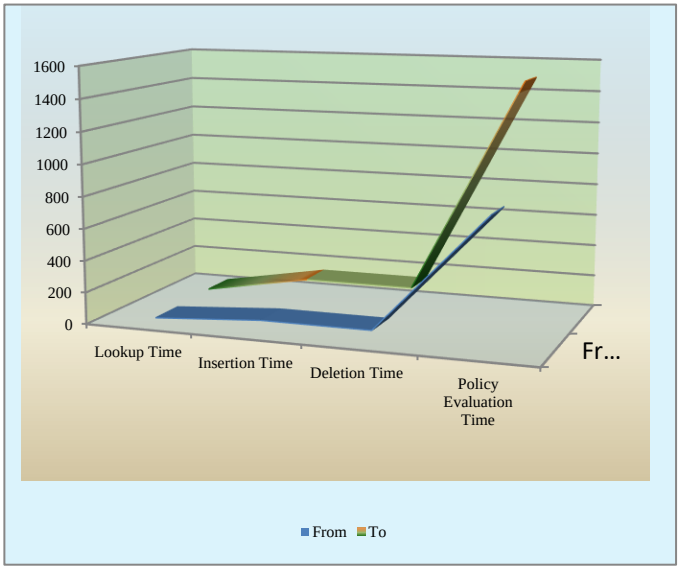


Graph 4: Single IP Hash Set-4

Metric	From	To
Lookup Time	15	30
Insertion Time	60	150
Deletion Time	60	150
Policy Evaluation Time	800	1500

Table 6: Single IP Hash Set-5

Table 6 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 15 micro seconds to 30 micro seconds. Insertion time is from the range 60 micro seconds to 50 micro seconds. Deletion time is from the range 60 micro seconds to 150 micro seconds and Policy evaluation time is from the range 800 micro seconds to 1500 micro seconds.



Graph 5: Single IP Hash Set-6

Please observe the graph representation of the same. It shows the avg lookup , Insertion time , deletion time

and policy evaluation time.

PROPOSAL METHOD

Problem Statement

Service abstraction is using IP tables to store the rules of services and provide matching to the incoming request to the IP tables. The existing IP tables have been implemented using Single IP Hash Set for storing the IP addresses, It can struggle to handle the scale in large Kubernetes clusters, where thousands of IP addresses are stored. It becomes more memory-intensive and slower in lookups due to higher collision rates in the hash set. As the hash set grows, search and update operations slow down, creating latency in packet processing. This affects cluster performance, as any latency in the network layer impacts the efficiency of service communication. To resolve all these issues we need to work on the sets of the IP Hash set.

Proposal

Multiple IP Hash Set is the one which we can use to overcome the issues like faster lookup times, multiple IP Hash sets reduce lookup times , improving network performance. Smaller IPHash sets minimize latency , ensuring faster packet processing. Multiple smaller IPHash sets consume less memory. Processing smaller IPHash sets decreases CPU utilization

SNo	IP Address
1	10.3.4.3, 10.3.4.5,10.3.4.7
2	10.3.5.3, 10.3.5.5,10.3.5.7
3	10.3.6.3, 10.3.6.5,10.3.6.7
4	10.3.2.3, 10.3.2.5,10.3.2.7
5	10.3.7.3, 10.3.7.5,10.3.7.7
6	10.3.8.3, 10.3.8.5,10.3.8.7

Table 7: Single IP Hash Set Storage

000	10.3.4.3, 10.3.4.5	**110**	10.3.4.3, 10.3.4.5
001	10.3.6.3, 10.3.6.6	**111**	10.3.6.3, 10.3.6.6
010	10.3.6.7, 10.3.6.9	**1000**	10.3.6.7, 10.3.6.9
011	10.3.6.6, 10.3.6.0	**1001**	10.3.6.6, 10.3.6.0
100	10.3.6.1, 10.3.6.2	**1010**	10.3.6.1, 10.3.6.2
101	10.3.6.11, 10.3.6.12	**1011**	10.3.6.11, 10.3.6.12

Table 8: Multiple IP Hash Set Storage

Table 7 shows the storage of IP addresses at IP Tables. In this it uses the Single IP Hash set to access the IP

Addresses.

Table 8 shows the storage of IP addresses at IP Tables. In this it uses the Single IP Hash set to access the IP Addresses. In the multi IP Hash set storage process , as per the octal representation the addresses will be stored at each tag. Based on the tag we can access multiple ip addresses at the same location. That is why we will get high performance by using this storage.

IMPLEMENTATION

Three node , four node , five node , six node , seven node , eight node , nine node and ten node clusters have been configured with 32 CPU, 64 GB and 500GB for master node and 24 CPU , 32 GB and 350 GB for all worker nodes.

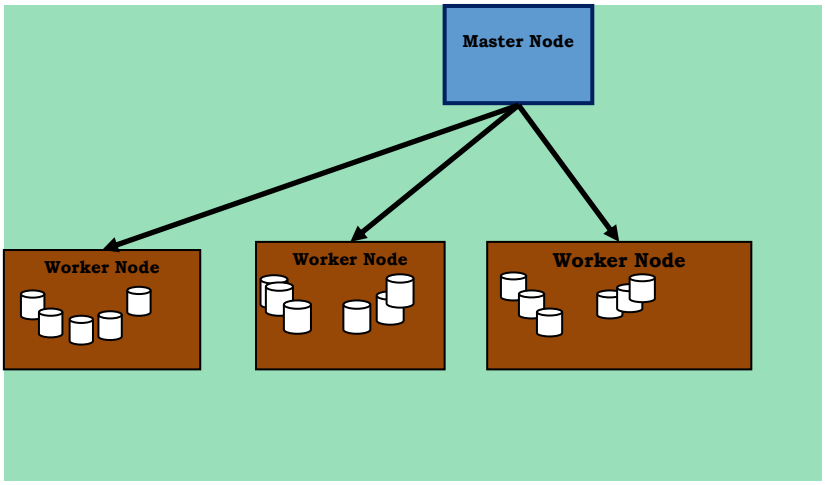


Fig. 4. Four Node Cluster One Master and Three worker Nodes

Fig. 4 shows the four node cluster, one node is the master node and the remaining three are the worker nodes. Master node will have control plane and all other kubernetes core libraries toi manage the cluster. Each node in the cluster having the kubelet process , this is the agent at all the machines which is taking care of connecting with other nodes. Docker and containerd are running at each machine along with kubelet agent. Kube proxy the process which is available at all machines to manage the IP Tables. Kubelet is responsible for managing the node health status and reporting to master node.

API server is available at master node (Control Plane) and it is the point of contact between worker nodes and other components of the control plane. When ever kuberenetes client want to do to some operation at Master it will send request to API server. This will validate the request by authenticating the client and verifies the authorization of the operation what the client wants to do at the cluster or node level.

Once the authentication is successful It will work with etcd to do the expected operation. If it is update of the existing manifest file It will update the copy of the file and stores at etcd. Etcd is the key value store , it is consistent data store for kubernetes cluster. If Kuberbetes cluster client wants to delete pod from the specific namespace it will get triggered to API server. API server will authenticate the client , if it is successful then it will verify that the client is having necessary permissions to delete the pod in that namespace. If both are successful the pod will get deleted from the namespace and parallelly it will get updated at ectd datastore. Please find the API lifecycle at the Fig. 4.

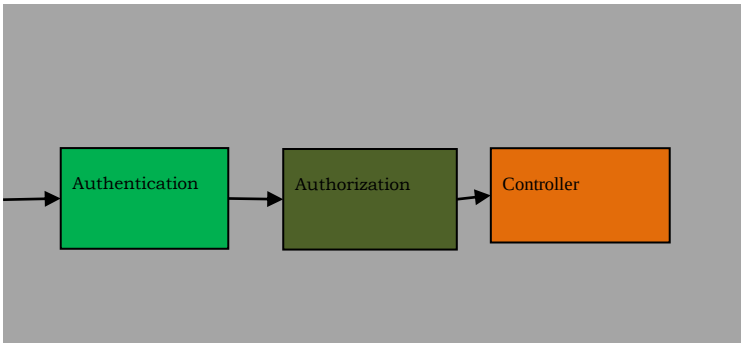


Fig. 5. API Server Life Cycle

Fig. 5 ,6 , 7 and 8 shows the clusters for five node . six node , seven node and eight nodes

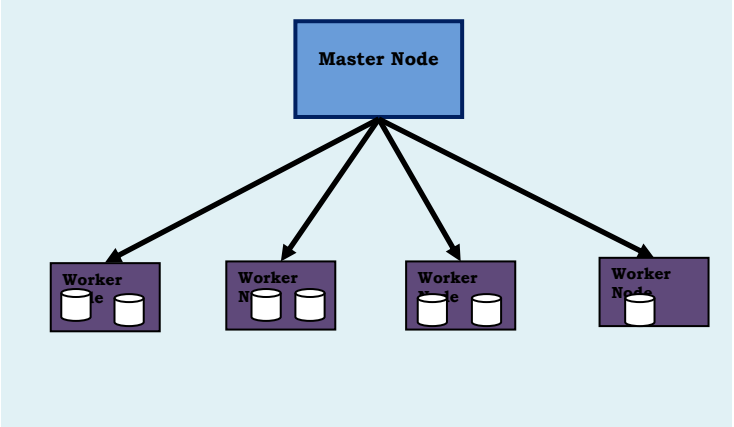


Fig. 6. Five Node Cluster One Master and Four worker Nodes

Pod will get deployed to specific node if there is any node affinity enabled , or else it will get scheduled to any node based on the scheduling algorithm used by the scheduler. Container network interface is the library which will take care of assigning the IP address to pod based on allowable ips from the specific node ips. Ecah node is having different range of ips , and it will get managed by CNI [15]. Flannel is the plugin from the CNI which we have used to implement this functionality. Calico is one more alternative for flannel which we can use. As soon as pods gets deployed to node , kubelet starts reporting to control plane on the health status of the pod.

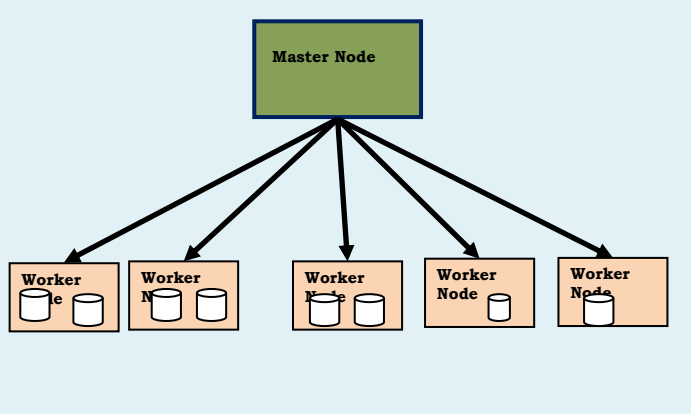


Fig. 7. Six Node Cluster One Master and Five worker Nodes

If we are not defining any storage location to pod , it will get automatic storage inside the container. But the data will get lost for each restart of the pod. This is the reason we can have number of storage classes , where we can attach the volume from the local disk to container. What ever the files we are having at local

to node , they will get exposed to container. Changes will get reflected automatically if we do something at the local files. Converse of this is always true.

If there any environment parameters [16] [22] [30] , we can pads them through env section of the pod manifest files. If there are any changes in the parameters we need to redeploy the pod for each update in the manifest files. To avoid this type of overhead we can deploy them using the configMap object of the kuberentes. This is what is called separation [17] of the parameters from the manifest files. We can do the changes at parameters independent of the pod deployment. The changes will get reflected automatically without having to redeploy the pod.

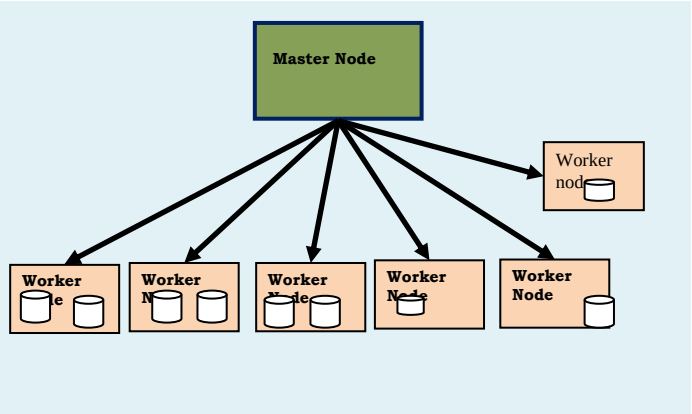


Fig. 8. Seven Node Cluster One Master and Six worker Nodes

We have different types of volumes [18] [21] which we can attach to pod. Need to create the volume (folder) at the node where the pod is getting scheduled. Using Node affinity we can schedule the pod in the expected location. If there is any chance of mismatch in the pod schedule , this architecture will not workout. We can use dynamic volume creation if there is any deployment in production and if we doesn't have access to prod location.

The volume gets created automatically as soon as we deploy the pod. Container Storage Interface [19] [20] [21] will take care of creation of volumes.

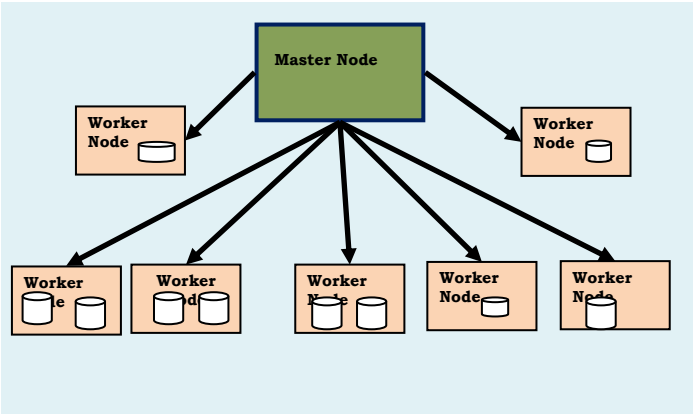


Fig. 9. Eight Node Cluster One Master and Seven worker Nodes

We can connect github location files as well to container using the volume mount plugin in yaml file. We can manage the pod to pod communication using the service abstraction. Since the pod ip is ephermal we need to use service abstraction to connect to pod.

Number of nodes in the cluster is no way related to size of the IP table, but if the number of services , ingress controllers are high in count , it will directly proportional to size of the IP Table. We have three

types of probes in Kubernetes liveness probe , readiness probe and startup probe. First one checks if the application is still running, second one checks if the application is ready to server the traffic and last one checks if the application has started properly.

We have configured different sizes of cluster and with different configurations on volumes like hostPath, gitRepo, emptyDir, nfs.

If there are number of pods working of interconnected functionalty like one pod is working on calculation , second pod is collecting the info from the first pod, where as third pod needs to record the log files. In this each pod needs to have access to another pods storage location or volume.

In this case instead of using the volume at each node , it would be better to define the volume at master location and make it available at all nodes in the cluster. This is what is called Network File System sharing mechanism. We have implemented this service as well.

The size of the IP Table depends on the number of services , as well as the number of pods , network policies , and ingress rules in the cluster irrespective of what is the implementation we are using for IP Tables [26] [27] [28] [29][30].

```yaml
apiVersion: apps/v1
kind: DaemonSet
metadata:
  name: iphashset-metrics
  namespace: kube-system
spec:
  selector:
    matchLabels:
      app: iphashset-metrics
  template:
    metadata:
      labels:
        app: iphashset-metrics
    spec:
      containers:
      - name: iphashset-metrics
        image: busybox
        securityContext:
          privileged: true
        command: ["/bin/sh", "-c"]
        args:
          - |
            # Create IP sets for the metrics
            ipset create iphashset_groupA hash:ip -exist
            ipset create iphashset_groupB hash:ip -exist

            # Time Insertion
            start_insertion=$(date +%s%3N)
            ipset add iphashset_groupA 10.0.1.1 -exist
            end_insertion=$(date +%s%3N)
            insertion_time=$((end_insertion - start_insertion))
            echo "Insertion Time: $insertion_time ms" >> /metrics/iphash_metrics.log

            # Time Lookup
            start_lookup=$(date +%s%3N)
            ipset test iphashset_groupA 10.0.1.1
            end_lookup=$(date +%s%3N)
            lookup_time=$((end_lookup - start_lookup))
            echo "Lookup Time: $lookup_time ms" >> /metrics/iphash_metrics.log
```

```
        # Time Deletion
        start_deletion=$(date +%s%3N)
        ipset del iphashset_groupA 10.0.1.1
        end_deletion=$(date +%s%3N)
        deletion_time=$((end_deletion - start_deletion))
        echo "Deletion Time: $deletion_time ms" >> /metrics/iphash_metrics.log

        # Time Policy Evaluation (using iptables)
        start_policy=$(date +%s%3N)
        iptables -C INPUT -m set --match-set iphashset_groupA src -j ACCEPT -exist
        end_policy=$(date +%s%3N)
        policy_time=$((end_policy - start_policy))
        echo "Policy Evaluation Time: $policy_time ms" >> /metrics/iphash_metrics.log

        # Keep the container running for logging
        sleep infinity
    volumeMounts:
      - name: metrics-volume
        mountPath: /metrics
    resources:
      requests:
        cpu: 100m
        memory: 50Mi
    volumeMounts:
    - mountPath: /lib/modules
      name: modules
      readOnly: true
  volumes:
  - name: metrics-volume
    emptyDir: {}
  - name: modules
    hostPath:
      path: /lib/modules
  hostNetwork: true
  hostPID: true
```

This setup will allow each node to maintain IP hash sets using ipset, useful for managing groups of IP addresses for access control or other network policies. This DaemonSet runs a pod on each Kubernetes node, setting up and managing IP hash sets directly on each node's network stack. Using ipset create, it creates two hash sets: iphashset_groupA and iphashset_groupB.

The -exist option ensures idempotency, avoiding errors if the set already exists. IP addresses are added to each hash set to specify allowed addresses for each group. iptables rules are added for each hash set, allowing traffic from IPs in iphashset_groupA and iphashset_groupB. hostNetwork: true ensures the iptables and ipset configurations apply to the node directly. The privileged: true security context grants the necessary permissions.

After deploying the daemonset , it deploys the pods on each node. After applying, you can check the logs for successful execution or troubleshoot any issues using kubectl log command. This approach allows efficient, node-specific IP-based traffic management and ensures a scalable, maintainable setup across Kubernetes nodes.

We have deployed daemon set at kube-system namespace, it is getting accommodated at all nodes in the cluster. It doesn't matter about dynamic increase or decrease of the number of nodes. We have taken the busybox image and ran the commands inside the docker container and invoking the multiple IPHash set and collected start insertion and end insertion, difference of the same. End lookup and start lookup and difference of the same,, end deletion , start deletion , difference of the same, end policy , start policy and difference of the same. Like we have found lookup time, insertion , deletion times and policy evaluation time. These parameters are getting at all machines in the corresponding log files.

Timing Operations, $(date +%s%3N) captures the current time in milliseconds. Each operation (insertion, lookup, deletion, policy evaluation) is timed, and the elapsed time is calculated and logged.

Logging Results, Each timing metric is logged in /metrics/iphash_metrics.log, which can be accessed by examining the logs of the running pod.

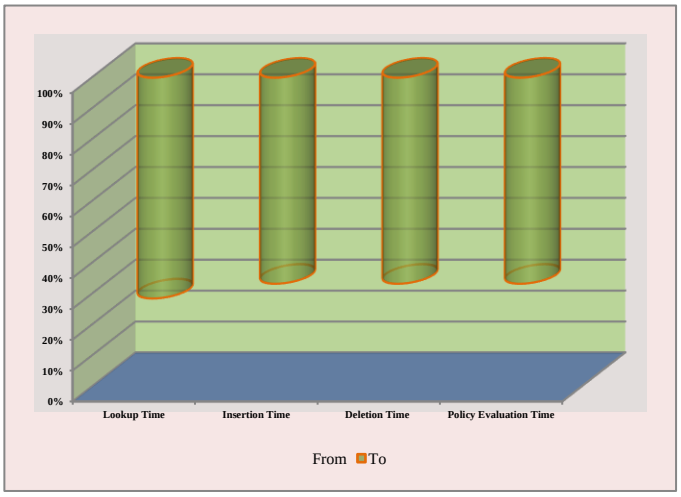
Persistent Logging (Optional), If you want to retain metrics logs across pod restarts or make them centrally accessible, you could mount a persistent volume or use a logging sidecar.

Please find the different parameters which we had using the previous code.

Metric	From	To
Lookup Time	2	5
Insertion Time	10	20
Deletion Time	10	20
Policy Evaluation Time	100	200

Table 9: Multiple IP Hash Set-1

Table 9 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 2 micro seconds to 5 micro seconds. Insertion time is from the range 20 micro seconds to 20 micro seconds. Deletion time is from the range 10 micro seconds to 20 micro seconds and Policy evaluation time is from the range 100 micro seconds to 200 micro seconds.



Graph 6: **Multiple IP Hash Set-1**

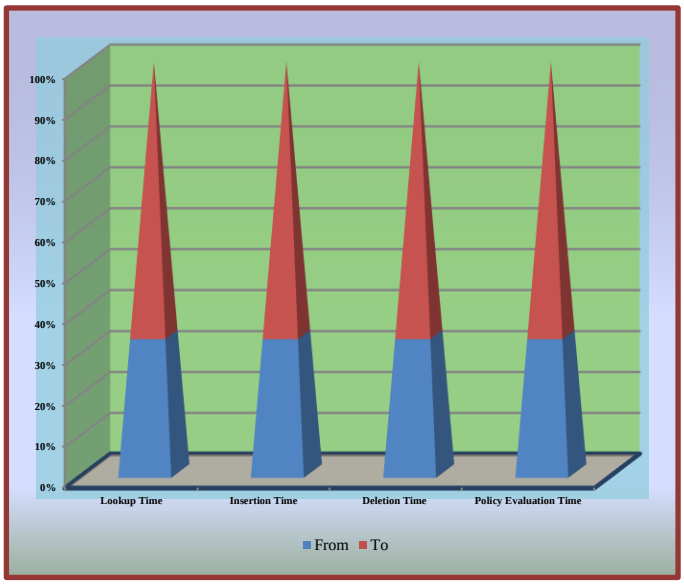
Graph 6 shows the From and to values but not showing from zero, Please observe the same.

Metric	From	To
Lookup Time	5	10
Insertion Time	15	30
Deletion Time	15	30
Policy Evaluation Time	1000	2000

Table 10: Multiple IP Hash Set-2

Table 9 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 5 micro seconds to 10 micro seconds. Insertion time is from the range 15 micro seconds to 30 micro seconds.

Deletion time is from the range 15 micro seconds to 30 micro seconds and Policy evaluation time is from the range 1000 micro seconds to 2000 micro seconds.



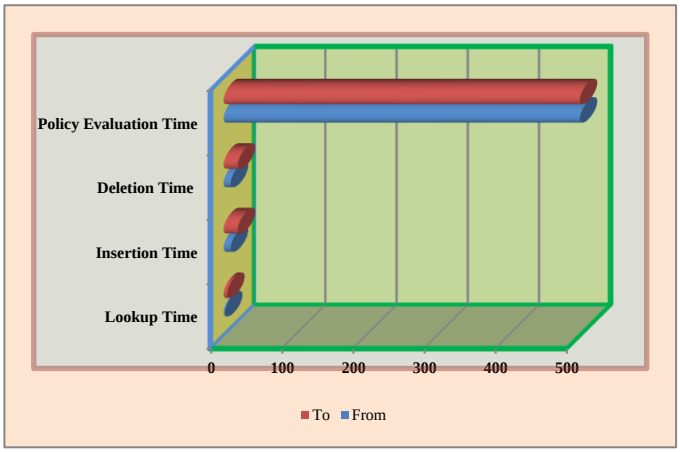
Graph 7: **Multiple IP Hash Set-2**

Graph 7 shows the From and to values or all the parameters like lookup time, insertion time, deletion time and policy evaluation time.

Metric	From	To
Lookup Time	2	5
Insertion Time	10	20
Deletion Time	10	20
Policy Evaluation Time	2000	4000

Table 11: Multiple IP Hash Set-3

Table 11 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 2 micro seconds to 5 micro seconds. Insertion time is from the range 10 micro seconds to 20 micro seconds. Deletion time is from the range 10 micro seconds to 20 micro seconds and Policy evaluation time is from the range 2000 micro seconds to 4000 micro seconds.



Graph 8: **Multiple IP Hash Set-3**

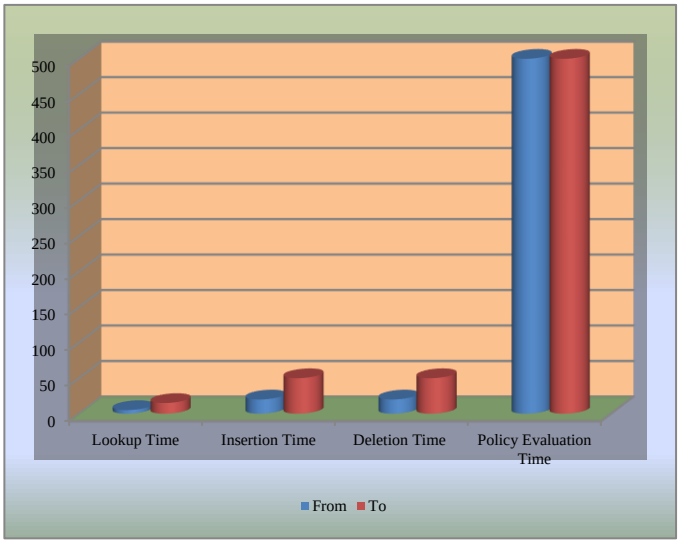
Graph 8 shows the From and to values or all the parameters like lookup time, insertion time, deletion time

and policy evaluation time.

Metric	From	To
Lookup Time	5	15
Insertion Time	20	50
Deletion Time	20	50
Policy Evaluation Time	1500	3000

Table 12: Multiple IP Hash Set-4

Table 12 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 5 micro seconds to 15 micro seconds. Insertion time is from the range 20 micro seconds to 50 micro seconds. Deletion time is from the range 20 micro seconds to 50 micro seconds and Policy evaluation time is from the range 1500 micro seconds to 3000 micro seconds.



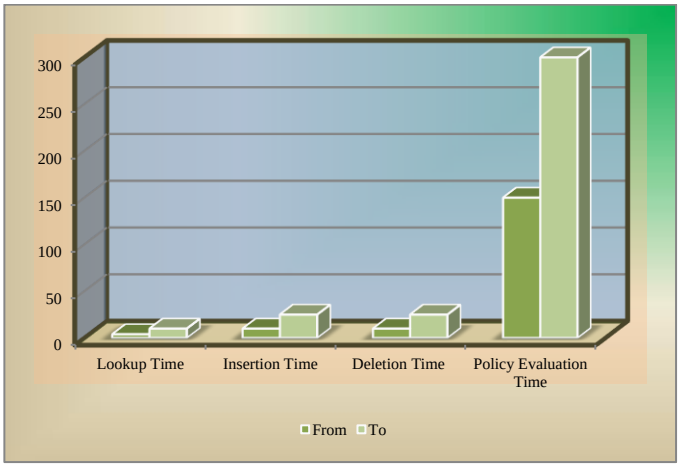
Graph 9: **Multiple IP Hash Set-4**

Graph 9 shows the From and to values or all the parameters like lookup time, insertion time, deletion time and policy evaluation time.

Metric	From	To
Lookup Time	4	10
Insertion Time	10	25
Deletion Time	10	25
Policy Evaluation Time	150	300

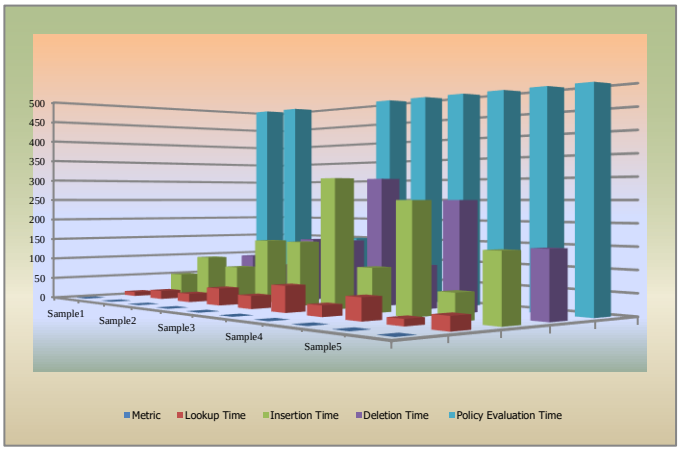
Table 13: Multiple IP Hash Set-5

Table 13 shows the parameters like lookup time, insertion time, deletion time and policy evaluation time while using Single IP Hash set for storing the IP addresses in IP Tables. Lookup time is in the range from 4 micro seconds to 10 micro seconds. Insertion time is from the range 20 micro seconds to 25 micro seconds. Deletion time is from the range 10 micro seconds to 25 micro seconds and Policy evaluation time is from the range 150 micro seconds to 300 micro seconds.

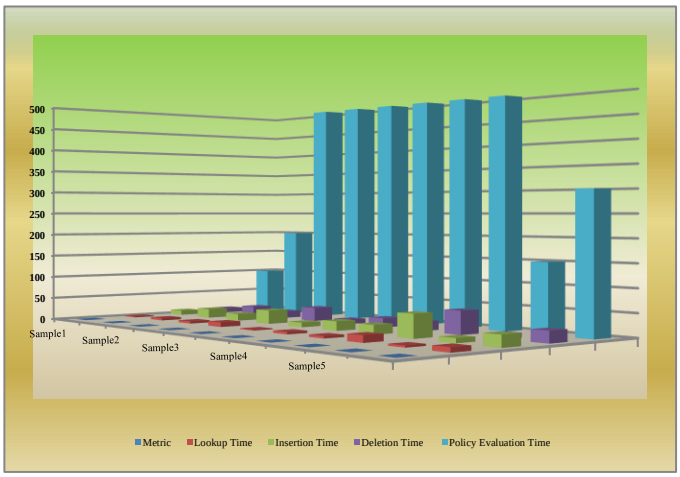


Graph 10: **Multiple IP Hash Set-5**

Graph 10 shows the From and to values or all the parameters like lookup time, insertion time, deletion time and policy evaluation time.

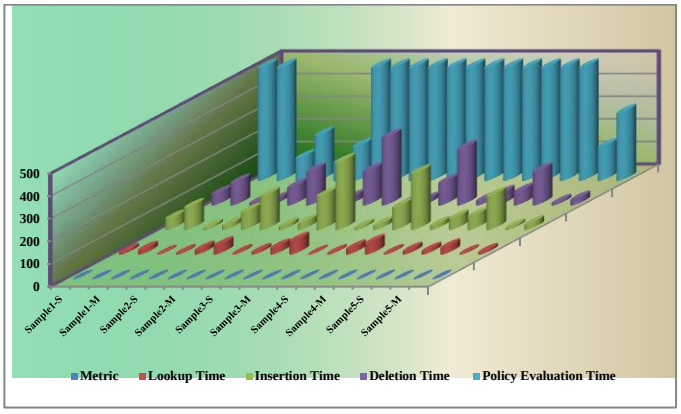


Graph 11: **Single IP Hash Set**



Graph 12: **Multiple IP Hash Set**

Graph 11 and 12 shows the statistics for single IPHash set and Multiple IPHash Set for different parameters like lookup speed, insertion time, deletion time and policy evaluation time.



Graph 13: **Single IP Hash Set** Vs **Multiple IP Hash Set**

Graph 13 shows that single IP Hashset statistics are higher than Multi HashSet IP statistics. Suppose in Single IP Hash set IP configuration , lookup speed is 10 to 20 range where it is 2 to 5 range in multiple IP Hash set configuration. Insertion time is 50 to 100 range and it is 10 to 20 range in multiple IP Hash set configuration. Deletion time is 50 to 100 range in single IP Hash set , where it is 10 to 20 range in multiple IP Hash Set configuration. Policy evaluation time is 500 to 1000 in Single IP Hash set configuration where it is 100 to 200 in multi IP Hash set configuration.

In sample 2 in Single IP Hash set IP configuration , lookup speed is 20 to 40 range where it is 5 to 10 range in multiple IP Hash set configuration. Insertion time is 80 to 150 range and it is 15 to 30 range in multiple IP Hash set configuration. Deletion time is 80 to 150 range in single IP Hash set , where it is 15 to 30 range in multiple IP Hash Set configuration. Policy evaluation time is 80 to 150 in Single IP Hash set configuration where it is 1000 to 2000 in multi IP Hash set configuration.

In sample 3 in Single IP Hash set IP configuration , lookup speed is 30 to 60 range where it is 2 to 5 range in multiple IP Hash set configuration. Insertion time is 150 to 300 range and it is 10 to 20 range in multiple IP Hash set configuration. Deletion time is 150 to 300 range in single IP Hash set , where it is 10 to 20 range in multiple IP Hash Set configuration. Policy evaluation time is 2000 to 4000 in Single IP Hash set configuration where it is 2000 to 4000 in multi IP Hash set configuration.

In sample 4 in Single IP Hash set IP configuration , lookup speed is 25 to 50 range where it is 5 to 15 range in multiple IP Hash set configuration. Insertion time is 100 to 250 range and it is 20 to 50 range in multiple IP Hash set configuration. Deletion time is 100 to 50 range in single IP Hash set , where it is 20 to 50 range in multiple IP Hash Set configuration. Policy evaluation time is 1500 to 3000 in Single IP Hash set configuration where it is 1500 to 3000 in multi IP Hash set configuration.

In sample 5 in Single IP Hash set IP configuration , lookup speed is 15 to 30 range where it is 4 to 10 range in multiple IP Hash set configuration. Insertion time is 60 to 150 range and it is 10 to 25 range in multiple IP Hash set configuration. Deletion time is 60 to 50 range in single IP Hash set , where it is 10 to 25 range in multiple IP Hash Set configuration. Policy evaluation time is 800 to 1500 in Single IP Hash set configuration where it is 150 to 300 in multi IP Hash set configuration.

EVALUATION

The comparison of Single I Hashset configuration with Multiple IP Hash aet configuration shows that in sample1 lookup time is reduced to 20% , where as insertion time , deletion time reduced to 50% , and policy evalution time reduced to 500%.

In sample 2 , lookup time is reduced to 50% , where as insertion time , deletion time reduced to 50% , and

policy evalution time reduced to 50%.

In sample 3 , lookup time is reduced to 150% , where as insertion time , deletion time reduced to 150% , and policy evalution time reduced to 150%.

In sample 4, lookup time is reduced to 500% , where as insertion time , deletion time reduced to 75% , and policy evalution time reduced to 200%.

In sample 5, lookup time is reduced to 400% , where as insertion time , deletion time reduced to 600% , and policy evalution time reduced to 500%.

CONCLUSION

We have configured three node , four node , five node , six node , seven node , eight node , nine node and ten node clusters with 32 CPU, 64 GB and 500GB for master node and 24 CPU , 32 GB and 350 GB for all worker nodes.

IP Table size is no way related to cluster size (number of nodes). size of the IP table is influenced by the number of pods, services, and network policies**,** it is not a direct measure of the cluster size (i.e., the number of nodes). Instead, it is more closely related to the complexity of the network configuration in the cluster.

A larger cluster with many pods and services, especially if there are complex network policies or ingress configurations, will likely result in a larger IP table.

I have tested the performance of ip tables having single IP Hash set and multiple IP Hash set , and shown in the table and graphs multi IP Hash set configuration of IP Tables is giving high performance compared to single hash set IP configuration. The main reason here is it is following the set associative concept , where it is storing all the related items in one set , so that it is easy to access the set number like index number and scanning the reaming number already stored at the set. With this we can conclude that implementing the IP Tables using Multi Set IP Hash set configuration gives best performance.

We didn't cover the concept of CPU utilization in this paper. Smaller IP HashSets decreases the CPU usage. The future work includes working on the smaller IPHash Sets and proving that smaller sets will consume less CPU resource.

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