Comprehensive Implementation Guide: Secure Hub-Spoke VCN Architecture with OCI Network Firewall (PRJ-OCI-NET-094)

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1. Project Overview

This project details the deployment of a **secure and scalable Hub-Spoke Virtual Cloud Network (VCN) architecture** within Oracle Cloud Infrastructure (OCI). This model is the industry standard for enterprise cloud networking, designed to centralize network security, management, and connectivity. The core principle is to establish a **Hub VCN** as the central point for all shared services, particularly the **OCI Network Firewall**, and a **Dynamic Routing Gateway (DRG)** for inter-VCN and hybrid connectivity.

The **Spoke VCNs** are dedicated to hosting application workloads, such as web servers, databases, and microservices. By forcing all Spoke-to-Internet and Spoke-to-Spoke traffic to traverse the Hub VCN via the DRG, we ensure that all network communication is subjected to deep packet inspection (DPI) and advanced threat prevention capabilities provided by the OCI Network Firewall. This architecture simplifies the security posture, reduces the attack surface, and ensures consistent application of security policies across the entire cloud footprint.

Key Components of the Architecture:

Component	Role in Hub-Spoke Architecture	OCI Service
Hub VCN	Centralized network for shared services, security, and external connectivity.	Virtual Cloud Network (VCN)
Spoke VCN	Isolated network for hosting application workloads and data.	Virtual Cloud Network (VCN)
Dynamic Routing Gateway (DRG)	High-performance, scalable router for inter-VCN peering and hybrid connectivity (FastConnect/VPN).	Dynamic Routing Gateway (DRG)
OCI Network Firewall	Provides Layer 7 inspection, intrusion prevention, and URL filtering for all transit traffic.	Network Firewall
VCN Flow Logs	Captures metadata about IP traffic for monitoring, security analysis, and auditing.	VCN Flow Logs

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2. Business Context

The adoption of cloud infrastructure often introduces network complexity and security challenges. This project directly addresses these issues by providing a standardized, secure, and auditable network foundation in OCI.

The Problem: Decentralized and Vulnerable Networks

In a typical, unmanaged OCI environment, each application team might deploy its own VCN, leading to a decentralized and fragmented network topology. This results in several critical issues:

1. **Security Gaps and Misconfigurations:** Without a centralized security enforcement point, individual VCNs are prone to security list misconfigurations, creating unintended ingress/egress paths and exposing workloads to threats.
2. **Lack of Visibility and Segmentation:** Monitoring traffic across dozens of VCNs is operationally complex. Furthermore, a flat network structure makes it difficult to enforce strict segmentation between development, staging, and production environments, increasing the risk of lateral movement in the event of a breach.

3. **Operational Overhead and Inefficiency:** Manual configuration of security rules and routing across multiple VCNs is time-consuming, error-prone, and does not scale with the business.

The Solution: Centralized Security and Simplified Management

The Hub-Spoke architecture with the OCI Network Firewall is the definitive solution to these problems. It enforces a **Zero Trust** networking model where all traffic, even internal (Spoke-to-Spoke), is inspected and verified.

- **Centralized Security Enforcement:** The Network Firewall in the Hub VCN becomes the single choke point for all non-local traffic, ensuring that a consistent, high-fidelity security policy is applied everywhere.
- **Simplified Routing:** The DRG handles the complex routing between VCNs, abstracting the complexity from the application teams and allowing them to focus on their core business logic.
- **Enhanced Monitoring:** VCN Flow Logs and Network Firewall logs are aggregated, providing a single source of truth for network activity, which is crucial for security operations and compliance auditing.

Quantified Business Value and ROI

The implementation of this architecture yields significant, quantifiable benefits:

Metric	Before Hub-Spoke	After Hub-Spoke	Business Value / ROI
Time to Deploy New Workload	Weeks (Network setup, security review, routing)	Days (Attach Spoke VCN to DRG, apply standard security group)	**~75% reduction in deployment time.** Accelerates time-to-market for new applications.
Security Incident Response Time	Hours/Days (Locating source, analyzing fragmented logs)	Minutes (Centralized logs, clear traffic path through Firewall)	**~90% faster incident resolution.** Reduces the mean time to detect and respond (MTTD/MTTR).
Operational Overhead (Network Security)	High (Managing N security lists across M VCNs)	Low (Managing one central Network Firewall policy)	**~60% reduction in network security management effort.** Frees up engineering resources for innovation.
Risk of Unauthorized Access	High (Due to configuration drift)	Low (Enforced by immutable, centralized firewall policy)	**Mitigates critical compliance and security risks**, preventing costly breaches and regulatory fines.

Risk Mitigation

This architecture is specifically designed to mitigate the following critical risks:

- **DDoS Attacks:** Leverages OCI's native edge protection, which is automatically applied to all public IPs, ensuring the architecture remains resilient against volumetric attacks.
- **Unauthorized Network Access:** Strict Security List and Network Security Group (NSG) rules, combined with the Network Firewall's Layer 7 inspection, block unauthorized access attempts at multiple layers.
- **Lateral Movement:** By routing all Spoke-to-Spoke traffic through the Network Firewall, any attempt by an attacker to move from a compromised workload in one Spoke to another is inspected and blocked by the Intrusion Prevention System (IPS).
- **Data Exfiltration:** Egress filtering rules on the Network Firewall can prevent unauthorized communication with known malicious IP addresses or domains,

protecting sensitive data.

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3. GRC Mapping

The Hub-Spoke VCN architecture is a foundational element for achieving and maintaining compliance with major global governance, risk, and compliance (GRC) frameworks. The centralization of security controls provides the necessary evidence and enforcement mechanisms required by auditors.

Compliance Framework	Control/Requirement	How PRJ-OCI-NET-094 Addresses It
NIST SP 800-53	**SC-7 (Boundary Protection)**	The Network Firewall acts as the primary boundary enforcement device, inspecting all ingress and egress traffic.
ISO/IEC 27001:2022	**A.8.20 (Network Security)**	Implements structured network security management, including segmentation (VCNs/Subnets) and control (Firewall).
SOC 2 (Trust Services Criteria)	**CC6.6 (Logical and Physical Access Controls)**	Addresses logical access by enforcing network segmentation and controlling traffic flow between segments via the DRG and Firewall.
PCI DSS v4.0	**Requirement 1 (Firewall/Router Configuration)**	Satisfies the requirement for implementing and managing network security controls (firewalls) to protect the Cardholder Data Environment (CDE).
HIPAA	**§ 164.312(e) (Transmission Security)**	Supports the protection of Electronic Protected Health Information (ePHI) by ensuring secure network transmission through inspected and controlled channels.
GDPR	**Article 32 (Security of Processing)**	Contributes to the technical and organizational measures required to ensure a level of security appropriate to the risk, specifically through network security and logging.
Zero Trust Architecture	**NIST SP 800-207**	Enforces the principle of “never trust, always verify” by inspecting all traffic, regardless of source or destination, via the Network Firewall.

Audit Evidence and Logging:

The architecture is configured to provide comprehensive audit evidence:

- **VCN Flow Logs:** Provides a complete, non-repudiable record of all network connection attempts, essential for forensic analysis and demonstrating

compliance with monitoring requirements.

- **Network Firewall Logs:** Detailed logs of all allowed, denied, and threat-detected traffic, proving the effectiveness of the security policy and satisfying deep packet inspection requirements.
- **Configuration as Code:** The use of Infrastructure as Code (IaC) for deployment ensures that the network configuration is auditable, version-controlled, and demonstrably consistent with security policies.

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4. Prerequisites

Before beginning the deployment, ensure the following prerequisites are met.

4.1. OCI Account and Permissions

You must have an active OCI account with a user configured with the necessary Identity and Access Management (IAM) policies. The user must belong to a group with the following minimum permissions:

```
Allow group <your-group> to manage virtual-network-family in compartment
<your-compartment>
Allow group <your-group> to manage network-firewalls in compartment <your-
compartment>
Allow group <your-group> to manage drgs in compartment <your-compartment>
Allow group <your-group> to manage network-firewall-policies in compartment
<your-compartment>
```

4.2. OCI Command Line Interface (CLI) Setup

The deployment instructions rely on the OCI CLI.

1. **Installation:** Install the OCI CLI on your local machine or a dedicated bastion host.

```
bash -c "$(curl -L https://raw.githubusercontent.com/oracle/oci-cli/master/install.sh)"
```

2. **Configuration:** Configure the CLI with your user credentials, tenancy OCID, and region.

   ```
   oci setup config
   ```

   Ensure the configuration file (`~/.oci/config`) is correctly pointing to the desired region (e.g., `us-ashburn-1`).

4.3. Compartment and Variables

A dedicated OCI compartment is required to host the network resources.

- **Compartment OCID:** Obtain the OCID of the target compartment. This will be stored in the `COMPARTMENT_OCID` variable.
- **Region:** Confirm the region where the resources will be deployed. This will be stored in the `REGION` variable.

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5. Architecture Overview

The architecture is a classic Hub-Spoke topology, utilizing the OCI Dynamic Routing Gateway (DRG) as the central interconnection point.

5.1. Hub VCN Components

The Hub VCN is the core of the network, hosting the centralized security and connectivity services.

- **Subnets:**
  - **Network Firewall Subnet (Private):** A dedicated private subnet (`10.0.1.0/24`) to host the OCI Network Firewall endpoint. This subnet

should have no direct route to the Internet Gateway (IGW).
    - **Public Subnet (Optional):** Can host the Internet Gateway (IGW) and a NAT Gateway (if needed), but the firewall itself resides in a private subnet for security.
- **Gateways:**
    - **Internet Gateway (IGW):** Provides public internet access, but traffic is routed through the Firewall.
    - **Dynamic Routing Gateway (DRG) Attachment:** Connects the Hub VCN to the DRG.
- **Security:**
    - **OCI Network Firewall:** The primary security appliance.
    - **Network Firewall Policy:** Contains the Layer 7 security rules (e.g., URL filtering, IPS signatures).

5.2. Spoke VCN Components

Spoke VCNs are isolated environments for application deployment.

- **Subnets:**
    - **Application Subnet (Private):** Hosts application servers (e.g., web/app tiers).
    - **Database Subnet (Private):** Hosts sensitive data stores.
- **Gateways:**
    - **Dynamic Routing Gateway (DRG) Attachment:** Connects the Spoke VCN to the DRG.
- **Routing Logic:**
    - The default route table for all Spoke subnets is configured to route all non-local traffic (`0.0.0.0/0`) to the DRG. This forces all outbound and inter-Spoke traffic to the Hub.

5.3. Traffic Flow and Routing

The routing configuration is the most critical aspect of this architecture:

1. **Spoke to Internet Traffic:**

- Application in Spoke VCN sends traffic to `0.0.0.0/0`.
- Spoke VCN Route Table routes traffic to the **DRG**.
- DRG forwards traffic to the **Hub VCN DRG Attachment**.
- Hub VCN DRG Attachment's Route Table routes traffic to the **OCI Network Firewall**.
- Network Firewall inspects the traffic.
- Network Firewall forwards traffic to the **Internet Gateway (IGW)** for egress.

2. **Spoke to Spoke Traffic:**
   - Application in Spoke VCN 1 sends traffic to Spoke VCN 2's CIDR block.
   - Spoke VCN 1 Route Table routes traffic to the **DRG**.
   - DRG forwards traffic to the **Hub VCN DRG Attachment**.
   - Hub VCN DRG Attachment's Route Table routes traffic to the **OCI Network Firewall**.
   - Network Firewall inspects the traffic (East-West inspection).
   - Network Firewall forwards traffic back to the **DRG** (via a specific route) which then sends it to Spoke VCN 2.

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6. Step-by-Step Implementation (OCI CLI)

This section provides the detailed OCI CLI commands to deploy the Hub-Spoke architecture. **Note:** For production environments, Infrastructure as Code (IaC) like Terraform is highly recommended.

Step 6.1: Define Variables

Define the necessary environment variables for the deployment. Replace the placeholder values with your actual OCID and desired CIDR blocks.

```
# Define your compartment OCID
COMPARTMENT_OCID="ocid1.compartment.oc1..exampleuniqueID"
REGION="us-ashburn-1"

# VCN CIDR Blocks
HUB_VCN_CIDR="10.0.0.0/16"
SPOKE_VCN_CIDR="10.1.0.0/16"

# Subnet CIDR Blocks
HUB_FW_SUBNET_CIDR="10.0.1.0/24"
SPOKE_APP_SUBNET_CIDR="10.1.1.0/24"

echo "Variables defined. Starting deployment in $REGION."
```

Step 6.2: Create VCNs and Dynamic Routing Gateway (DRG)

The DRG is the central component that enables connectivity between the VCNs.

```
# 1. Create Hub VCN
echo "Creating Hub VCN..."
HUB_VCN_ID=$(oci network vcn create --compartment-id $COMPARTMENT_OCID --
display-name "HubVCN-PRJ-094" --cidr-block $HUB_VCN_CIDR --query 'data.id' -
-raw-output)
echo "Hub VCN ID: $HUB_VCN_ID"

# 2. Create Spoke VCN
echo "Creating Spoke VCN..."
SPOKE_VCN_ID=$(oci network vcn create --compartment-id $COMPARTMENT_OCID --
display-name "SpokeVCN-PRJ-094" --cidr-block $SPOKE_VCN_CIDR --query
'data.id' --raw-output)
echo "Spoke VCN ID: $SPOKE_VCN_ID"

# 3. Create Dynamic Routing Gateway (DRG)
echo "Creating Central DRG..."
DRG_ID=$(oci network drg create --compartment-id $COMPARTMENT_OCID --
display-name "CentralDRG-PRJ-094" --query 'data.id' --raw-output)
echo "DRG ID: $DRG_ID"

# 4. Attach VCNs to DRG
echo "Attaching VCNs to DRG..."
HUB_ATTACHMENT_ID=$(oci network drg-attachment create --drg-id $DRG_ID --
vcn-id $HUB_VCN_ID --display-name "HubAttachment-PRJ-094" --query 'data.id'
--raw-output)
echo "Hub Attachment ID: $HUB_ATTACHMENT_ID"

SPOKE_ATTACHMENT_ID=$(oci network drg-attachment create --drg-id $DRG_ID --
vcn-id $SPOKE_VCN_ID --display-name "SpokeAttachment-PRJ-094" --query
'data.id' --raw-output)
echo "Spoke Attachment ID: $SPOKE_ATTACHMENT_ID"

# Wait for attachments to be provisioned (critical step)
echo "Waiting for DRG attachments to become available..."
# In a real script, you would use a 'wait' command here.
sleep 60
```

Step 6.3: Configure Hub VCN Gateways and Subnets

We create the necessary gateways and the dedicated subnet for the Network Firewall.

```
# 1. Create Internet Gateway (IGW) in Hub VCN
echo "Creating Internet Gateway in Hub VCN..."
IGW_ID=$(oci network internet-gateway create --compartment-id
$COMPARTMENT_OCID --vcn-id $HUB_VCN_ID --display-name "HubIGW-PRJ-094" --is-
enabled true --query 'data.id' --raw-output)
echo "IGW ID: $IGW_ID"

# 2. Create Hub Firewall Subnet (Private)
echo "Creating Hub Firewall Subnet..."
HUB_FW_SUBNET_ID=$(oci network subnet create --compartment-id
$COMPARTMENT_OCID --vcn-id $HUB_VCN_ID --display-name "HubFwSubnet-PRJ-094"
--cidr-block $HUB_FW_SUBNET_CIDR --prohibit-public-ip-on-vnic true --query
'data.id' --raw-output)
echo "Hub FW Subnet ID: $HUB_FW_SUBNET_ID"

# 3. Create Route Table for IGW (Outbound Internet traffic from Firewall)
echo "Creating Hub Route Table for IGW..."
HUB_IGW_RT_ID=$(oci network route-table create --compartment-id
$COMPARTMENT_OCID --vcn-id $HUB_VCN_ID --display-name "HubIGWRT-PRJ-094" --
route-rules "[{\"cidrBlock\":\"0.0.0.0/0\",
\"networkEntityId\":\"$IGW_ID\"}]" --query 'data.id' --raw-output)
echo "Hub IGW Route Table ID: $HUB_IGW_RT_ID"

# 4. Update Hub VCN Default Route Table to route Spoke traffic to DRG
# This is for traffic originating in the Hub VCN destined for the Spoke VCN
echo "Updating Hub VCN Default Route Table for Spoke traffic..."
HUB_DEFAULT_RT_ID=$(oci network vcn get --vcn-id $HUB_VCN_ID --query
'data."default-route-table-id"' --raw-output)
oci network route-table update --rt-id $HUB_DEFAULT_RT_ID --route-rules "
[{\"cidrBlock\":\"$SPOKE_VCN_CIDR\", \"networkEntityId\":\"$DRG_ID\"}]"
```

Step 6.4: Deploy OCI Network Firewall

The Network Firewall requires a policy defining its security rules.

```
# 1. Create Network Firewall Policy (The policy is where all rules are
defined)
echo "Creating Central Network Firewall Policy..."
FW_POLICY_ID=$(oci network network-firewall-policy create --compartment-id
$COMPARTMENT_OCID --display-name "CentralFWPolicy-PRJ-094" --query 'data.id'
--raw-output)
echo "FW Policy ID: $FW_POLICY_ID"

# 2. Create Network Firewall instance in the dedicated subnet
echo "Creating Central Network Firewall instance..."
FW_ID=$(oci network network-firewall create --compartment-id
$COMPARTMENT_OCID --display-name "CentralNetworkFirewall-PRJ-094" --network-
firewall-policy-id $FW_POLICY_ID --vcn-id $HUB_VCN_ID --subnet-id
$HUB_FW_SUBNET_ID --query 'data.id' --raw-output)
echo "Network Firewall ID: $FW_ID"

# 3. Wait for the firewall to be active (This can take 15-20 minutes in a
real deployment)
echo "Waiting for Network Firewall to become active (omitted 'wait' for
brevity)..."
# In a real script, a polling loop is necessary.
sleep 120

# 4. Get the Network Firewall's private IP (This is the next hop for
routing)
FW_IP=$(oci network network-firewall get --network-firewall-id $FW_ID --
query 'data."network-firewall-ip-address"' --raw-output)
echo "Network Firewall IP: $FW_IP"
```

Step 6.5: Configure Routing for Traffic Inspection

This is the most crucial step, ensuring all traffic is steered through the Network Firewall.

A. Hub VCN Routing (Traffic from Spoke to Internet)

Traffic arriving at the Hub DRG Attachment, destined for the Internet (`0.0.0.0/0`), must be routed to the Network Firewall.

```
# 1. Create a route table for the DRG Attachment in the Hub VCN
echo "Creating Hub DRG Route Table to steer traffic to Firewall..."
HUB_DRG_RT_ID=$(oci network route-table create --compartment-id
$COMPARTMENT_OCID --vcn-id $HUB_VCN_ID --display-name "HubDRGRT-FW-PRJ-094"
--route-rules "[{\"cidrBlock\":\"0.0.0.0/0\",
\"networkEntityId\":\"$FW_ID\"}]" --query 'data.id' --raw-output)
echo "Hub DRG Route Table ID: $HUB_DRG_RT_ID"

# 2. Update the DRG Attachment in the Hub VCN to use this route table
echo "Updating Hub DRG Attachment to use the Firewall Route Table..."
oci network drg-attachment update --drg-attachment-id $HUB_ATTACHMENT_ID --
route-table-id $HUB_DRG_RT_ID
```

B. Spoke VCN Routing (Traffic from Spoke to Hub)

All traffic from the Spoke VCN must be routed to the DRG.

```
# 1. Create Spoke Application Subnet
echo "Creating Spoke Application Subnet..."
SPOKE_APP_SUBNET_ID=$(oci network subnet create --compartment-id
$COMPARTMENT_OCID --vcn-id $SPOKE_VCN_ID --display-name "SpokeAppSubnet-PRJ-
094" --cidr-block $SPOKE_APP_SUBNET_CIDR --prohibit-public-ip-on-vnic true -
-query 'data.id' --raw-output)
echo "Spoke App Subnet ID: $SPOKE_APP_SUBNET_ID"

# 2. Create Route Table for Spoke Subnet
echo "Creating Spoke App Route Table to steer traffic to DRG..."
SPOKE_APP_RT_ID=$(oci network route-table create --compartment-id
$COMPARTMENT_OCID --vcn-id $SPOKE_VCN_ID --display-name "SpokeAppRT-DRG-PRJ-
094" --route-rules "[{\"cidrBlock\":\"0.0.0.0/0\",
\"networkEntityId\":\"$DRG_ID\"}]" --query 'data.id' --raw-output)
echo "Spoke App Route Table ID: $SPOKE_APP_RT_ID"

# 3. Update Spoke App Subnet to use this route table
echo "Updating Spoke App Subnet to use the DRG Route Table..."
oci network subnet update --subnet-id $SPOKE_APP_SUBNET_ID --route-table-id
$SPOKE_APP_RT_ID
```

Step 6.6: Configure Network Firewall Policy Rules

The Network Firewall Policy (`$FW_POLICY_ID`) is where the actual security rules are defined. This is typically done via a complex JSON structure.

Conceptual Steps for Policy Configuration:

1. **Create a Decryption Profile:** If you need to inspect HTTPS traffic, a decryption profile is required.
2. **Create Security Rules:** Define rules for traffic inspection. A rule consists of a source/destination, application/protocol, and an action (ALLOW, DENY, INSPECT).
3. **Example Rule (Conceptual):** Allow outbound HTTP/HTTPS traffic from the Spoke VCN to the Internet.

```
# Conceptual: Define a rule to allow all outbound web traffic
echo "--- Conceptual Firewall Policy Configuration ---"
echo "Rule 1: Allow outbound HTTP/HTTPS from Spoke VCN to 0.0.0.0/0"
echo "Rule 2: Deny all other outbound traffic (Implicit Deny)"
echo "Rule 3: Allow inter-Spoke traffic (10.1.0.0/16 to 10.2.0.0/16) for
specific ports (e.g., 22, 3389) and INSPECT."

# In a production environment, you would use a JSON file and the following
command:
# oci network network-firewall-policy rule-list create --network-firewall-
policy-id $FW_POLICY_ID --from-json file://policy_rules.json
```

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7. Validation & Testing

Validation is essential to confirm that the architecture is not only deployed but is functioning securely as intended.

7.1. Connectivity Test (Spoke to Internet)

Objective: Verify that a workload in the Spoke VCN can reach the internet and that this traffic is being inspected.

1. **Deployment:** Deploy a Linux Compute Instance (e.g., Oracle Linux) into the `SpokeAppSubnet-PRJ-094`.
2. **Test:** From the Compute Instance, attempt to ping an external IP and access a website.

```
# Test connectivity
ping 8.8.8.8 -c 4
curl -I https://www.oracle.com
```

3. **Verification:** If the connection is successful, the routing is correct. The next step is to verify inspection.

7.2. Firewall Log Validation

Objective: Confirm that the Network Firewall is actively inspecting and logging the traffic.

1. **Access Logs:** Navigate to the OCI Console, find the `CentralNetworkFirewall-PRJ-094`, and check its associated logs (typically integrated with OCI Logging).
2. **Search:** Search the logs for the source IP address of the Compute Instance deployed in the Spoke VCN.
3. **Confirm:** You should see log entries showing the `ALLOW` action for the `ping` and `curl` traffic, along with Layer 7 details (if HTTPS inspection is enabled).

7.3. Segmentation Test (Spoke to Spoke)

Objective: Verify that the Network Firewall controls traffic between different Spoke VCNs (or even between subnets within the same Spoke VCN if configured).

1. **Setup:** Deploy a second Compute Instance in a different subnet (e.g., a hypothetical `SpokeDBSubnet`).
2. **Test:** Attempt to connect from the first Compute Instance to the second (e.g., `ssh` or `telnet`).
3. **Verification:**

- If the connection is **allowed** by the Firewall Policy, the connection should succeed, and a log entry should be generated.
- If the connection is **denied** by the Firewall Policy, the connection should fail, and a `DENY` log entry should be generated, proving the segmentation control is active.

7.4. Flow Log Validation

Objective: Ensure VCN Flow Logs are capturing all network metadata for auditing purposes.

1. **Enable Flow Logs:** Ensure VCN Flow Logs are enabled on the `SpokeAppSubnet-PRJ-094` and configured to send data to an OCI Logging log group.
2. **Check Log Group:** Access the target log group in OCI Logging.
3. **Confirm:** Verify that log entries containing source/destination IPs, ports, and the action (ACCEPT/REJECT) are being generated for the test traffic.

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8. Troubleshooting

This section addresses common issues encountered during the deployment and operation of the Hub-Spoke architecture.

Issue	Potential Cause	Resolution
No Internet Access from Spoke VCN	**Routing Loop or Missing Route:** Incorrect routing from Spoke Subnet to DRG, or from Hub DRG Attachment to Network Firewall.	**1.** Verify the Spoke Subnet's Route Table has a `0.0.0.0/0` rule pointing to the **DRG**. **2.** Verify the Hub DRG Attachment's Route Table has a `0.0.0.0/0` rule pointing to the **Network Firewall ID** (`$FW_ID`).
Traffic is not being inspected	**Firewall Bypass:** The Network Firewall is not the next hop in the route table, or the traffic is using a different gateway (e.g., a NAT Gateway in the Spoke VCN).	Ensure the Hub DRG Attachment's Route Table explicitly uses the Network Firewall ID (`$FW_ID`) as the target for the `0.0.0.0/0` route. Remove any other default routes that could bypass the firewall.
OCI CLI Command Fails (e.g., "NotAuthorizedOrNotFound")	**Missing OCID or Incorrect Permissions:** The `$COMPARTMENT_OCID` is wrong, or the user lacks the necessary `manage` permissions for `virtual-network-family` or `network-firewalls` .	**1.** Double-check all defined variables, especially the OCIDs. **2.** Review the IAM policies for the deploying user group to ensure all required `manage` statements are present.
Network Firewall is stuck in "Updating" or "Failed" state	**Subnet Misconfiguration:** The Network Firewall was deployed into a subnet that is too small or has incorrect security list rules preventing its management plane from communicating.	**1.** Ensure the `HUB_FW_SUBNET_CIDR` is large enough (e.g., `/24`). **2.** Check the Security List/NSG associated with the firewall subnet to ensure it allows necessary OCI control plane traffic.
Inter-Spoke traffic fails	**Missing DRG Route Distribution:** The DRG is not correctly distributing	Verify the DRG Route Tables are configured to import routes from all VCN

Issue	Potential Cause	Resolution
	routes between the VCN attachments.	attachments. Ensure the Hub DRG Attachment's route table has a rule to route the Spoke VCN 2 CIDR block back to the DRG.

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9. Cost Optimization

While the OCI Network Firewall provides superior security, it is a managed service with associated costs. Optimizing the architecture can significantly reduce the total cost of ownership (TCO).

9.1. Right-Sizing and Monitoring

The OCI Network Firewall is billed based on throughput (GB processed) and the number of firewall hours.

- **Monitor Utilization:** Use OCI Monitoring to track the throughput of the Network Firewall.
- **Scale Down:** If traffic is consistently low, evaluate if a smaller security solution (e.g., enhanced Security Lists/NSGs) could suffice, or if the Network Firewall tier can be adjusted (if applicable in future OCI offerings). For the current OCI Network Firewall, focus on minimizing unnecessary traffic passing through it.

9.2. Flow Log Retention Policy

VCN Flow Logs are critical for compliance but generate significant storage costs if retained indefinitely.

- **Define a Policy:** Implement a clear retention policy (e.g., 90 days in OCI Logging, then archive to OCI Object Storage for 7 years).
- **Filter Logs:** Only enable flow logs on subnets that host critical or sensitive workloads. Avoid logging high-volume, low-value traffic (e.g., internal health checks) unless strictly required for compliance.

9.3. Strategic Use of NAT Gateway

For Spoke VCNs that only require outbound internet access (e.g., patching servers, downloading updates) and do not need deep packet inspection, a NAT Gateway can be a cost-effective alternative to routing all traffic through the Network Firewall.

- **Cost Comparison:** NAT Gateways are generally cheaper than Network Firewall throughput.
- **Security Trade-off:** Using a NAT Gateway bypasses the Network Firewall's Layer 7 inspection. This should only be done for low-risk, non-critical traffic, or where the security requirements are met by other means (e.g., endpoint protection on the compute instance). In a strict security posture, all traffic should go through the Hub Firewall.

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10. Security Best Practices

Beyond the core architecture, maintaining a robust security posture requires adherence to operational best practices.

10.1. Principle of Least Privilege with NSGs

While Security Lists (SLs) are applied at the subnet level, **Network Security Groups (NSGs)** are the preferred method for micro-segmentation.

- **NSG Preference:** Use NSGs to apply security rules directly to the Virtual Network Interface Cards (VNICs) of individual compute instances. This allows for granular control, ensuring that only the necessary ports are open for a specific application instance, regardless of the subnet it resides in.
- **Minimize SL Usage:** Use Security Lists only for broad, non-critical subnet-level controls, and rely on NSGs for application-specific rules.

10.2. Centralized Logging and SIEM Integration

Centralizing all security-relevant logs is non-negotiable for effective monitoring and threat detection.

- **Aggregation:** Ensure all logs (VCN Flow Logs, Network Firewall Logs, OCI Audit Logs, Compute Instance OS Logs) are aggregated into a central repository (e.g., OCI Logging Analytics).
- **SIEM Integration:** Integrate the central log repository with a Security Information and Event Management (SIEM) solution (e.g., Splunk, Microsoft Sentinel) for real-time correlation, alerting, and automated response.

10.3. Immutable Infrastructure and IaC

Manual changes to network infrastructure introduce configuration drift and security vulnerabilities.

- **Infrastructure as Code (IaC):** Manage the entire architecture (VCNs, Subnets, DRG, Firewall Policy) using Terraform. This ensures that the configuration is version-controlled, peer-reviewed, and repeatable.
- **Avoid Manual Changes:** Treat the infrastructure as **immutable**. Any change should be made by modifying the IaC code and redeploying, rather than making direct changes in the OCI Console.

10.4. Regular Audits and Policy Review

Security policies are not static; they must evolve with the application and threat landscape.

- **Quarterly Policy Review:** Conduct a quarterly audit of the Network Firewall Policy rules. Remove any rules that are no longer necessary (e.g., temporary access rules) to reduce the attack surface.
- **Vulnerability Scanning:** Implement regular vulnerability scanning on the compute instances within the Spoke VCNs. Ensure the Network Firewall policy is updated to block any newly identified malicious traffic patterns.

Appendix: Cleanup Commands

Use these commands to tear down the deployed resources in the correct reverse order. **Caution:** Ensure you have the correct environment variables set before execution.

```
# WARNING: These commands will permanently delete the resources.

# 1. Delete DRG Attachments (must be deleted before VCNs or DRG)
echo "Deleting DRG Attachments..."
oci network drg-attachment delete --drg-attachment-id $HUB_ATTACHMENT_ID --
force
oci network drg-attachment delete --drg-attachment-id $SPOKE_ATTACHMENT_ID -
-force

# 2. Delete Network Firewall and Policy
echo "Deleting Network Firewall and Policy..."
oci network network-firewall delete --network-firewall-id $FW_ID --force
oci network network-firewall-policy delete --network-firewall-policy-id
$FW_POLICY_ID --force

# 3. Delete Subnets (and their associated route tables/security lists if not
default)
echo "Deleting Subnets..."
oci network subnet delete --subnet-id $HUB_FW_SUBNET_ID --force
oci network subnet delete --subnet-id $SPOKE_APP_SUBNET_ID --force

# 4. Delete Gateways
echo "Deleting Internet Gateway..."
oci network internet-gateway delete --ig-id $IGW_ID --force

# 5. Delete DRG
echo "Deleting Dynamic Routing Gateway..."
oci network drg delete --drg-id $DRG_ID --force

# 6. Delete VCNs
echo "Deleting VCNs..."
oci network vcn delete --vcn-id $HUB_VCN_ID --force
oci network vcn delete --vcn-id $SPOKE_VCN_ID --force

echo "Cleanup complete."
```