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Packet Walk(s) In Kubernetes

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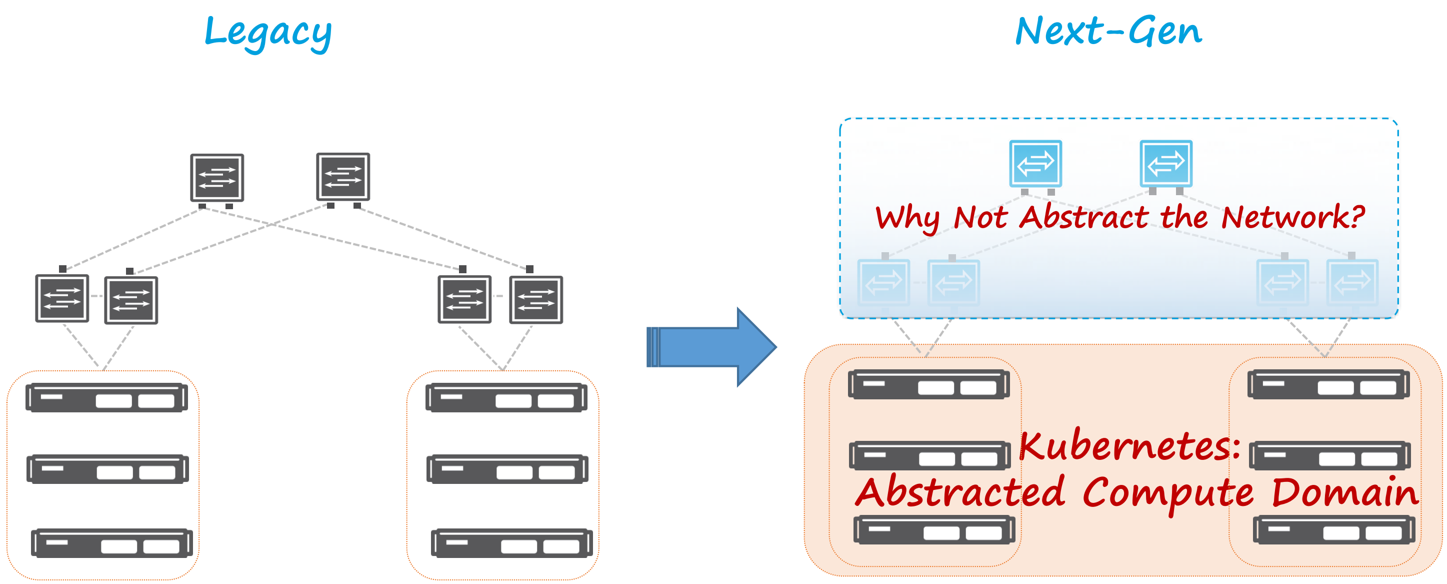
About

About Big Switch

- We are in the business of "Abstracting Networks" (As one Big Switch) using Open Networking Hardware

About Me

- Spent 4 years in Engineering building our products. Now in Technical Product Management



http://www.youtube.com/watch?v=HIAXp0-M6SY&t=0m43s

Agenda

Intro: K8S Networking

- Namespace/Pods/CNIs?
- What's that "Pause" Container really do?
- Flannel: Intro / Packet Flows
- Exposing Services

Calico: Networking

- Architecture
- IP-IP Mode (Route formation / Pod-to-pod communication / ARP Resolution/ Packet Flow)
- BGP Mode (Peering requirements/ Packet Flow)

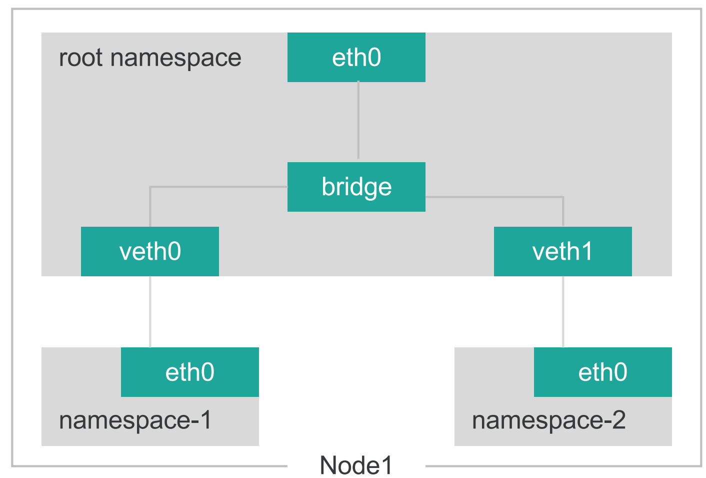
Cilium: Networking

- Architecture
- Overlay Network Mode (Configuration/ Pod-to-pod communication/ Datapath / ARP Resolution/ Packet Flow)
- Direct Routing Mode

K8S Networking: Basics

Namespaces

- Linux kernel has 6 types of namespaces: pid, **net**, mnt, uts, ipc, user
- Network namespaces provide a brand-new network stack for all the processes within the namespace
- That includes **network interfaces**, **routing tables** and **iptables rules**



K8S Networking: Basics

Pods

- Lowest common denominator in K8S. Pod is comprised of one or more containers along with a “pause” container
- Pause container act as the “parent” container for other containers inside the pod. One of it’s primary responsibilities is to bring up the network namespace
- Great for the redundancy: Termination of other containers do not result in termination of the network namespace

```
[root@Master1 ~]# kubectl get pods --namespace web -o wide
NAME                               READY   STATUS    AGE    IP              NODE
nginx-deployment-76bf4969df-5xzv7  1/1     Running   7m53s  172.31.155.17   Worker-1
```

```
[root@Worker-1 ~]# docker ps
CONTAINER ID    IMAGE                      COMMAND                  CREATED          NAMES
93490bfce728    docker.io/nginx@sha256     "nginx -g 'daemon off'"  47 seconds ago   k8s_nginx_nginx-deployment
2ef012ea5db0    k8s.gcr.io/pause:3.1       "/pause"                 57 seconds ago   k8s_POD_nginx-deployment
```

K8S Networking: Basics

Accessing Pod Namespaces

- Multiple ways to access pod namespaces
- 'kubectl exec --it'
- 'docker exec --it'
- nsenter ("**na**mespace **enter**", let you run commands that are installed on the host but not on the container)

```
[root@worker-1 ~]# docker ps
CONTAINER ID        IMAGE                  COMMAND             CREATED             NAMES
5b54f2a44c3b        d8233ab899d4           "sleep 3600"        35 minutes ago      k8s_busybox_busybox0-6hc7c
43e42c45522b        k8s.gcr.io/pause:3.1   "/pause"            10 hours ago        k8s_POD_busybox0-6hc7c
```

```
[root@worker-1 ~]# docker inspect -f '{{.State.Pid}}' 5b54f2a44c3b
21388

[root@worker-1 ~]# nsenter -t 21388 -n ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
17: eth0@if18: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP
    link/ether fa:4d:26:0b:4a:c7 brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet 192.168.1.196/32 brd 192.168.1.196 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::f84d:26ff:fe0b:4ac7/64 scope link
       valid_lft forever preferred_lft forever
[root@worker-1 ~]#
```

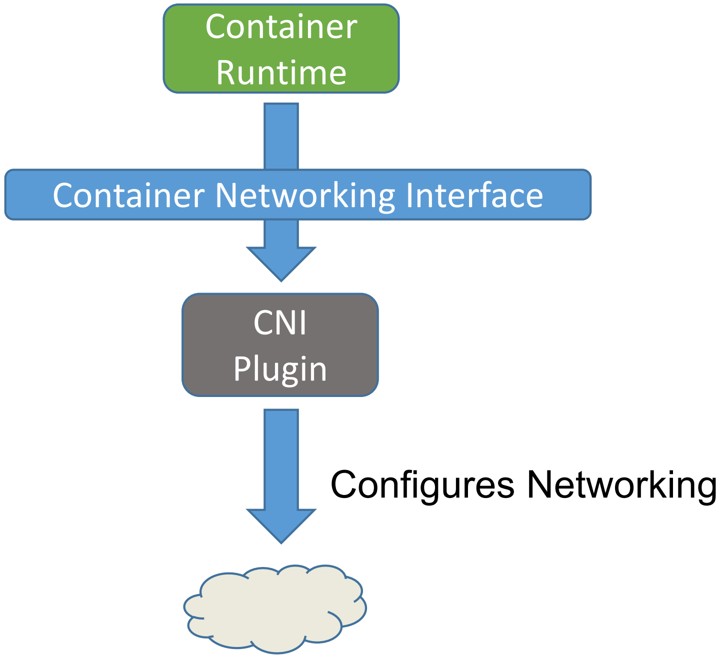
```
[root@worker-1 ~]# docker inspect -f '{{.State.Pid}}' 43e42c45522b
8112

[root@worker-1 ~]# nsenter -t 8112 -n ip a
1: lo: <LOOPBACK,UP,LOWER_UP> mtu 65536 qdisc noqueue state UNKNOWN qlen 1000
    link/loopback 00:00:00:00:00:00 brd 00:00:00:00:00:00
    inet 127.0.0.1/8 scope host lo
       valid_lft forever preferred_lft forever
    inet6 ::1/128 scope host
       valid_lft forever preferred_lft forever
17: eth0@if18: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP
    link/ether fa:4d:26:0b:4a:c7 brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet 192.168.1.196/32 brd 192.168.1.196 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::f84d:26ff:fe0b:4ac7/64 scope link
       valid_lft forever preferred_lft forever
[root@worker-1 ~]#
```

Both containers belong to the same pod => Same Network Namespace => same 'ip a' output

K8S Networking: Basics

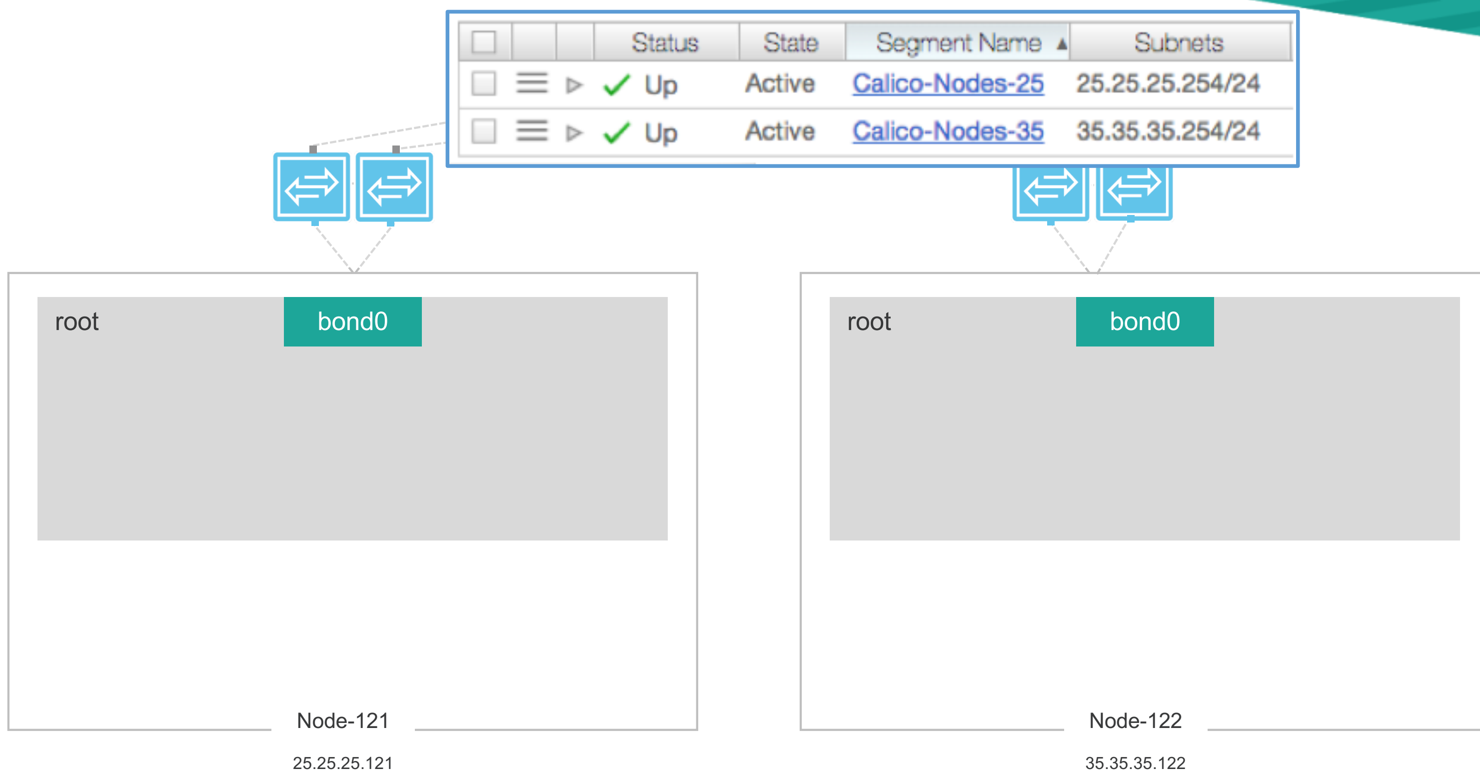
Container Networking Interface : CNI

- Interface between container runtime and network implementation
- Network plugin implements the CNI spec. It takes a container runtime and configure (attach/detach) it to the network
- CNI plugin is an executable (in: /opt/cni/bin)
- When invoked it reads in a JSON config & Environment Variables to get all the required parameters to configure the container with the network



Credit:https://www.slideshare.net/weaveworks/introduction-to-the-container-network-interface-cni

Topology



Topology Info

- Node IP belongs to 2 different subnets: 25.25.25.0/24 & 35.35.35.0/24
- Gateway is configured with .254 in the network for each network segment
- Bond0 interface is created by bonding two 10G interfaces

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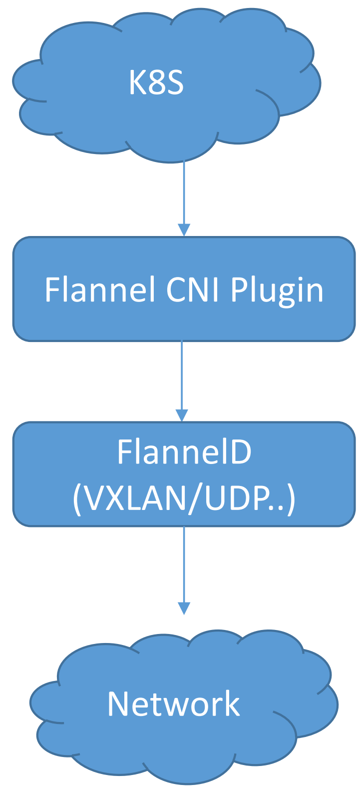
Flannel

Intro

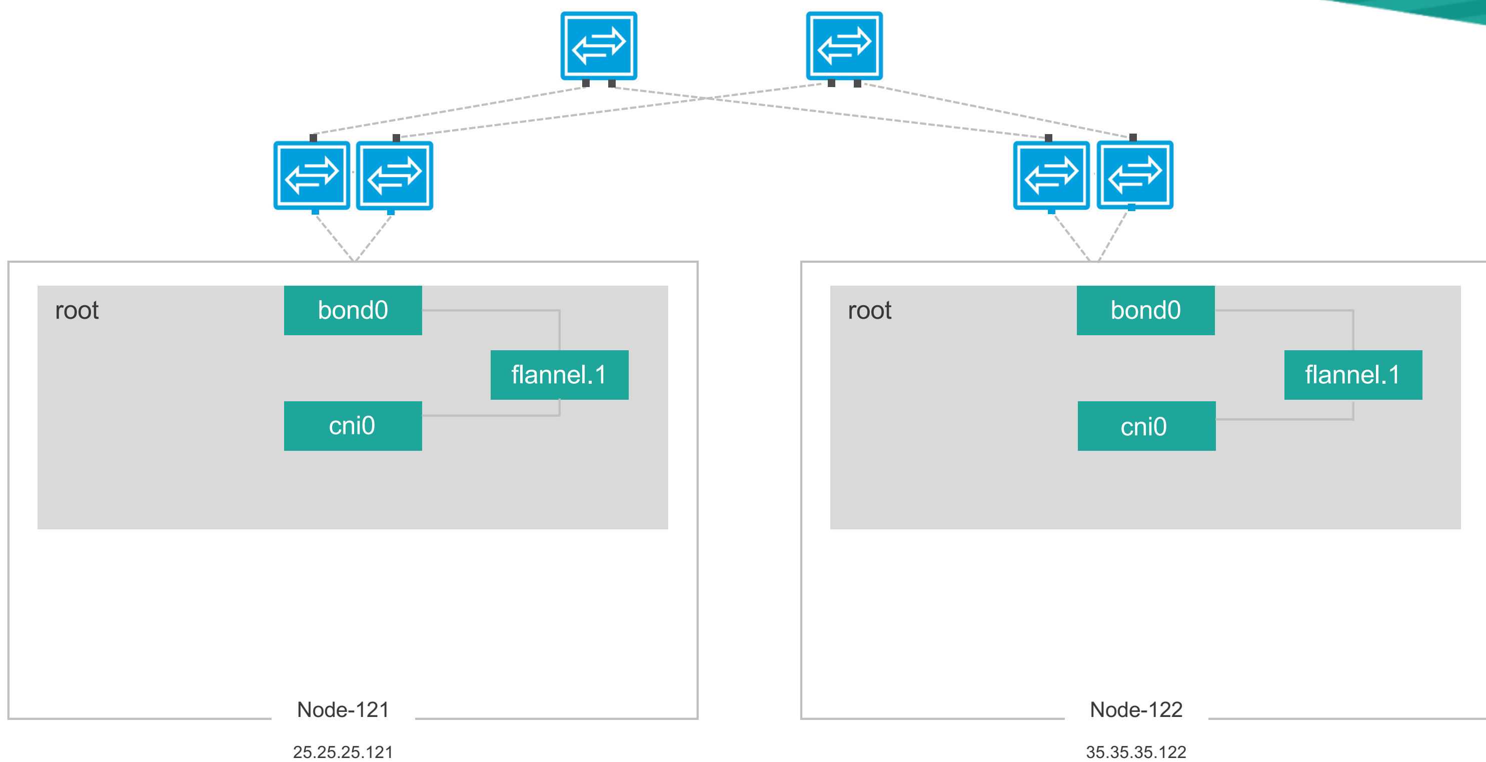
- To make networking easier, Kubernetes does away with port-mapping and assigns a unique IP address to each pod
- If a host cannot get an entire subnet to itself things get pretty complicated
- Flannel aims to solve this problem by creating an overlay mesh network that provisions a subnet to each server



Flannel

Default Config

- “Flannel.1” Is the VXLAN interface
- CNI0 is the bridge



Flannel

```
$ kubectl get pods -n test -o wide
NAME             READY     STATUS    RESTARTS   AGE    IP            NODE
busybox0-nzxgg   1/1       Running   10         10h    10.244.1.2    flannel-node-18121
busybox0-6qrqm   1/1       Running   9          10h    10.244.2.2    flannel-node-18122
```

Pod-to-Pod Communication

- Brought up 2 pods

notice the index on veth.
eg: "eth0@if12" on pod1 ns corresponds to 12th interface on the root ns

Flannel

Pod-to-Pod Communication

- VETH Interface with "veth-" got created on the root namespace
- Other end is attached to the pod namespace

```
[root@flannel-node-18121 ~]# ip a
11: cni0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1450 qdisc noqueue state UP qlen 1000
    link/ether 0a:58:0a:f4:01:01 brd ff:ff:ff:ff:ff:ff
    inet 10.244.1.1/24 scope global cni0
       valid_lft forever preferred_lft forever
    inet6 fe80::906e:29ff:fe39:26f7/64 scope link
       valid_lft forever preferred_lft forever
12: vetha0e32af3@if3: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1450 qdisc noqueue master cni0 state UP
    link/ether 9e:1c:eb:bf:e8:b3 brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet6 fe80::9c1c:ebff:febf:e8b3/64 scope link
       valid_lft forever preferred_lft forever
```

```
[root@flannel-node-18122 ~]# ip a
11: cni0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1450 qdisc noqueue state UP qlen 1000
    link/ether 0a:58:0a:f4:02:01 brd ff:ff:ff:ff:ff:ff
    inet 10.244.2.1/24 scope global cni0
       valid_lft forever preferred_lft forever
    inet6 fe80::3c3b:29ff:fe29:286d/64 scope link
       valid_lft forever preferred_lft forever
12: veth047ac7bb@if3: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1450 qdisc noqueue master cni0 state UP
    link/ether 06:8c:15:09:9f:63 brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet6 fe80::48c:15ff:fe09:9f63/64 scope link
       valid_lft forever preferred_lft forever
```


```
$ kubectl exec -it busybox0-nzxgg -n test /bin/sh
/ # ip a
3: eth0@if12: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1450 qdisc noqueue
    link/ether 0a:58:0a:f4:01:02 brd ff:ff:ff:ff:ff:ff
    inet 10.244.1.2/24 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::4c4e:5bff:fe16:dbf9/64 scope link
       valid_lft forever preferred_lft forever
/ #
```

```
$ kubectl exec -it busybox0-6qrqm -n test /bin/sh
/ # ip a
3: eth0@if12: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1450 qdisc noqueue
    link/ether 0a:58:0a:f4:02:02 brd ff:ff:ff:ff:ff:ff
    inet 10.244.2.2/24 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::2c16:d4ff:fef6:85c9/64 scope link
       valid_lft forever preferred_lft forever
/ #
```

Flannel

```
$ kubectl get pods -n test -o wide
NAME             READY   STATUS    RESTARTS   AGE   IP           NODE
busybox0-nzxgg   1/1     Running   10         10h   10.244.1.2   flannel-node-18121
busybox0-6qrqm   1/1     Running   9          10h   10.244.2.2   flannel-node-18122
```

ARP Handling

- 'cni0' bridge is replying to ARP requests from the pod

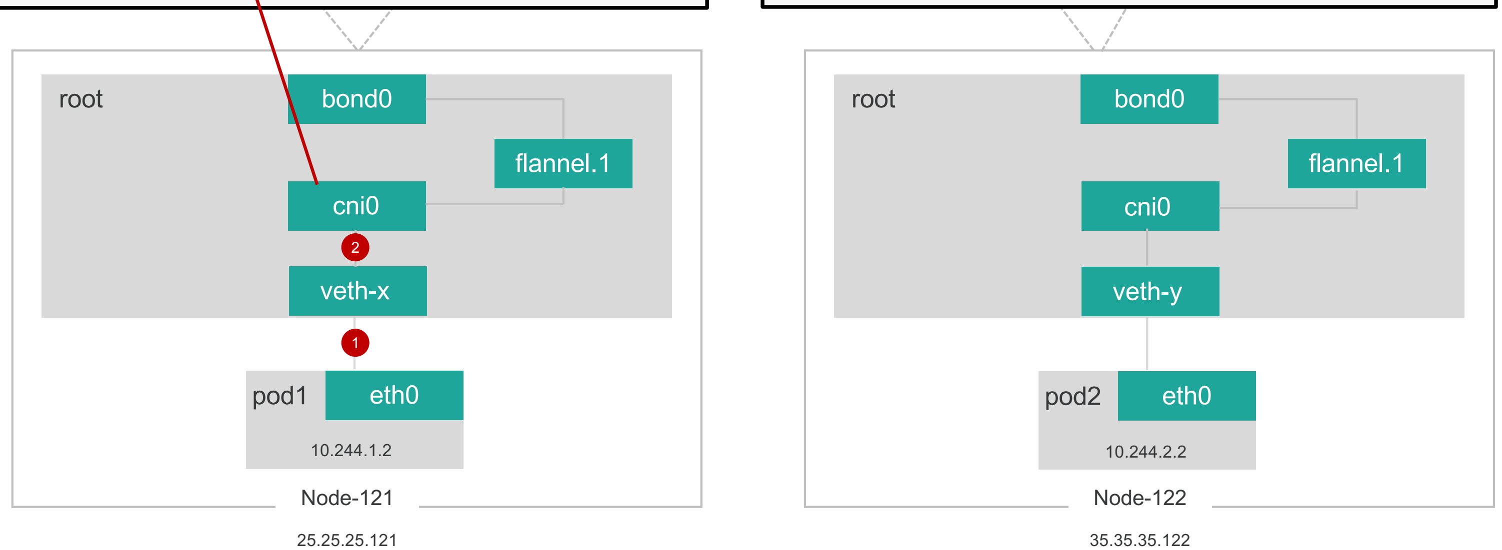
Flannel

Packet Flow

- Routing table lookup to figure out where to send the packet

```
[root@flannel-node-18121 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.244.1.0      0.0.0.0         255.255.255.0   U     0      0        0 cni0
10.244.2.0      10.244.2.0      255.255.255.0   UG    0      0        0 flannel.1
25.25.25.0      0.0.0.0         255.255.255.0   U     0      0        0 bond0
35.35.35.0      25.25.25.254    255.255.255.0   UG    0      0        0 bond0
[root@flannel-node-18121 ~]#
```

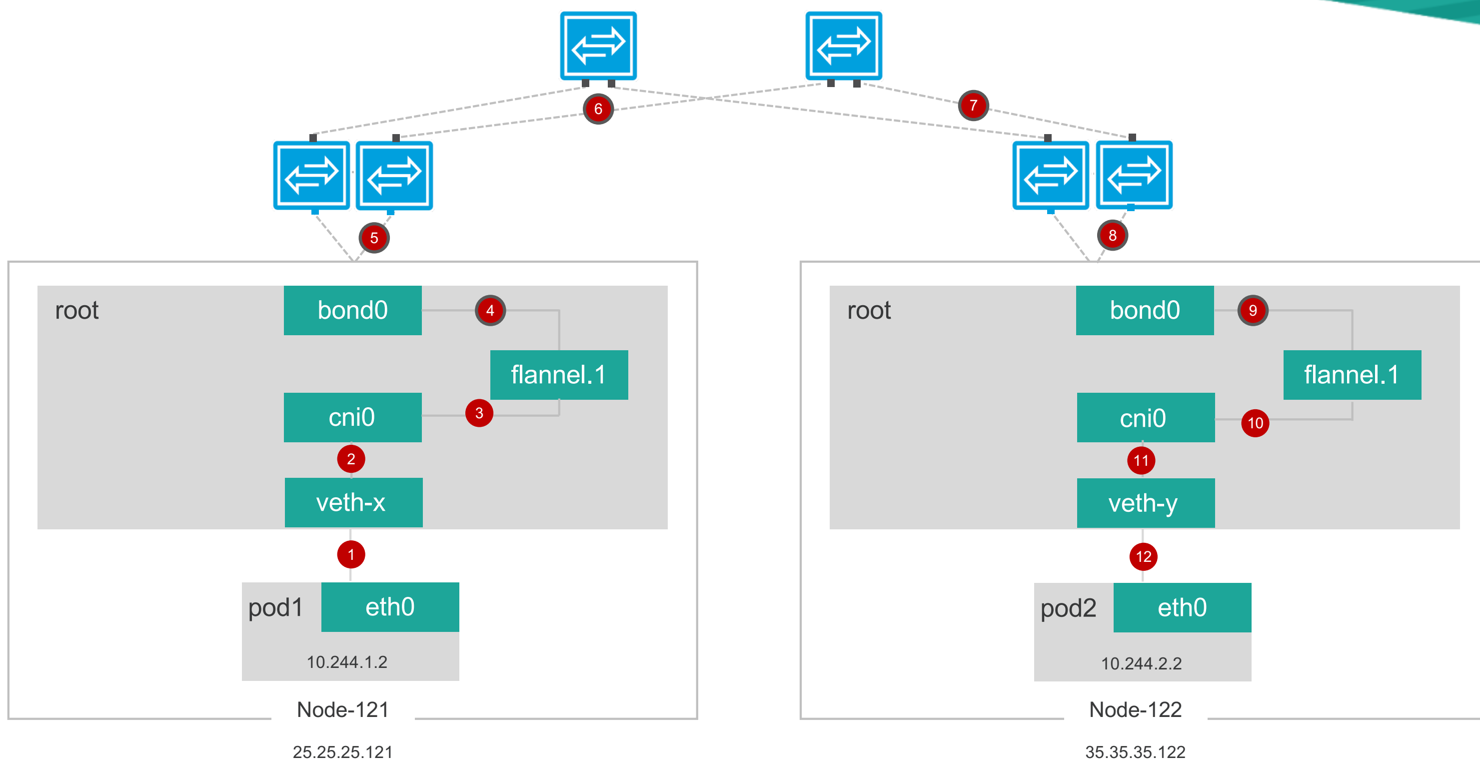
```
[root@flannel-node-18122 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
10.244.1.0      10.244.1.0      255.255.255.0   UG    0      0        0 flannel.1
10.244.2.0      0.0.0.0         255.255.255.0   U     0      0        0 cni0
25.25.25.0      35.35.35.254    255.255.255.0   UG    0      0        0 bond0
35.35.35.0      0.0.0.0         255.255.255.0   U     0      0        0 bond0
[root@flannel-node-18122 ~]#
```



Flannel

Packet Flow

- Flannel.1 device does VXLAN encap/decap
- Traffic from pod1 is going through "flannel.1" device before exiting



Calico

Felix

- The primary Calico agent that runs on each machine that hosts endpoints.
- Responsible for programming routes and ACLs, and anything else required on the host

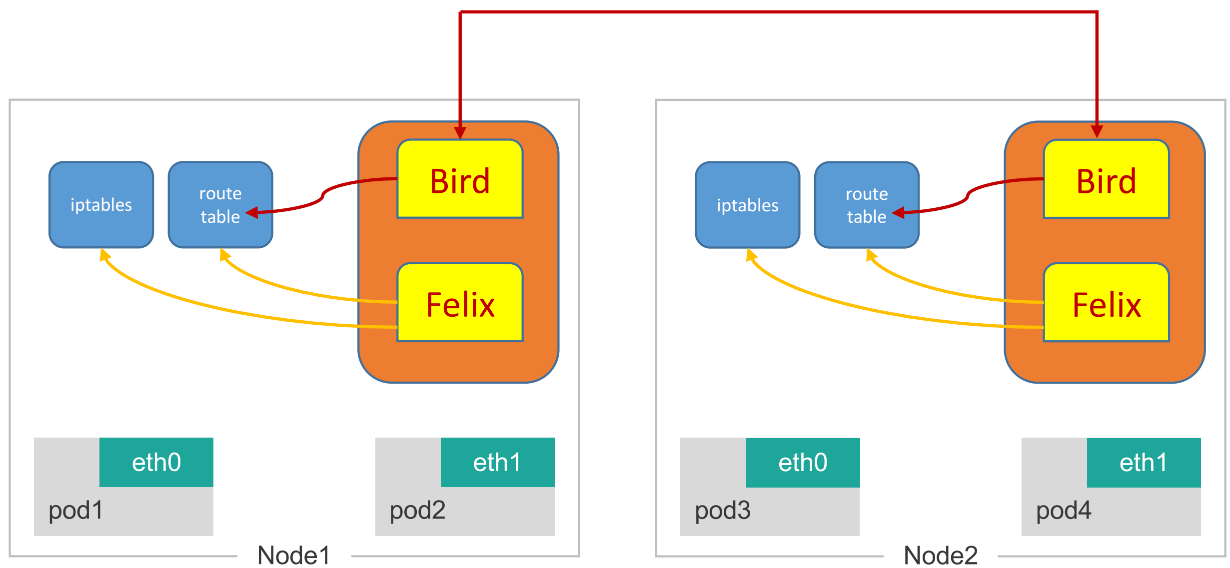
Bird

- BGP Client: responsible of route distribution
- When Felix inserts routes into the Linux kernel FIB, Bird will pick them up and distribute them to the other nodes in the deployment

Calico

Architecture

- Felix's primary responsibility is to program the host's iptables and routes to provide the connectivity to pods on that host.
- Bird is a BGP agent for Linux that is used to exchange routing information between the hosts. The routes that are programmed by Felix are picked up by bird and distributed among the cluster hosts



*etcd/confd components are not shown for clarity

Calico

Default Configuration

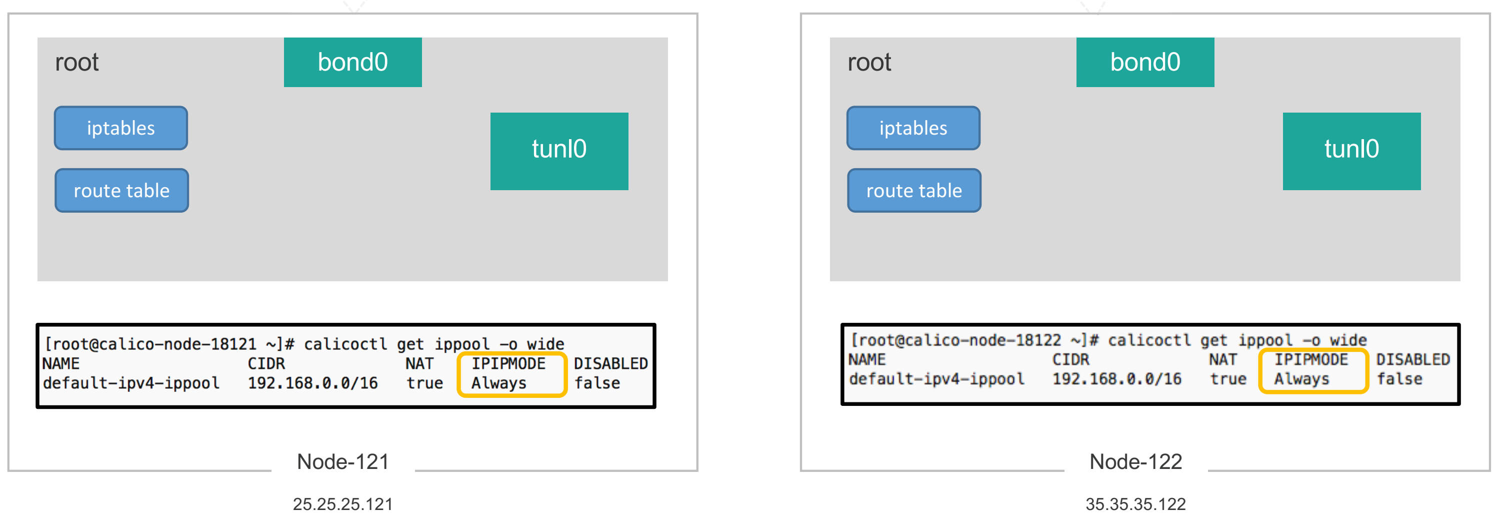
- Node-to-node mesh
- IP-IP encapsulation

```
[root@calico-node-18121 ~]# calicoctl node status
Calico process is running.

IPv4 BGP status
+--------------+-------------------+-------+------------+-------------+
| PEER ADDRESS |     PEER TYPE     | STATE |   SINCE    |    INFO     |
+--------------+-------------------+-------+------------+-------------+
| 35.35.35.122 | node-to-node mesh | up    | 2019-03-20 | Established |
+--------------+-------------------+-------+------------+-------------+
```

```
[root@calico-node-18122 ~]# calicoctl node status
Calico process is running.

IPv4 BGP status
+--------------+-------------------+-------+------------+-------------+
| PEER ADDRESS |     PEER TYPE     | STATE |   SINCE    |    INFO     |
+--------------+-------------------+-------+------------+-------------+
| 25.25.25.121 | node-to-node mesh | up    | 2019-03-20 | Established |
+--------------+-------------------+-------+------------+-------------+
```




```
[root@calico-node-18121 ~]# calicoctl get ippool -o wide
NAME                 CIDR             NAT    IPIPMODE   DISABLED
default-ipv4-ippool  192.168.0.0/16   true   Always     false
```

```
[root@calico-node-18122 ~]# calicoctl get ippool -o wide
NAME                 CIDR             NAT    IPIPMODE   DISABLED
default-ipv4-ippool  192.168.0.0/16   true   Always     false
```

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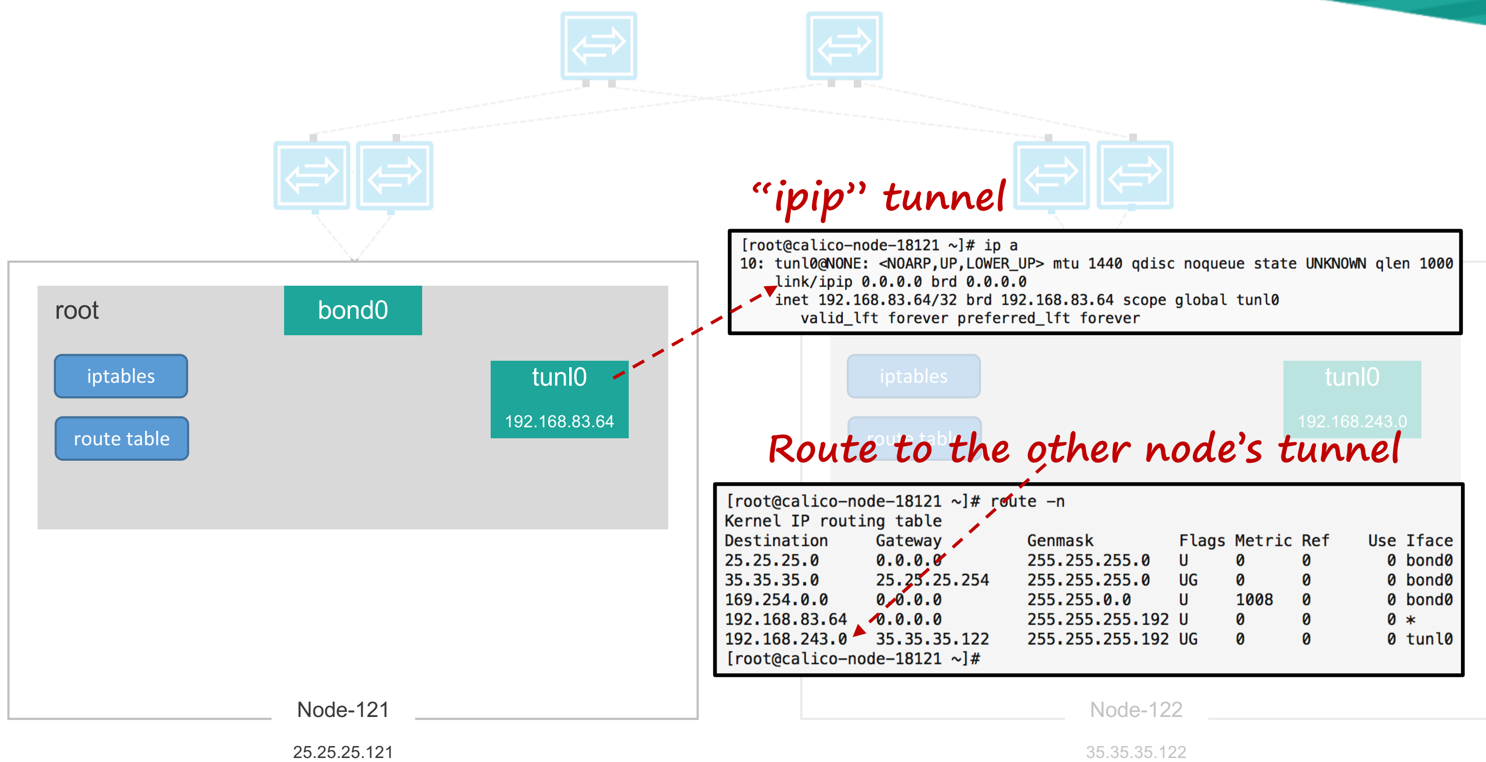
Calico

Default Configuration

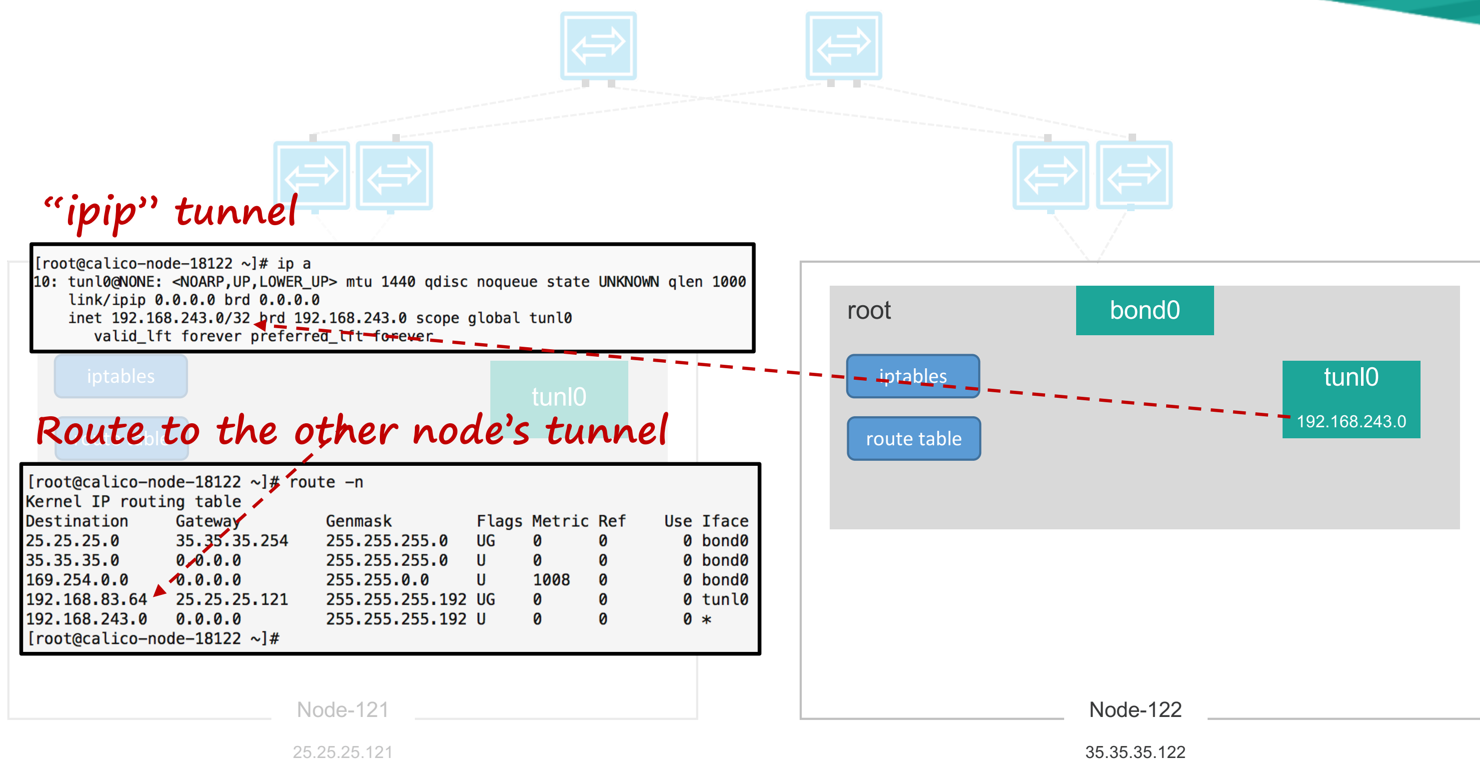
- Default: Node Mesh with IP-IP tunnel
- Route table has entries to all the other tunl0 interfaces through other node IPs



Calico

Default Configuration

- Default: Node Mesh with IP-IP tunnel
- Route table has entries to all the other tunl0 interfaces through other node IPs



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Calico

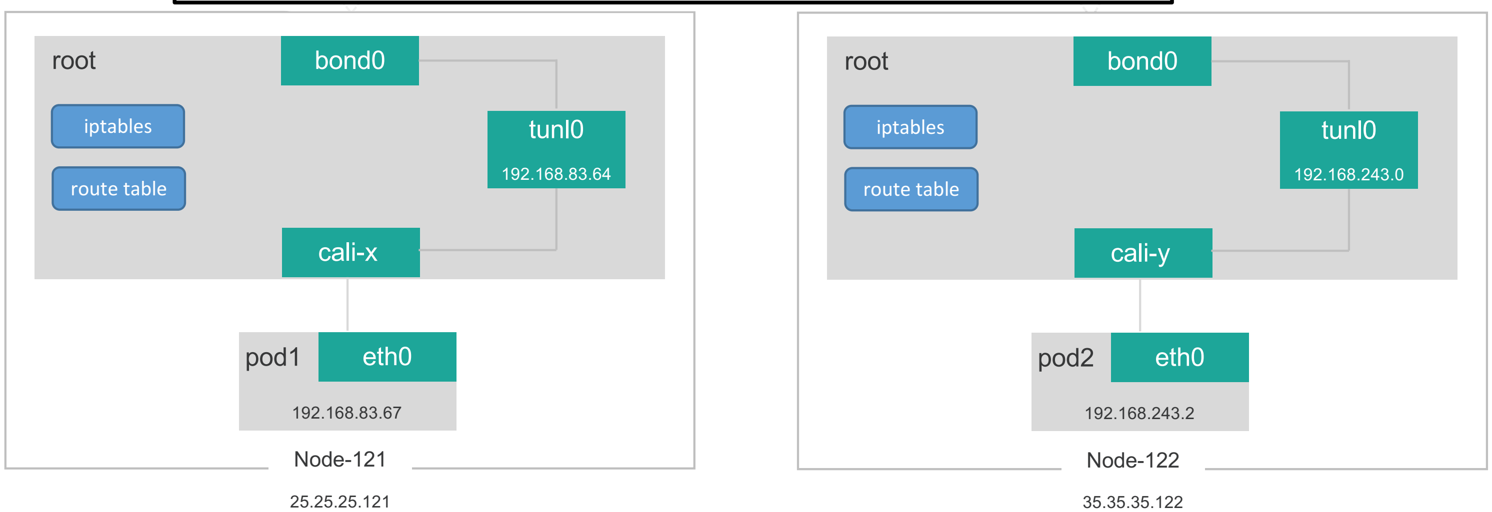
```
$ kubectl get pods -n test -o wide
NAME             READY   STATUS    RESTARTS   AGE   IP                NODE
busybox0-4ldqp   1/1     Running   0          13s   192.168.83.67     calico-node-18121
busybox0-c4bl8   1/1     Running   0          13s   192.168.243.2     calico-node-18122
```

veth interfaces

```
$ calicoctl get wep -n test -o wide
NAMESPACE   WORKLOAD         NODE                NETWORKS             INTERFACE
test        busybox0-4ldqp   calico-node-18121   192.168.83.67/32     cali4e7dc5a6ea0
test        busybox0-c4bl8   calico-node-18122   192.168.243.2/32     cali596577171e6
```

Pod-to-Pod Communication

- Brought up 2 pods
- “calicoctl get wep” (”workloadendpoints”) shows the endpoints in calico end



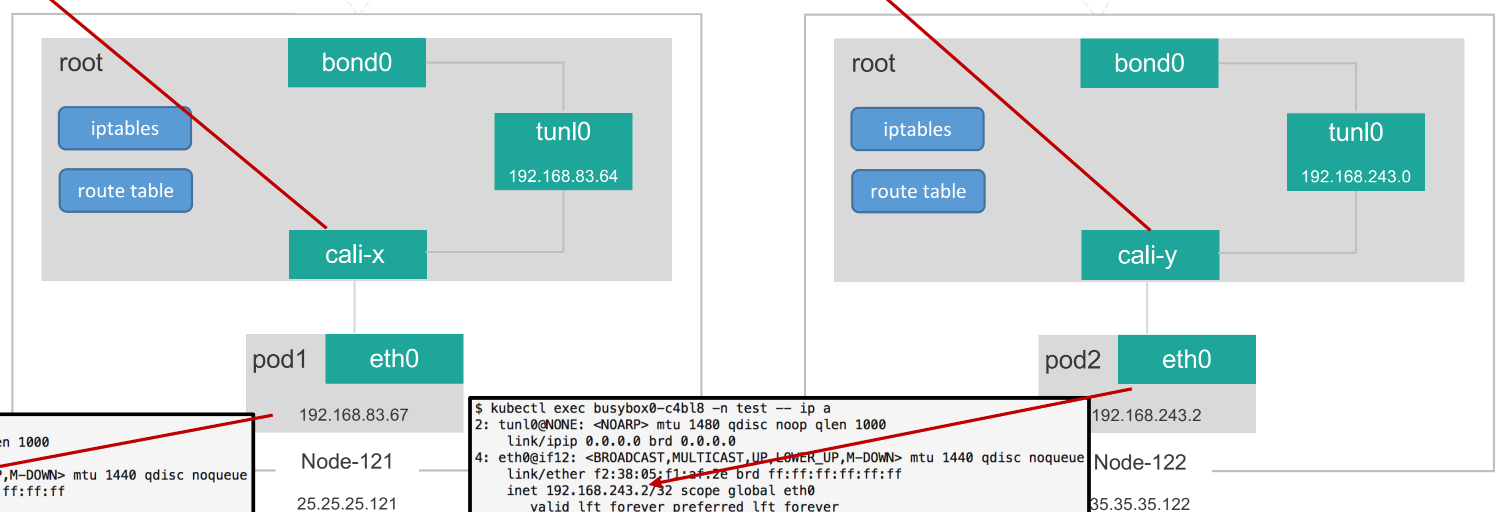
Calico

```
[root@calico-node-18121 ~]# ip a
10: tunl0@NONE: <NOARP,UP,LOWER_UP> mtu 1440 qdisc noqueue state UNKNOWN qlen 1000
    link/ipip 0.0.0.0 brd 0.0.0.0
    inet 192.168.83.64/32 brd 192.168.83.64 scope global tunl0
       valid_lft forever preferred_lft forever
13: cali4e7dc5a6ea0@if4: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1440 qdisc noqueue state UP
    link/ether ee:ee:ee:ee:ee:ee brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet6 fe80::ecee:eeff:feee:eeee/64 scope link
       valid_lft forever preferred_lft forever
```

```
[root@calico-node-18122 ~]# ip a
10: tunl0@NONE: <NOARP,UP,LOWER_UP> mtu 1440 qdisc noqueue state UNKNOWN qlen 1000
    link/ipip 0.0.0.0 brd 0.0.0.0
    inet 192.168.243.0/32 brd 192.168.243.0 scope global tunl0
       valid_lft forever preferred_lft forever
12: cali596577171e6@if4: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1440 qdisc noqueue state UP
    link/ether ee:ee:ee:ee:ee:ee brd ff:ff:ff:ff:ff:ff link-netnsid 0
    inet6 fe80::ecee:eeff:feee:eeee/64 scope link
       valid_lft forever preferred_lft forever
```

Pod-to-Pod Communication

- VETH Interface with “cali-xxx” got created on the root namespace
- Other end is attached to the pod namespace



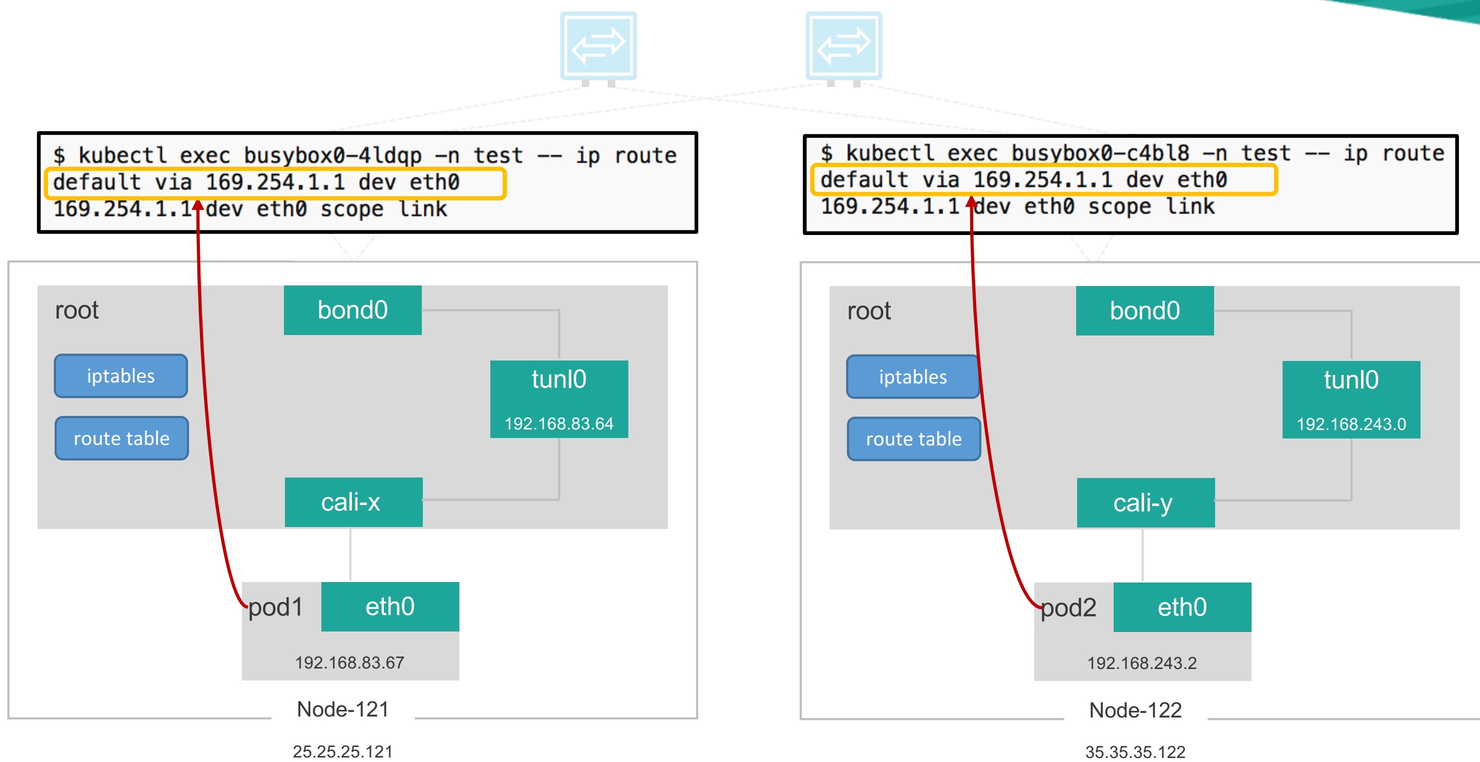

```
$ kubectl exec busybox0-4ldqp -n test -- ip a
2: tunl0@NONE: <NOARP> mtu 1480 qdisc noop qlen 1000
    link/ipip 0.0.0.0 brd 0.0.0.0
4: eth0@if13: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1440 qdisc noqueue
    link/ether 72:ec:8a:4b:3e:23 brd ff:ff:ff:ff:ff:ff
    inet 192.168.83.67/32 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::70ec:8aff:fe4b:3e23/64 scope link
       valid_lft forever preferred_lft forever
```

```
$ kubectl exec busybox0-c4bl8 -n test -- ip a
2: tunl0@NONE: <NOARP> mtu 1480 qdisc noop qlen 1000
    link/ipip 0.0.0.0 brd 0.0.0.0
4: eth0@if12: <BROADCAST,MULTICAST,UP,LOWER_UP,M-DOWN> mtu 1440 qdisc noqueue
    link/ether f2:38:05:f1:af:2e brd ff:ff:ff:ff:ff:ff
    inet 192.168.243.2/32 scope global eth0
       valid_lft forever preferred_lft forever
    inet6 fe80::f038:5ff:fef1:af2e/64 scope link
       valid_lft forever preferred_lft forever
```

Calico

ARP Resolution

- How does ARP gets resolved?
- pod1 & pod2 default route is pointing to private IPv4 “169.254.1.1”



Calico

ARP Resolution

- Initiate ping from pod1-to pod2
- ARP request is send to default GW 169.254.1.1
- cali interface replies to ARP request with it's own MAC

2 *tcpdump on root veth*

```
[root@calico-node-18121 ~]# tcpdump -i cali4e7dc5a6ea0 -nn
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on cali4e7dc5a6ea0, link-type EN10MB (Ethernet), capture size 262144 bytes
20:44:31.575726 ARP, Request who-has 169.254.1.1 tell 192.168.83.67, length 28
20:44:31.575746 ARP, Reply 169.254.1.1 is-at ee:ee:ee:ee:ee:ee, length 28
20:44:31.575752 IP 192.168.83.67 > 192.168.243.2: ICMP echo request, id 5632, seq 0, length 64
20:44:31.575931 IP 192.168.243.2 > 192.168.83.67: ICMP echo reply, id 5632, seq 0, length 64
```

3 *root veth is replying with its own MAC*

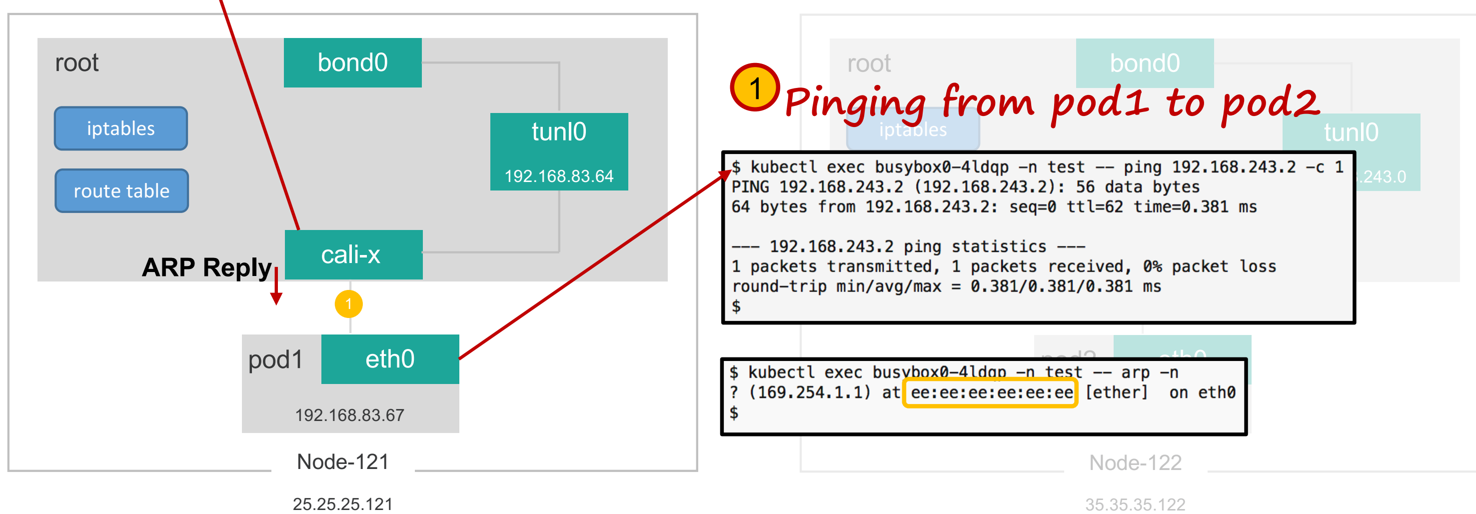
```
[root@calico-node-18121 ~]# ifconfig cali4e7dc5a6ea0
cali4e7dc5a6ea0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1440
        inet6 fe80::ecee:eeff:feee:eeee  prefixlen 64  scopeid 0x20<link>
        ether ee:ee:ee:ee:ee:ee  txqueuelen 0  (Ethernet)
```

1 *Pinging from pod1 to pod2*

```
$ kubectl exec busybox0-4ldqp -n test -- ping 192.168.243.2 -c 1
PING 192.168.243.2 (192.168.243.2): 56 data bytes
64 bytes from 192.168.243.2: seq=0 ttl=62 time=0.381 ms

--- 192.168.243.2 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max = 0.381/0.381/0.381 ms
$
```

```
$ kubectl exec busybox0-4ldqp -n test -- arp -n
? (169.254.1.1) at ee:ee:ee:ee:ee:ee [ether]  on eth0
$
```



Calico

ARP Resolution

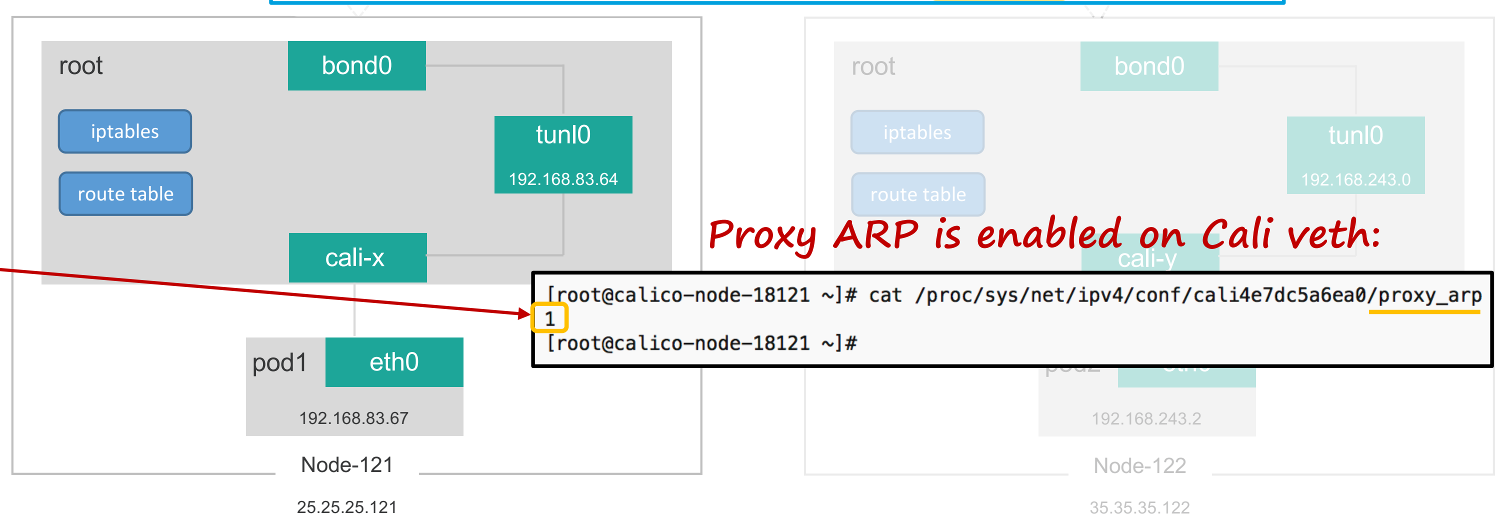
- Why “Cali-” VETH Interfaces replies to the ARP request?
- Reason: Proxy-ARP is enabled on the veth interface on root namespace
- Network is only learning the Node IP/MACs, not pod macs

No pod-MAC/IPs will be learned on the network. Only Node-IPs

Endpoints

Calico-VPC

Tenant VPC	Segment	MAC	Name	Source	State	IP Addresses	State
Calico-VPC	Calico-Nodes-25	a0:36:9f:e2:fd:e4	—	Learned	Active	25.25.25.121 (learned) fe80::a236:9fff:fee2:fde4 (learned-L2 Only)	Learned
Calico-VPC	Calico-Nodes-35	a0:36:9f:e3:05:d0	—	Learned	Active	35.35.35.122 (learned) fe80::a236:9fff:fee3:5d0 (learned-L2 Only)	Learned



Proxy ARP is enabled on Cali veth:

```
[root@calico-node-18121 ~]# cat /proc/sys/net/ipv4/conf/cali4e7dc5a6ea0/proxy_arp
1
[root@calico-node-18121 ~]#
```

Calico

Notice the 2 IP headers: IP-IP protocl

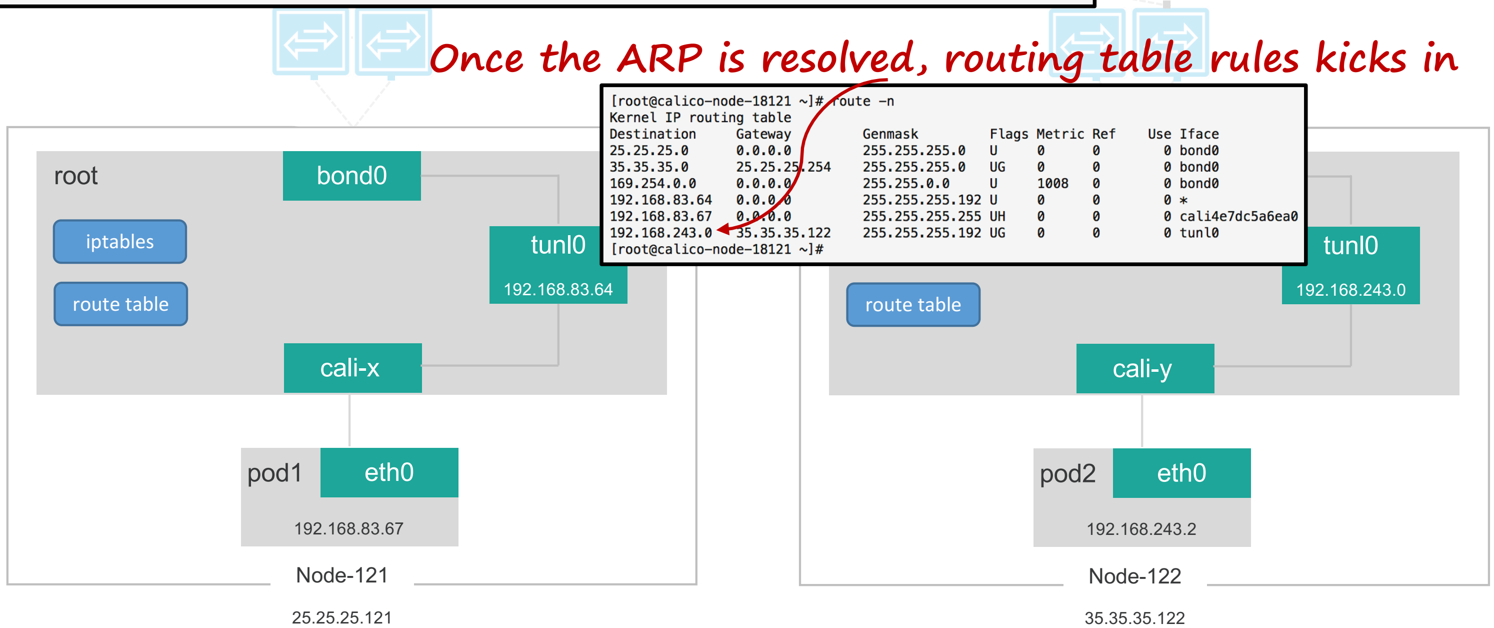
```
[root@calico-node-18121 ~]# tcpdump -i bond0 -nn proto 4
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on bond0, link-type EN10MB (Ethernet), capture size 262144 bytes
22:39:00.890339 IP 25.25.25.121 > 35.35.35.122: IP 192.168.83.67 > 192.168.243.2: ICMP echo request, id 4864, seq 0, length 64 (ipip-proto-4)
22:39:00.890502 IP 35.35.35.122 > 25.25.25.121: IP 192.168.243.2 > 192.168.83.67: ICMP echo reply, id 4864, seq 0, length 64 (ipip-proto-4)
```

Once the ARP is resolved, routing table rules kicks in

```
[root@calico-node-18121 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
25.25.25.0      0.0.0.0         255.255.255.0   U     0      0        0 bond0
35.35.35.0      25.25.25.254    255.255.255.0   UG    0      0        0 bond0
169.254.0.0     0.0.0.0         255.255.0.0     U     1008   0        0 bond0
192.168.83.64   0.0.0.0         255.255.255.192 U     0      0        0 *
192.168.83.67   0.0.0.0         255.255.255.255 UH    0      0        0 cali4e7dc5a6ea0
192.168.243.0   35.35.35.122    255.255.255.192 UG    0      0        0 tunl0
[root@calico-node-18121 ~]#
```

Packet Forwarding

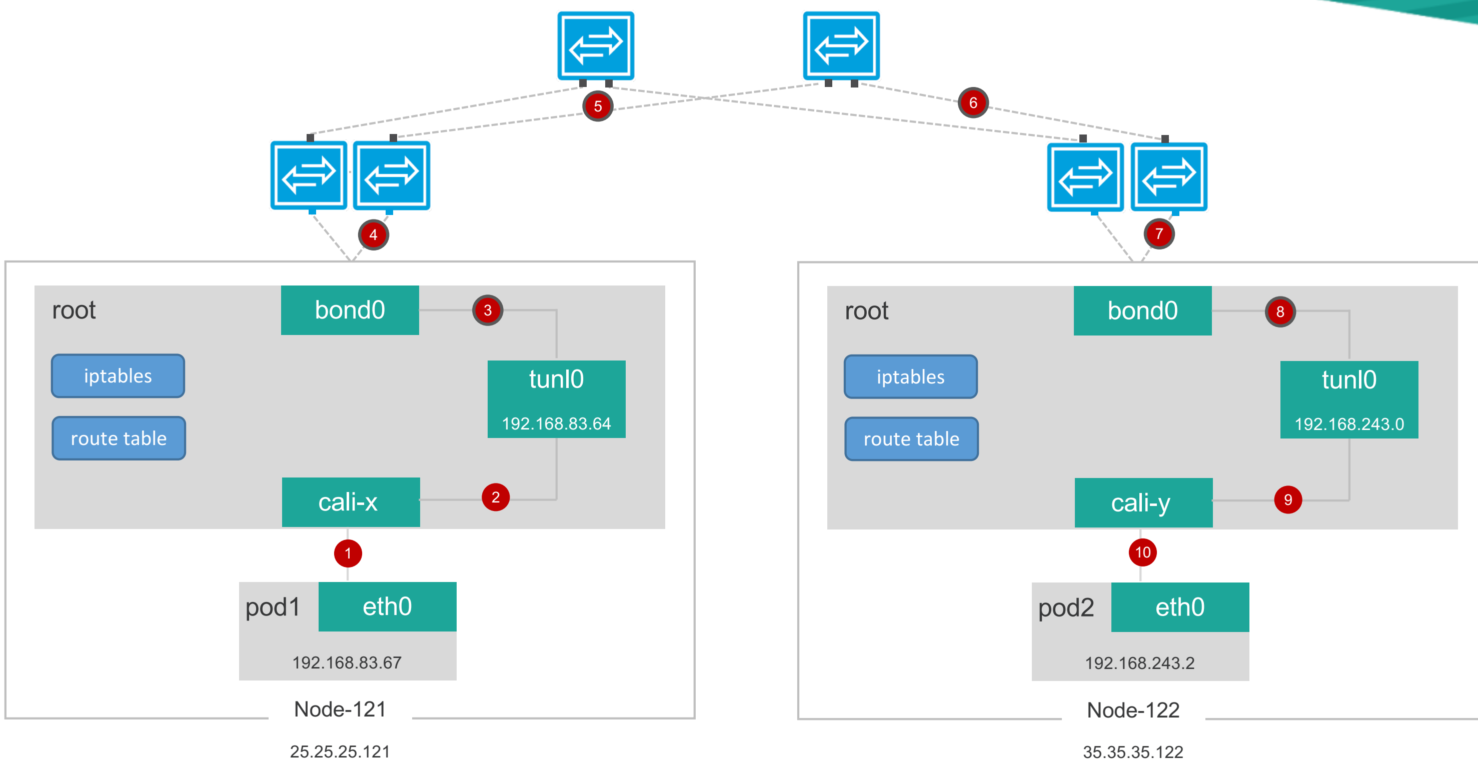
- After ARP Resolution packet gets forwarded according to the routing table entries
- Packets will get encapsulated via IP-IP



Calico

Packet Forwarding

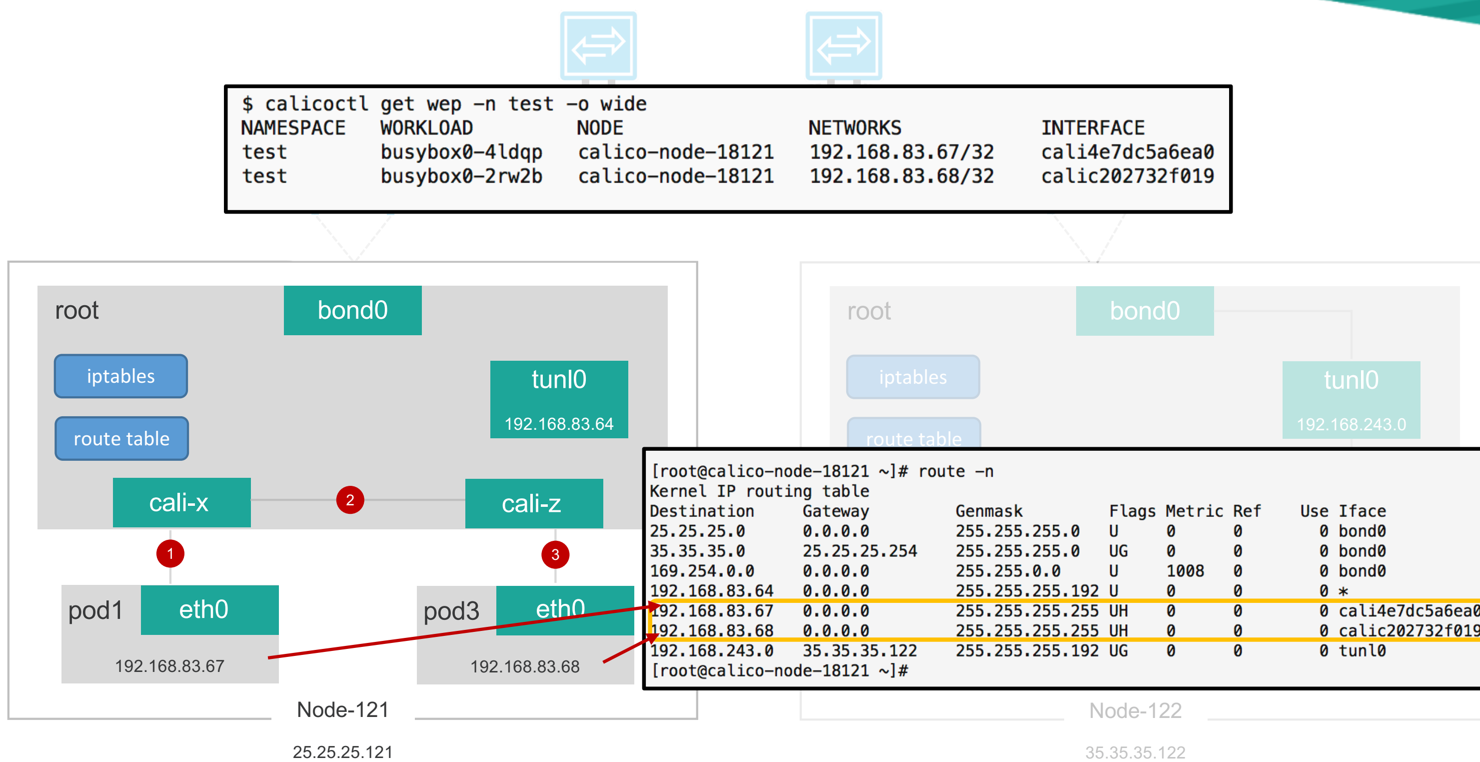
- After ARP Resolution packet gets forwarded according to the routing table entries
- Packets will get encapsulated via IP-IP



Calico

Packet Forwarding in the same host

- /32 routes are present in the routing table for all the containers
- Packets get forwarded to the appropriate calico veth interface based on the routing rules



Calico

Non IP-IP

- Disable IP-IP Mode

```
$ calicoctl get ippool -o wide
NAME                  CIDR             NAT    IPIPMODE   DISABLED
default-ipv4-ippool   192.168.0.0/16   true   Always     false
```

```
$ cat changeIPPool.yaml
apiVersion: projectcalico.org/v3
kind: IPPool
metadata:
  name: default-ipv4-ippool
spec:
  cidr: 192.168.0.0/16
  ipipMode: Never
  natOutgoing: false
```

```
$ calicoctl apply -f changeIPPool.yaml
Successfully applied 1 'IPPool' resource(s)
```

```
$ calicoctl get ippool -o wide
NAME                  CIDR             NAT     IPIPMODE   DISABLED
default-ipv4-ippool   192.168.0.0/16   false   Never      false
```

root
bond0
iptables
Node-121
25.25.25.121
Node-122
35.35.35.122

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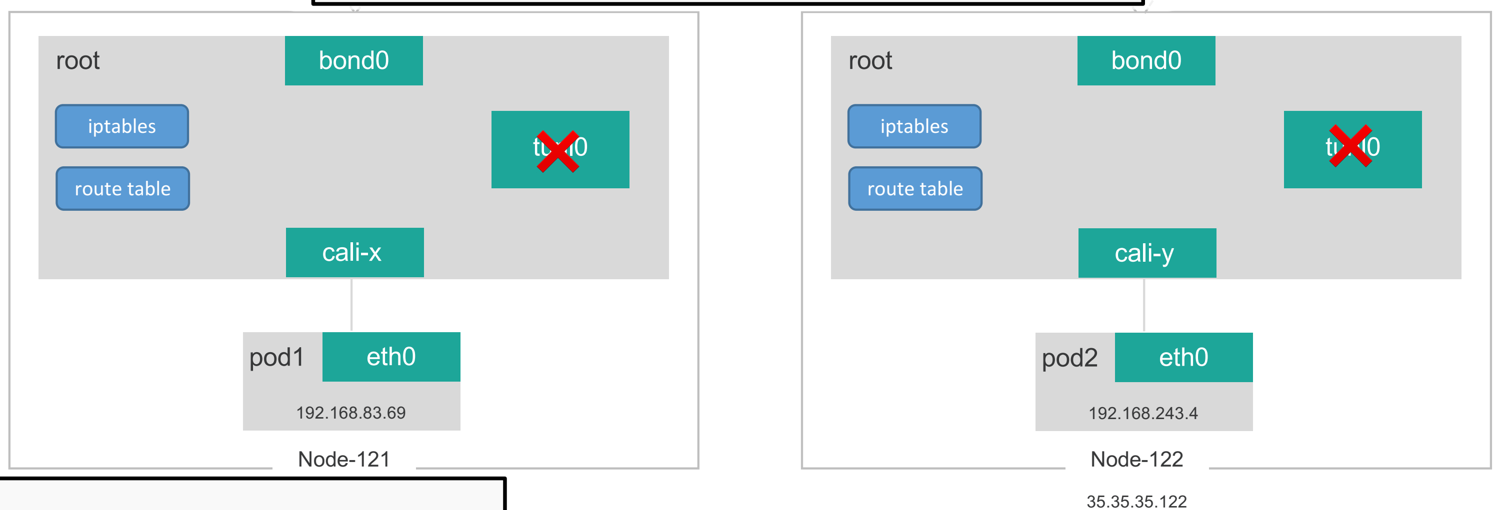
Calico

No more tunl0. Pod routes are directly pointing to bond0

```
[root@calico-node-18121 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
25.25.25.0      0.0.0.0         255.255.255.0   U     0      0        0 bond0
35.35.35.0      25.25.25.254    255.255.255.0   UG    0      0        0 bond0
169.254.0.0     0.0.0.0         255.255.0.0     U     1008   0        0 bond0
192.168.83.64   0.0.0.0         255.255.255.192 U     0      0        0 *
192.168.243.0   25.25.25.254    255.255.255.192 UG    0      0        0 bond0
[root@calico-node-18121 ~]#
```

Non IP-IP

- Disable IP-IP Mode. tunl0 interface is not present anymore
- Routes are pointing to the bond0 interface
- Bring up 2 pods as before

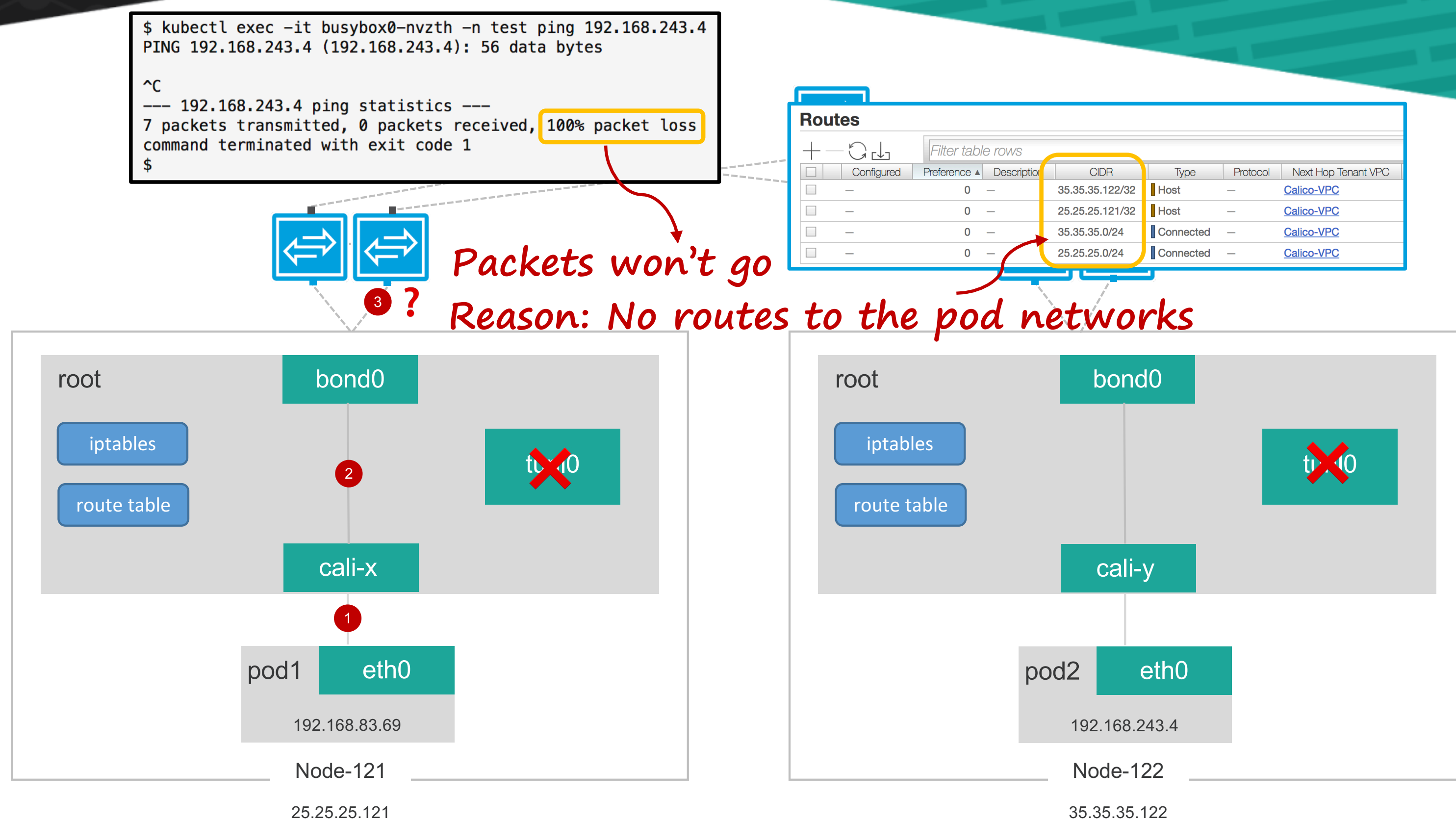



```
$ calicoctl get wep -n test -o wide
NAMESPACE   WORKLOAD          NODE                NETWORKS           INTERFACE
test        busybox0-nvzth    calico-node-18121   192.168.83.69/32   cali12c689f4d96
test        busybox0-wcm2w    calico-node-18122   192.168.243.4/32   calia75062cc7be
```

Calico

Non IP-IP

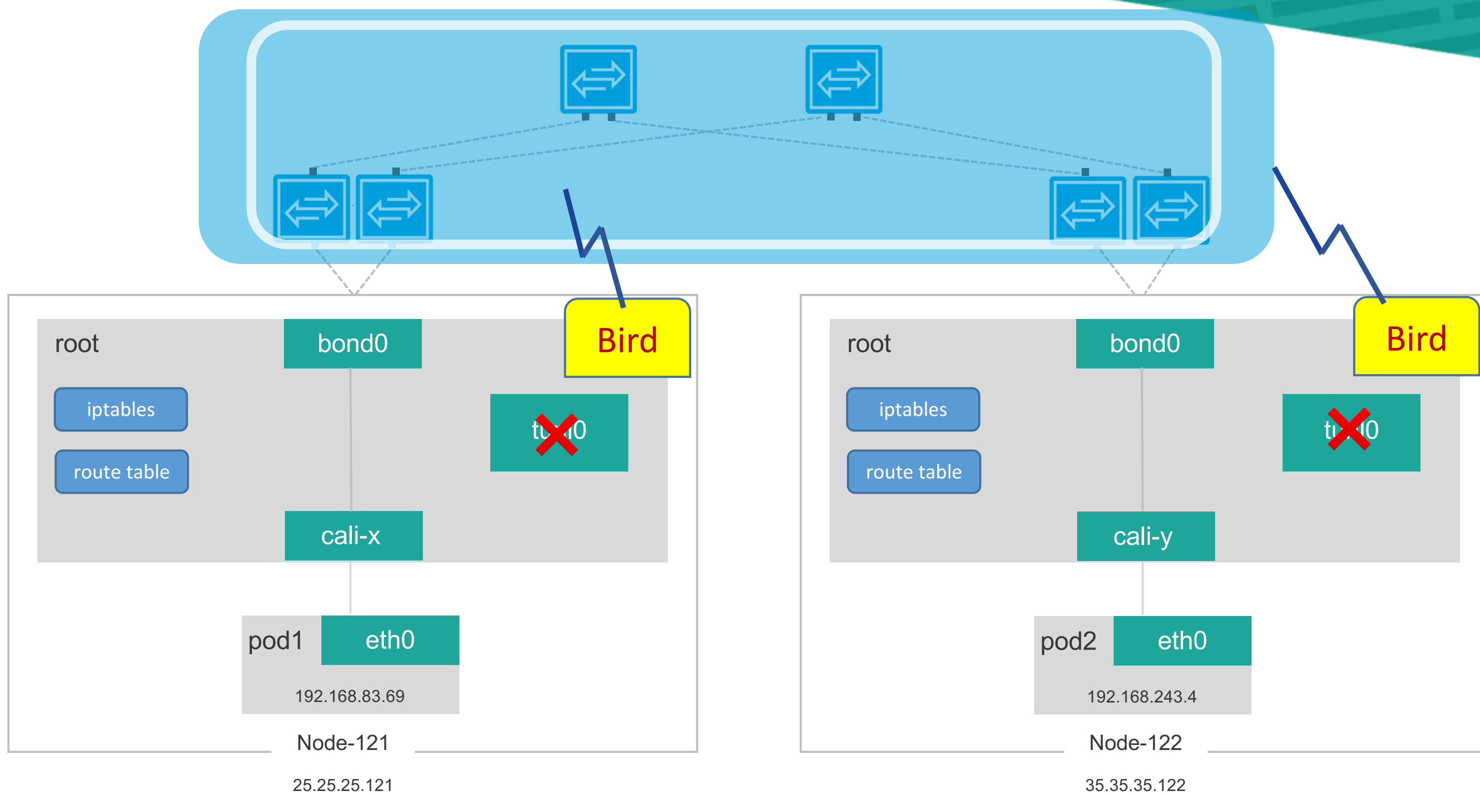
- Ping from pod1 to pod2 is unsuccessful
- Reason: Routes are not advertised to the Network



Calico

BGP mode

- Need the Calico nodes to peer with the network fabric



Calico

BGP Mode

- Create a global BGP configuration
- Create the network as a BGP Peer (**Assuming an abstracted cloud network. Config will vary depending on vendor)

Create a BGP configuration with AS:63400

```
$ cat defaultNodeMesh.yaml
 apiVersion: projectcalico.org/v3
 kind: BGPConfiguration
 metadata:
   name: default
 spec:
   logSeverityScreen: Info
   nodeToNodeMeshEnabled: true
   asNumber: 63400

$ calicoctl apply -f defaultNodeMesh.yaml
Successfully applied 1 'BGPConfiguration' resource(s)

$ calicoctl get bgpconfig -o wide
NAME      LOGSEVERITY   MESHENABLED   ASNUMBER
default   Info          true          63400
```

Create a "global" BGP Peer

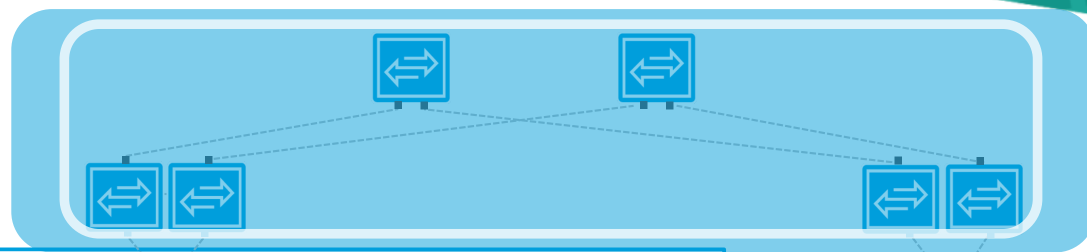
```
$ cat bgpGlobalPeer.yaml
apiVersion: projectcalico.org/v3
kind: BGPPeer
metadata:
  name: bgppeer-bcf
spec:
  peerIP: 2.2.2.2
  asNumber: 63400

$ calicoctl create -f bgpGlobalPeer.yaml
Successfully created 1 'BGPPeer' resource(s)

$ calicoctl get bgppeer
NAME          PEERIP    NODE       ASN
bgppeer-bcf   2.2.2.2   (global)   63400
```

```
[root@calico-node-18121 ~]# calicoctl node status
Calico process is running.

IPv4 BGP status
+--------------+-------------------+-------+----------+-------------+
| PEER ADDRESS |     PEER TYPE     | STATE |  SINCE   |    INFO     |
+--------------+-------------------+-------+----------+-------------+
| 35.35.35.122 | node-to-node mesh | up    | 05:00:33 | Established |
| 2.2.2.2      | global            | up    | 05:02:40 | Established |
+--------------+-------------------+-------+----------+-------------+

IPv6 BGP status
No IPv6 peers found.

[root@calico-node-18121 ~]#
```

```
[root@calico-node-18122 ~]# calicoctl node status
Calico process is running.

IPv4 BGP status
+--------------+-------------------+-------+----------+-------------+
| PEER ADDRESS |     PEER TYPE     | STATE |  SINCE   |    INFO     |
+--------------+-------------------+-------+----------+-------------+
| 25.25.25.121 | node-to-node mesh | up    | 05:00:31 | Established |
| 2.2.2.2      | global            | up    | 05:04:19 | Established |
+--------------+-------------------+-------+----------+-------------+

IPv6 BGP status
No IPv6 peers found.

[root@calico-node-18122 ~]#
```

Both Nodes are peering with the global BGP Peer

Calico



BGP Neighbors

Network is peering with both the Calico Nodes

Name ▲	State	Type	IP Address	Remote Autonomous System ID	Admin Status
RR-25	Established	Internal	25.25.25.121	63400	✓ Up
RR-35	Established	Internal	35.35.35.122	63400	✓ Up

Routes

Network is learning pod network routes via BGP

Filter table rows

Configured	Preference ▲	Description	CIDR	Type	Protocol	Next Hop Tenant VPC
–	0	–	35.35.35.122/32	Host	–	Calico-VPC
–	0	–	25.25.25.121/32	Host	–	Calico-VPC
–	0	–	35.35.35.0/24	Connected	–	Calico-VPC
–	0	–	25.25.25.0/24	Connected	–	Calico-VPC
–	200	–	192.168.83.64/26	Dynamic	BGP	Calico-VPC
–	200	–	192.168.243.0/26	Dynamic	BGP	Calico-VPC

BGP Mode

- Configure the Calico nodes as BGP Neighbors on the network
- As a result network will get to learn about 192.168.83.64/26 & 192.168.243.0/26 routes

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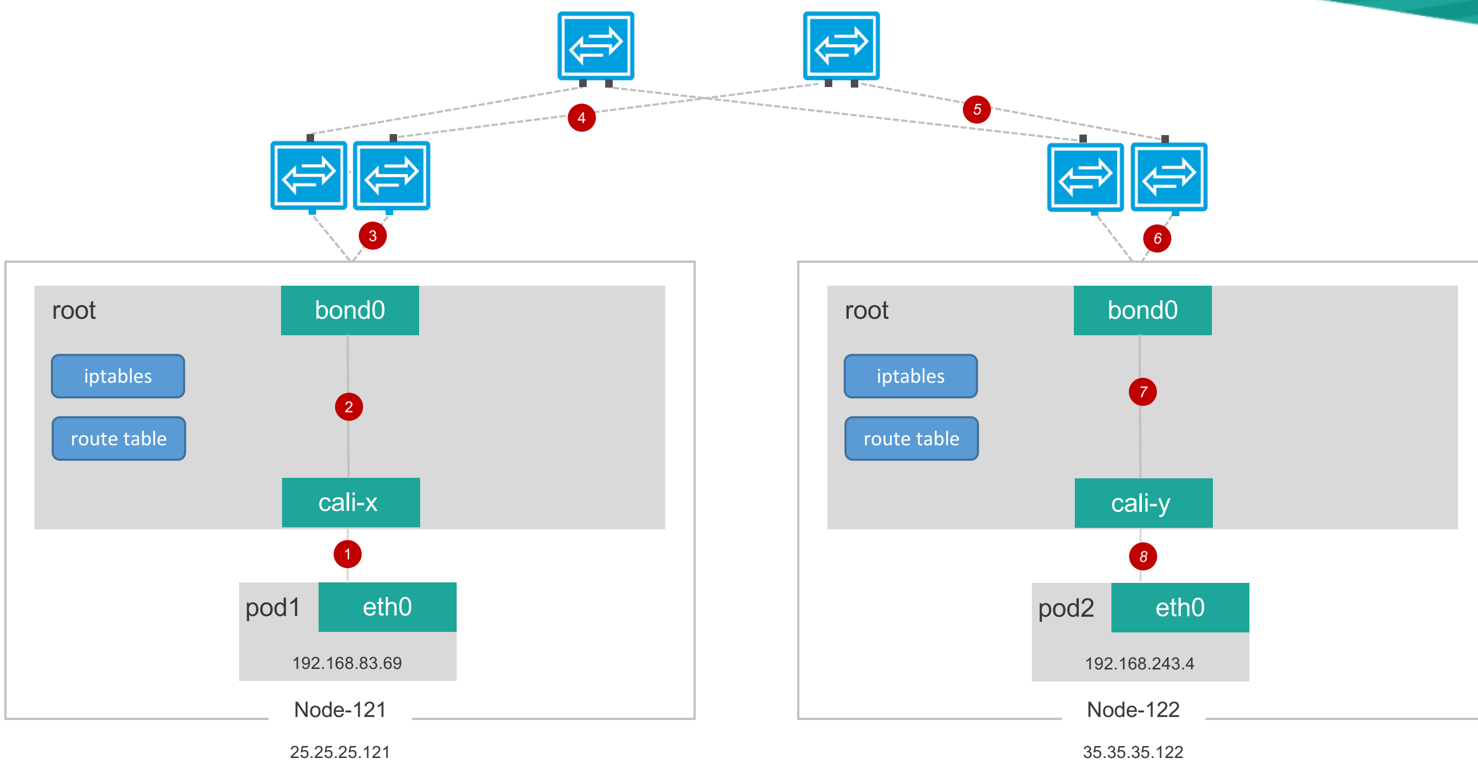
Calico

BGP Mode

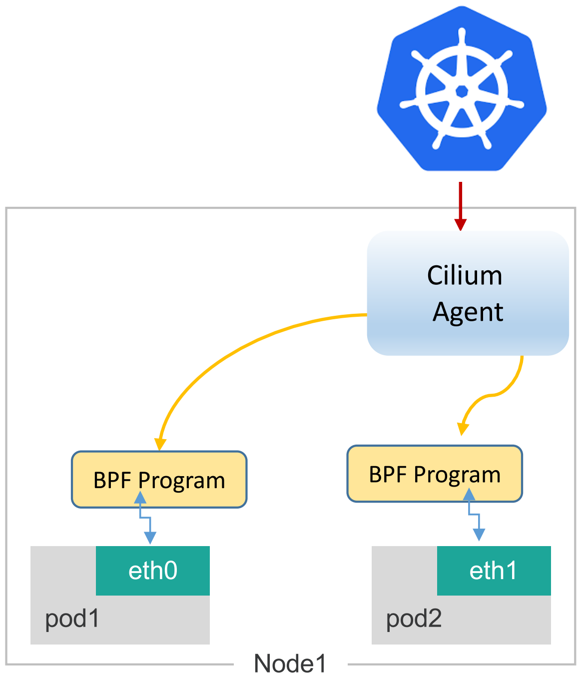
- Packets goes across the network without any encapsulations



Cilium

Architecture

- Cilium Agent, Cilium CLI Client, CNI Plugin will be running on every node
- Cilium agent compiles BPF programs and make the kernel runs these programs at key points in the network stack to have visibility and control over all network traffic in/out of all containers
- Cilium interacts with the Linux kernel to install BPF program which will then perform networking tasks and implement security rules



*etcd/monitor components are not shown for clarity

Cilium: Networking

Overlay Network Mode

- All nodes form a mesh of tunnels using the UDP based encapsulation protocols: VXLAN (default) or Geneve
- Simple: Only requirement is cluster nodes should be able to reach each other using IP/UDP
- Auto-configured: Kubernetes is being run with the-"--allocate-node-cidrs" option, Cilium can form an overlay network automatically without any configuration by the user

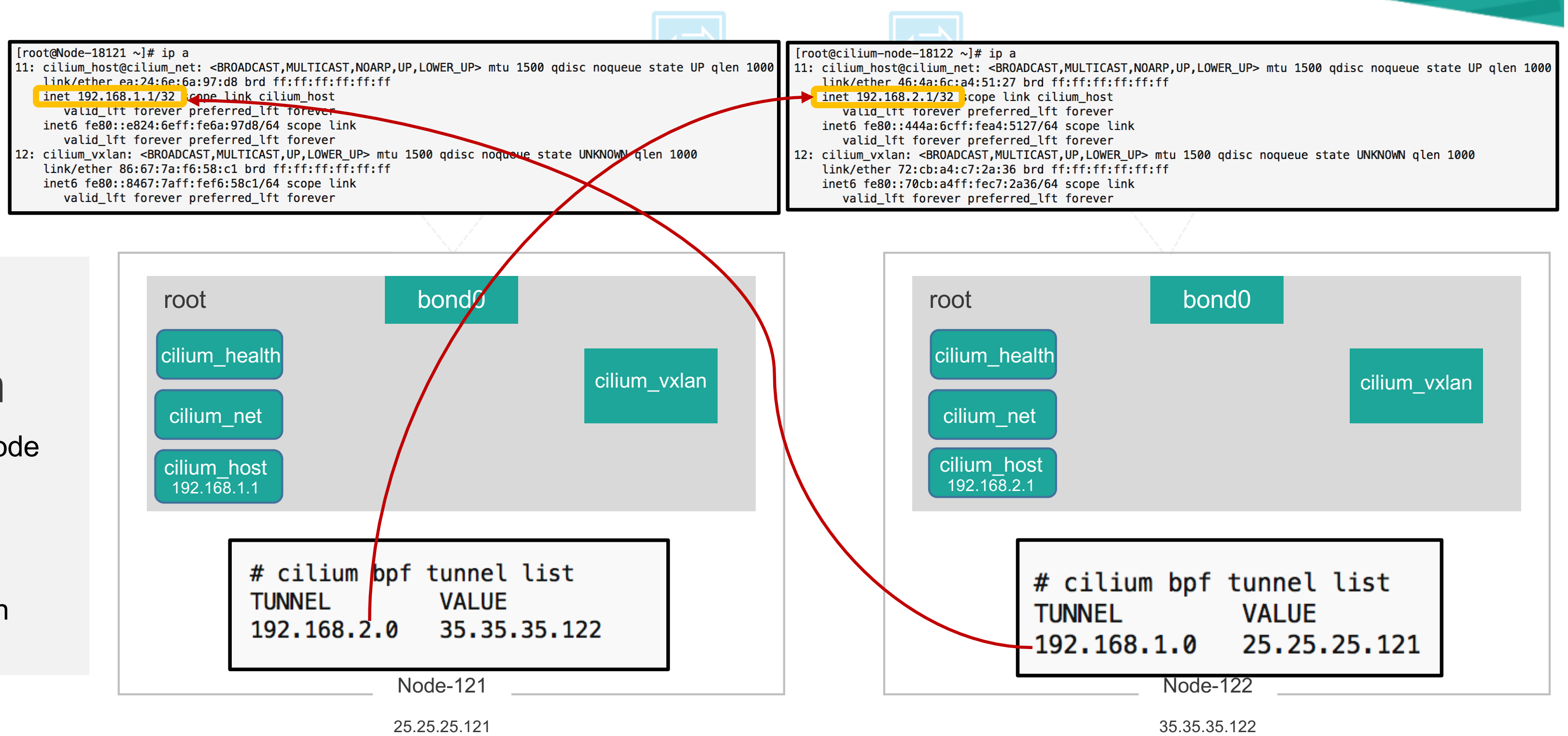
Direct/Native Routing Mode

- In direct routing mode, Cilium will hand all packets which are not addressed for another local endpoint to the routing subsystem of the Linux kernel
- Packets will be routed as if a local process would have emitted the packet
- Admins can use routing daemon such as Zebra, Bird , BGPD. The routing protocols will announce the node allocation prefix via the node's IP to all other nodes.

Cilium

Default Configuration

- Overlay Networking Mode
- VXLAN encapsulation
- Both VETH/IPVLAN is supported (Higher Performance gains with IPVLAN)



Cilium

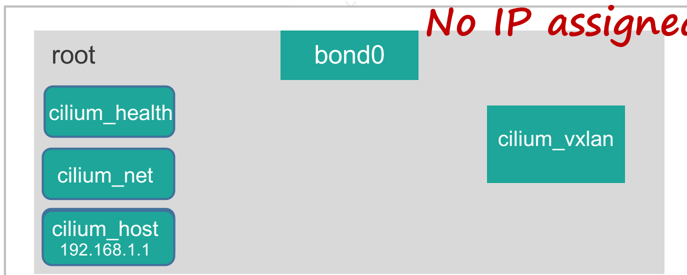
Default Configuration

- ”cilium_vxlan” interface is in metadata mode. It can send & receive on multiple addresses
- Cilium addressing model allows to derive the node address from each container address.
- This is also used to derive the VTEP address, so you don’t need to run a control plane protocol to distribute these addresses. All you need to have are routes to make the node addresses routable

```
[root@Node-18121 ~]# ip a
11: cilium_host@cilium_net: <BROADCAST,MULTICAST,NOARP,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP qlen 1000
    link/ether ea:24:6e:6a:97:d8 brd ff:ff:ff:ff:ff:ff
    inet 192.168.1.1/32 scope link cilium_host
       valid_lft forever preferred_lft forever
    inet6 fe80::e824:6eff:fe6a:97d8/64 scope link
       valid_lft forever preferred_lft forever
12: cilium_vxlan: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UNKNOWN qlen 1000
    link/ether 86:67:7a:f6:58:c1 brd ff:ff:ff:ff:ff:ff
    inet6 fe80::8467:7aff:fef6:58c1/64 scope link
       valid_lft forever preferred_lft forever
```

```
[root@cilium-node-18122 ~]# ip a
11: cilium_host@cilium_net: <BROADCAST,MULTICAST,NOARP,UP,LOWER_UP> mtu 1500 qdisc noqueue state UP qlen 1000
    link/ether 46:4a:6c:a4:51:27 brd ff:ff:ff:ff:ff:ff
    inet 192.168.2.1/32 scope link cilium_host
       valid_lft forever preferred_lft forever
    inet6 fe80::444a:6cff:fea4:5127/64 scope link
       valid_lft forever preferred_lft forever
12: cilium_vxlan: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500 qdisc noqueue state UNKNOWN qlen 1000
    link/ether 72:cb:a4:c7:2a:36 brd ff:ff:ff:ff:ff:ff
    inet6 fe80::70cb:a4ff:fec7:2a36/64 scope link
       valid_lft forever preferred_lft forever
```

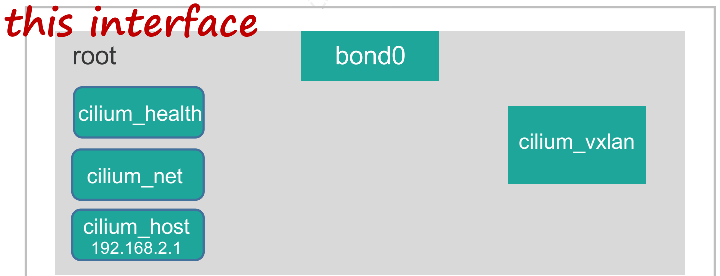
‘cilium_vxlan’ interface is in Metadata mode.
No IP assigned to this interface




```
[root@Node-18121 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
35.35.35.0      25.25.25.254    255.255.255.0   UG    0      0        0 bond0
192.168.1.0     192.168.1.1     255.255.255.0   UG    0      0        0 cilium_host
192.168.1.1     0.0.0.0         255.255.255.255 UH    0      0        0 cilium_host
192.168.2.0     192.168.1.1     255.255.255.0   UG    0      0        0 cilium_host
```

Node-121

25.25.25.121




```
[root@cilium-node-18122 ~]# route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
25.25.25.0      35.35.35.254    255.255.255.0   UG    0      0        0 bond0
192.168.1.0     192.168.2.1     255.255.255.0   UG    0      0        0 cilium_host
192.168.2.0     192.168.2.1     255.255.255.0   UG    0      0        0 cilium_host
192.168.2.1     0.0.0.0         255.255.255.255 UH    0      0        0 cilium_host
```

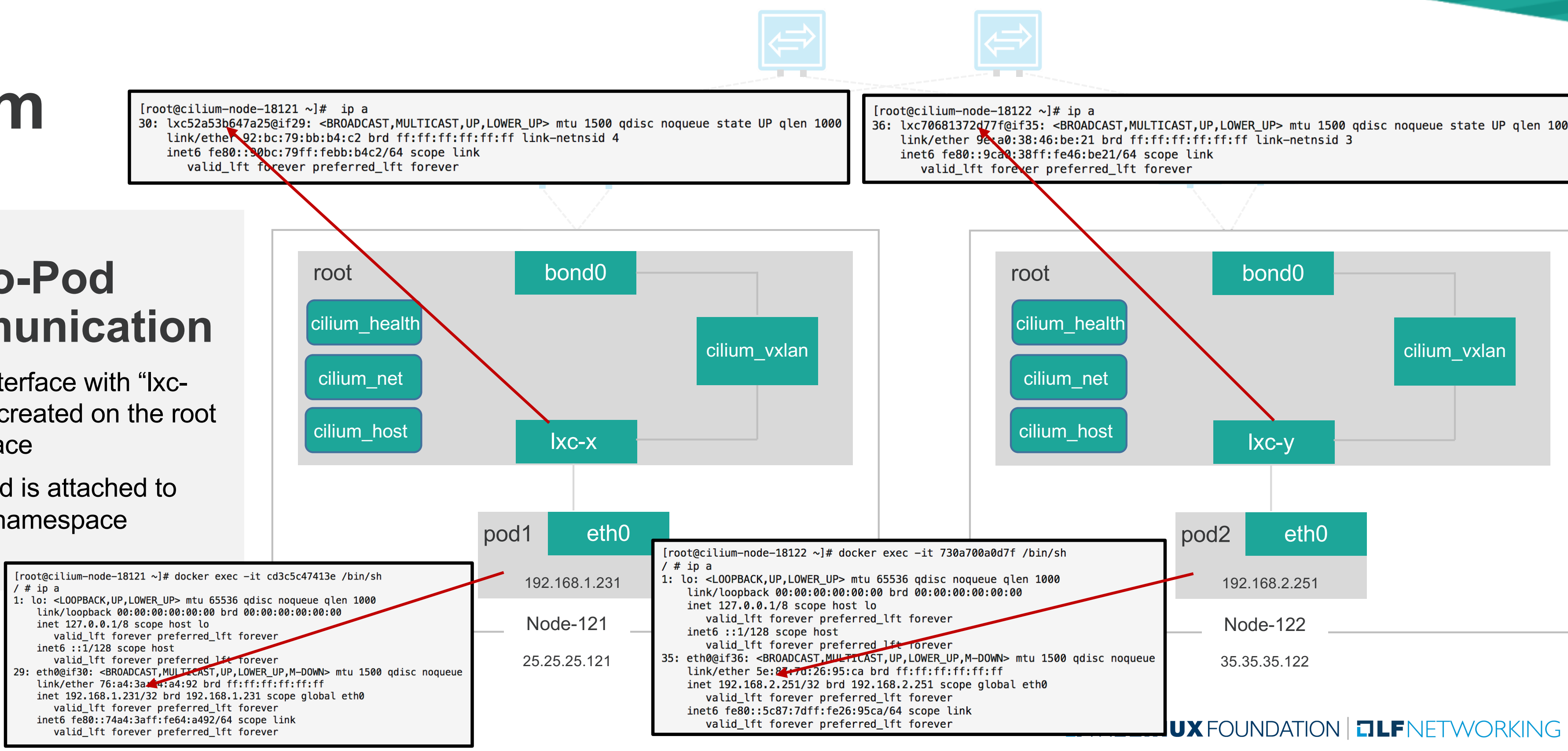
Node-122

35.35.35.122

Cilium

Pod-to-Pod Communication

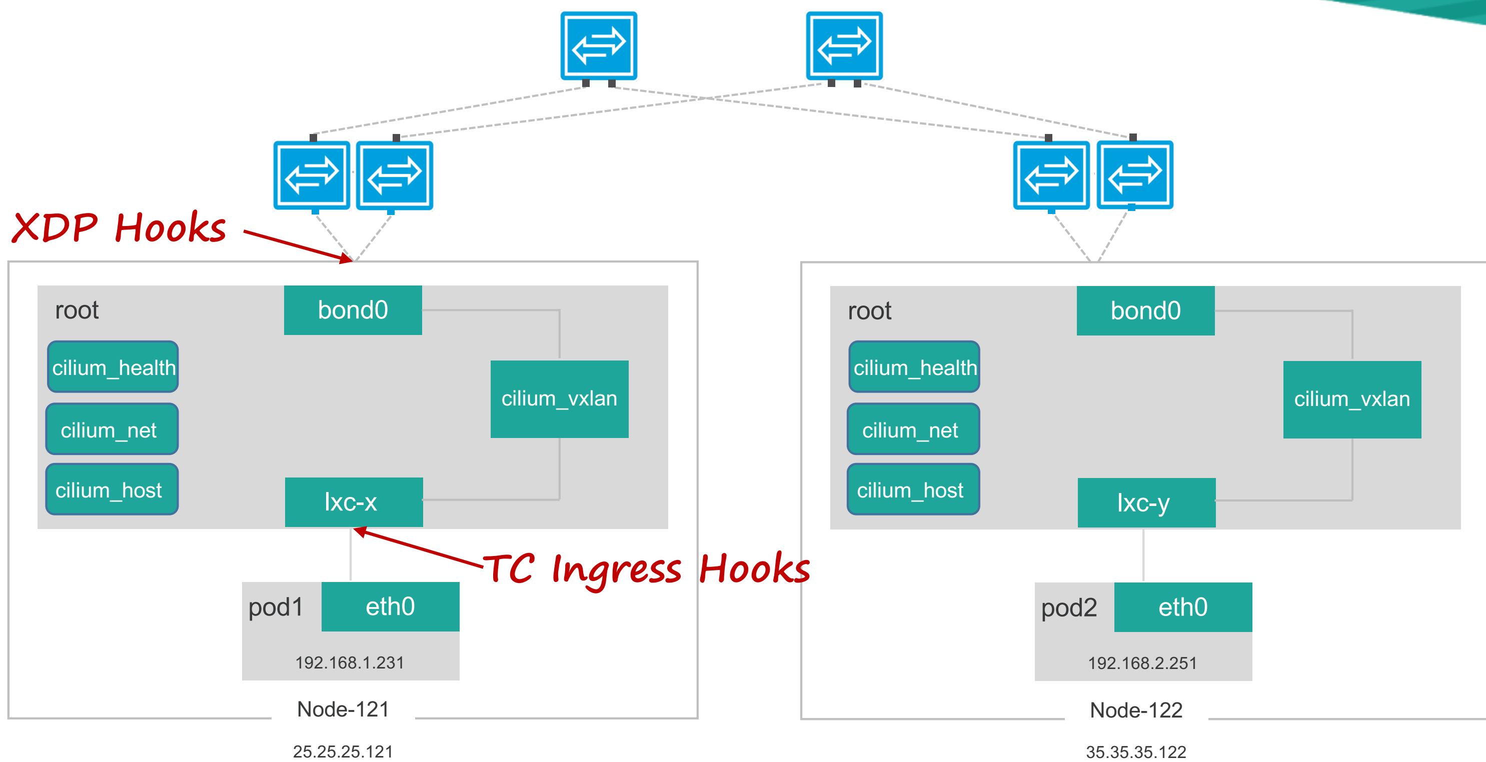
- VETH Interface with “lxc-xxx” got created on the root namespace
- Other end is attached to the pod namespace



Cilium

Datapath

- Cilium datapath uses eBPF hooks to load BPF programs
- XDP BPF hook is at the earliest point possible in the networking driver and triggers a run of the BPF program upon packet reception
- Traffic Control (TC) Hooks: BPF programs are attached to the TC Ingress hook of host side of the VETH pair for monitoring & enforcement



BPF program is responding with to the ARP with VETH's (lxc-x) MAC

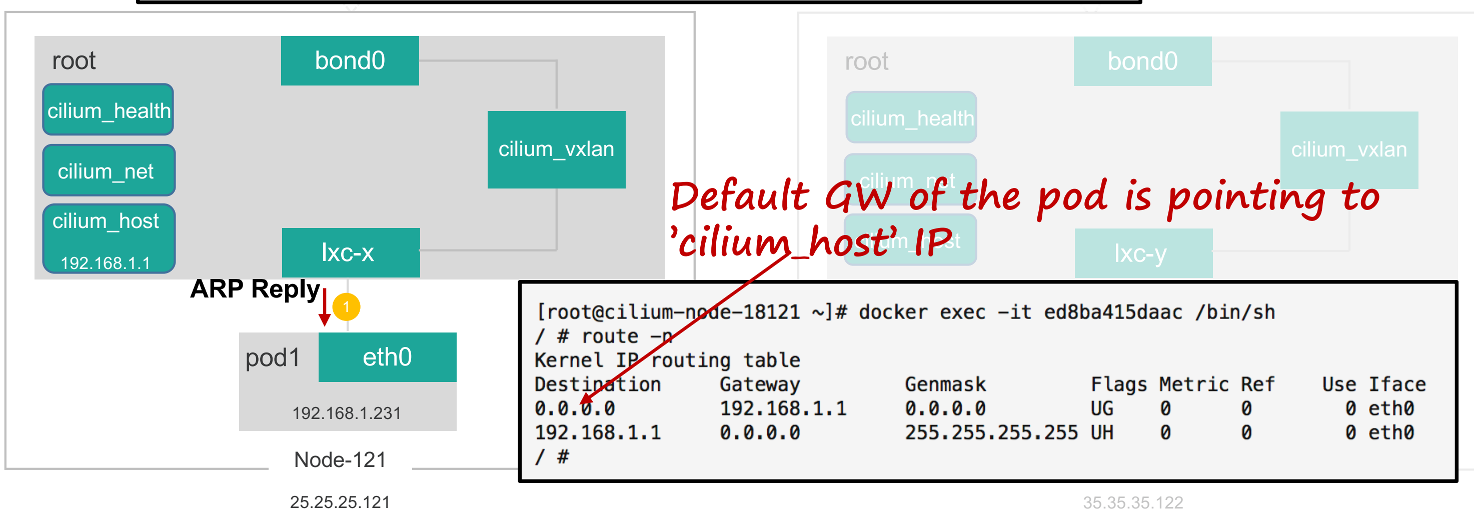
```
[root@Node-18121 ~]# tcpdump -i lxc97b73386ee5f -nn
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode
listening on lxc97b73386ee5f, link-type EN10MB (Ethernet), capture size 262144 bytes

01:11:02.484685 ARP, Request who-has 192.168.1.1 tell 192.168.1.22, length 28
01:11:02.484705 ARP, Reply 192.168.1.1 is-at ea:22:19:a6:88:22, length 28
```

Cilium

ARP Resolution

- Default GW of the container is pointing to the IP of "cilium_host"
- BPF Program is installed to reply to the ARP request
- LXC Interface MAC is used for the ARP reply



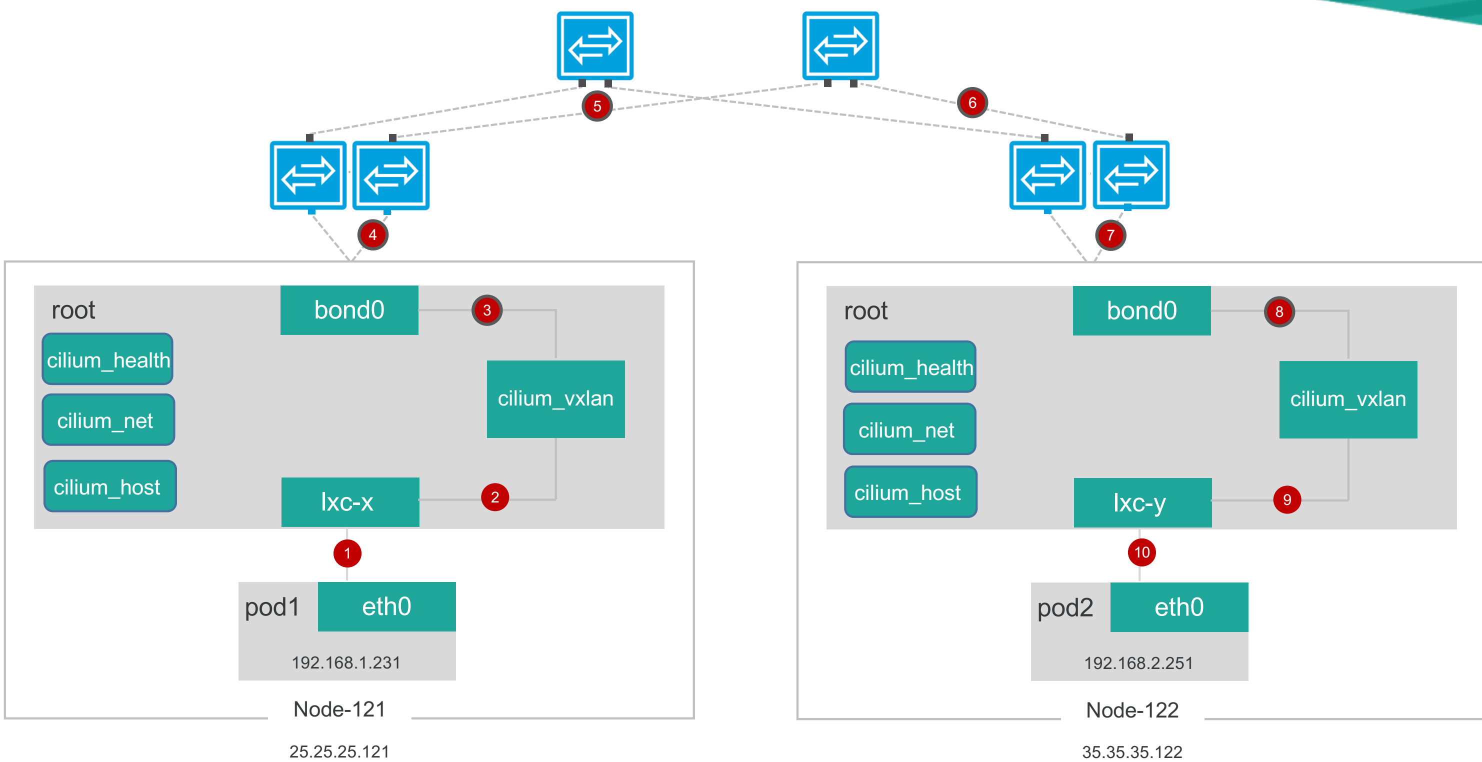
Default GW of the pod is pointing to 'cilium_host' IP

```
[root@cilium-node-18121 ~]# docker exec -it ed8ba415daac /bin/sh
/ # route -n
Kernel IP routing table
Destination     Gateway         Genmask         Flags Metric Ref    Use Iface
0.0.0.0         192.168.1.1     0.0.0.0         UG    0      0        0 eth0
192.168.1.1     0.0.0.0         255.255.255.255 UH    0      0        0 eth0
/ #
```

Cilium

Packet Flow

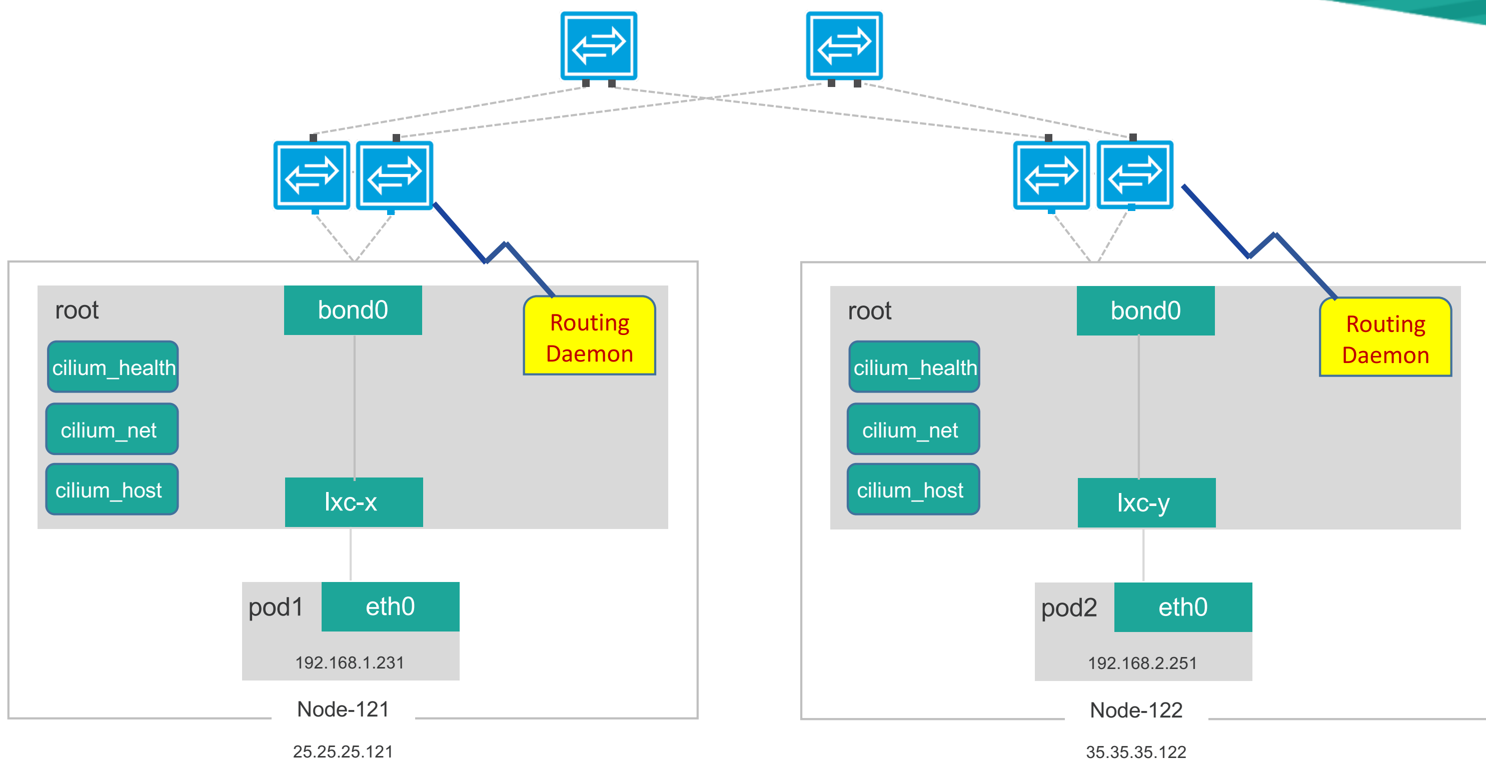
- cilium_vxlan device does VXLAN encap/decap
- Traffic from pod1 is going through "cilium_vxlan" device before exiting



Cilium

Direct Routing

- No VXLAN/GENEVE overlays
- As an admin you are able to run your own flavor of routing daemon (Bird/BGPD/Zebra etc) to distribute routes
- You can make the Pod IP's routable as a result

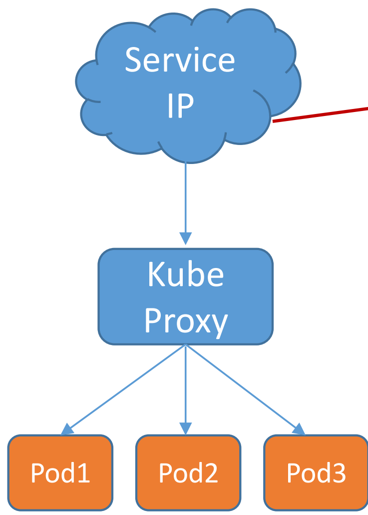


Yes! Back to the Basics…

K8S Networking: Basics

Services

- Pods are mortal
- Need a higher level abstractions: Services
- “Service” in Kubernetes is a conceptual concept. Service is not a process/daemon. Outside networks doesn’t learn Service IP addresses
- Implemented through Kube Proxy with IPTables rules




```
$ kubectl get services -n demo -o wide
NAME        TYPE        CLUSTER-IP     EXTERNAL-IP   PORT(S)   AGE   SELECTOR
hostnames   ClusterIP   10.96.13.117   <none>        80/TCP    23h   app=hostnames
```

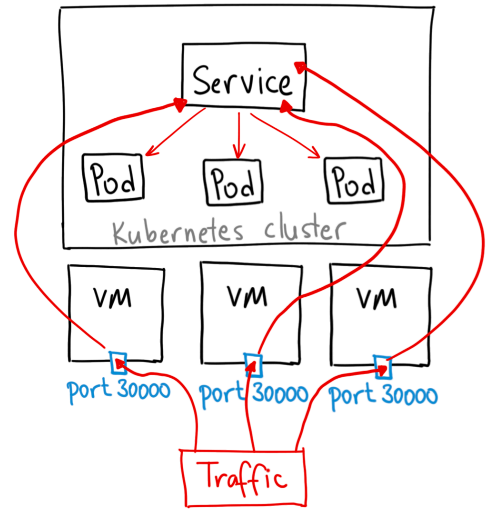
```
$ kubectl describe service -n demo
Name:              hostnames
Namespace:         demo
Labels:            <none>
Annotations:       <none>
Selector:          app=hostnames
Type:              ClusterIP
IP:                10.96.13.117
Port:              default  80/TCP
TargetPort:        9376/TCP
Endpoints:         192.168.1.63:9376,192.168.2.171:9376,192.168.3.155:9376
Session Affinity:  None
Events:            <none>
```

K8S Networking: Basics

Exposing Services

- If Services are an abstracted concept without any meaning outside of the K8S cluster how do we access?
  - NodePort / LoadBalancer / Ingress etc.

NodePort: Service is accessed via 'NodeIP:port'



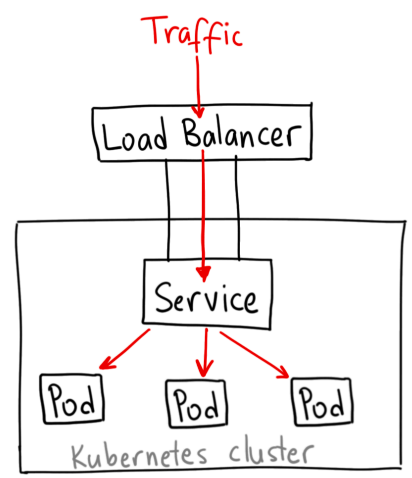
Credit: https://medium.com/google-cloud/kubernetes-nodeport-vs-loadbalancer-vs-ingress-when-should-i-use-what-922f010849e0

K8S Networking: Basics

Exposing Services

- Load Balancer: Spins up a load balancer and binds service IPs to Load Balancer VIP
- Very common in public cloud environments
- For baremetal workloads: '**MetalLB**' (Up & coming project, load-balancer implementation for bare metal K8S clusters, using standard routing protocols)

LoadBalancer: Service is accessed via Loadbalancer

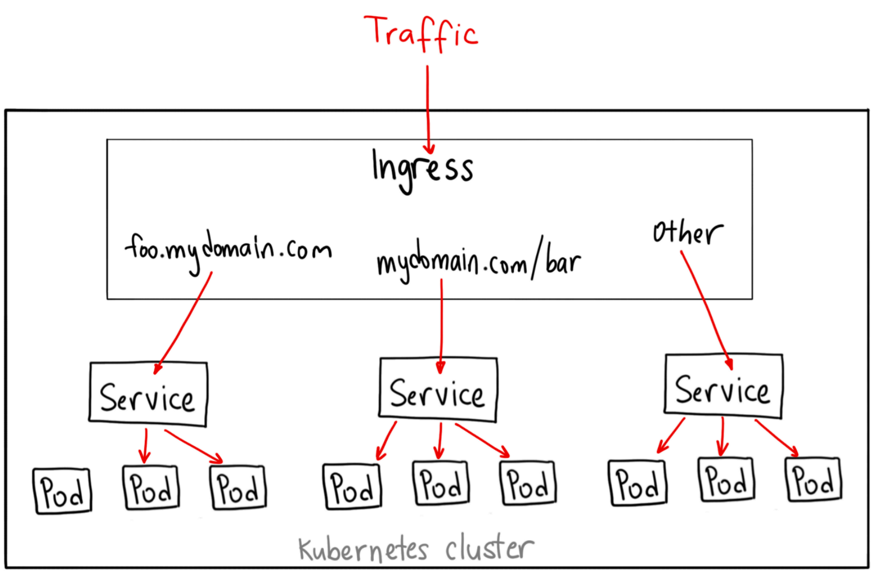


Credit: https://medium.com/google-cloud/kubernetes-nodeport-vs-loadbalancer-vs-ingress-when-should-i-use-what-922f010849e0

K8S Networking: Basics

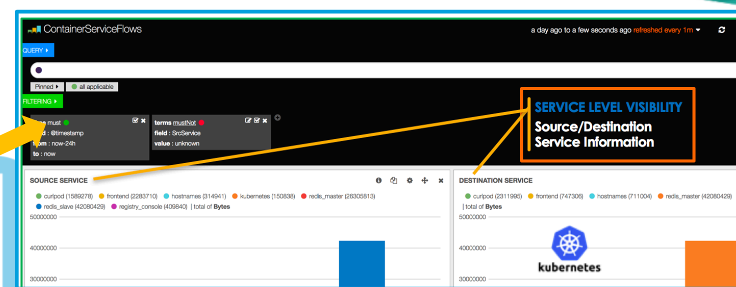
Exposing Services

- **Ingress**: K8S Concept that lets you decide how to let traffic into the cluster
- Sits in front of multiple services and act as a ”router”
- Implemented through an ingress controller (NGINX/HA Proxy)



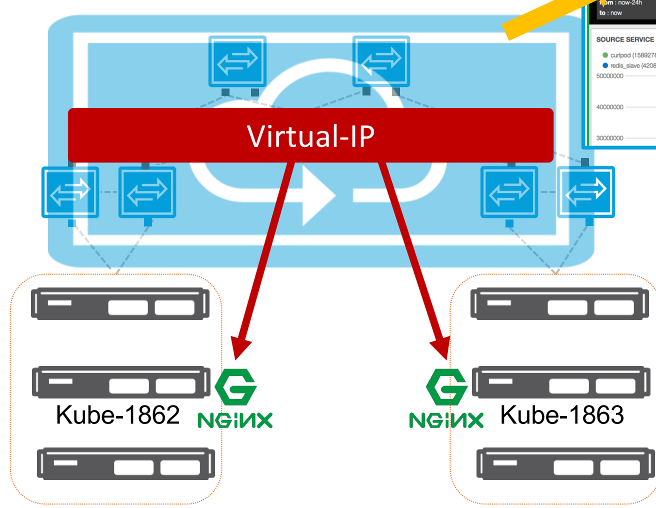
Credit: https://medium.com/google-cloud/kubernetes-nodeport-vs-loadbalancer-vs-ingress-when-should-i-use-what-922f010849e0

K8S Networking: Basics



Exposing Services

- **Ingress**: Network ("Abstracted Network") can really help you out here
- Ingress controllers are deployed in some of your "public" nodes in your cluster
- Eg: **Big Cloud Fabric** (by Big Switch), can expose a Virtual IP in front of the Ingress Controllers and perform Load Balancing/Health Checks/Analytics




```
$ kubectl get pods --all-namespaces -o wide
kube-system                 nginx-ingress-controller-5b95b96fb7-r6ltd   1/1     Running   10.2.18.62        kube-1862
kube-system                 nginx-ingress-controller-5b95b96fb7-vj88x   1/1     Running   10.2.18.63        kube-1863
```

Thanks!

- Repo for all the command outputs/PDF slides:
https://github.com/jayakody/ons-2019

- Credits:
    - Inspired by Life of a Packet- Michael Rubin, Google (https://www.youtube.com/watch?v=0Omvgd7Hg1I)
    - Sarath Kumar, Prashanth Padubidry : Big Switch Engineering
    - Thomas Graf, Dan Wendlandt: Isovalent (Cilium Project)
    - Project Calico Slack Channel: special shout out to: Casey Davenport, Tigera
    - And so many other folks who took time to share knowledge around this emerging space through different mediums (Blogs/YouTube videos etc)