CANONICAL LIVING OVERVIEW GUIDE

Ethernet Switching, VLANs, STP, MLAG, and Layer-2 Resilience

A comprehensive Layer-2 engineering guide covering Ethernet forwarding, VLAN segmentation, spanning tree, link aggregation, multichassis designs, loop prevention, failure behavior, security, observability, and migration toward EVPN fabrics.

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Publication position
This is a living field guide. It is designed for frequent revision while retaining a stable permanent identity. Candidate status means the content is ready for structured use and review but is not represented as an external certification or authority publication.

LEVEL	CLASS	CADENCE	EVIDENCE
L1-L4	FIELD GUIDE	QUARTERLY	SOURCE-BOUND
Foundational through frontier	Practical and educational	Interim updates as needed	Limitations remain visible

Reader orientation

Dimension	Engineering position
Primary domain	MYTHOS-NET - Network Engineering & Architecture
Secondary domain	MYTHOS-SEC; MYTHOS-DAT
Audience	Enterprise, campus, data-center, wireless, security, and infrastructure engineers responsible for switched networks.
Prerequisites	Basic understanding of Ethernet frames, IP addressing, and switch interfaces.
Publisher / owner	Mythos Systems / Aaron Stovall
Public classification	Public technical guidance

Expected outcomes

Design bounded Layer-2 domains with explicit segmentation, resiliency, and failure behavior.

Explain MAC learning, flooding, STP roles, LACP state, and MLAG forwarding using packet and control-plane evidence.

Prevent and diagnose loops, broadcast storms, VLAN mismatches, orphan-port failures, and split-brain conditions.

Validate convergence and traffic continuity rather than relying on topology diagrams alone.

Choose when to retain Layer 2 and when to transition to routed access or EVPN.

How to use this guide

Read the guide as a progressive system rather than a disconnected encyclopedia. Foundational material establishes the mental model; practitioner sections convert it into repeatable implementation and operations; advanced sections expose architecture, scale, security, and failure behavior; frontier sections describe technologies whose evidence or maturity is still evolving.

Suggested reading path
New practitioners should follow the chapters in order and complete the laboratories. Experienced engineers may begin with the architecture, failure, validation, or frontier sections, then use the related-document map to deepen a specific topic.

Learning and assurance model

Level	Reader outcome
L1 - Foundational	Terminology, first principles, component roles, packet or state flow, and simple working examples.
L2 - Practitioner	Implementation, configuration, automation, testing, troubleshooting, and operational evidence.
L3 - Advanced	Architecture, scale, concurrency, resilience, threat models, performance, and complex migrations.
L4 - Frontier	Emerging systems, research directions, technical uncertainty, readiness gates, and adoption signals.

Contents

CHAPTER 01

Ethernet forwarding foundations

Establish precise forwarding behavior before adding redundancy and control protocols.

Chapter operating position
Establish precise forwarding behavior before adding redundancy and control protocols.

1.1 Frame format and MAC addressing

Frame format and MAC addressing is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Relate source, destination, EtherType, optional tags, payload, FCS, unicast, multicast, and broadcast behavior. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for frame format and mac addressing.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating frame format and mac addressing as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for frame format and mac addressing.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

1.2 MAC learning and forwarding databases

MAC learning and forwarding databases is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Explain source learning, destination lookup, aging, moves, static entries, table pressure, and control-plane synchronization. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for mac learning and forwarding databases.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

Treating mac learning and forwarding databases as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for mac learning and forwarding databases.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

1.3 Flooding domains and unknown traffic

Flooding domains and unknown traffic is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Distinguish broadcast, unknown unicast, and multicast flooding and define acceptable boundaries. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing,

tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for flooding domains and unknown traffic.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating flooding domains and unknown traffic as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for flooding domains and unknown traffic.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

1.4 Physical errors and duplex behavior

Physical errors and duplex behavior is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Correlate CRC, runts, giants, alignment, symbol errors, negotiation, optics, and duplex problems with service symptoms. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for physical errors and duplex behavior.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating physical errors and duplex behavior as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for physical errors and duplex behavior.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 01 laboratory and review

Practical laboratory
Build a three-switch topology and observe learning, aging, unknown-unicast flooding, MAC movement, and physical-error counters.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Extend forwarding analysis to cut-through switches, programmable pipelines, SmartNICs, and optical switching.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 02

VLAN architecture and segmentation

Use VLANs as controlled broadcast and policy boundaries rather than arbitrary numbering.

Chapter operating position
Use VLANs as controlled broadcast and policy boundaries rather than arbitrary numbering.

2.1 Access ports, trunks, and tagging

Access ports, trunks, and tagging is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Define ingress classification, tag insertion, tag removal, allowed VLANs, and native or untagged handling. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for access ports, trunks, and tagging.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating access ports, trunks, and tagging as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for access ports, trunks, and tagging.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

2.2 VLAN design and naming

VLAN design and naming is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Align identifiers with services, ownership, failure domains, addressing, policy, and lifecycle. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for vlan design and naming.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

- Treating vlan design and naming as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for vlan design and naming.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

2.3 Voice, wireless, virtualization, and dynamic VLANs

Voice, wireless, virtualization, and dynamic VLANs is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Handle multi-domain ports, tunneled clients, hypervisors, APs, and identity-assigned segmentation. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for voice, wireless, virtualization, and dynamic vlans.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating voice, wireless, virtualization, and dynamic vlans as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for voice, wireless, virtualization, and dynamic vlans.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

2.4 QinQ and provider bridging concepts

QinQ and provider bridging concepts is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Understand stacked tags, customer and service VLANs, transparency, MTU, operations, and security implications. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for qinq and provider bridging concepts.
- Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating qinq and provider bridging concepts as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for qinq and provider bridging concepts.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 02 laboratory and review

Practical laboratory
Create access, trunk, voice, AP, and hypervisor port profiles. Intentionally introduce native-VLAN and allowed-list mismatches and prove each failure.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Evaluate VXLAN VNIs, policy groups, identity-derived segments, and VLAN reduction through routed or overlay fabrics.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 03

Spanning-tree architecture

Understand how bridged networks prevent loops and select forwarding topologies.

Chapter operating position
Understand how bridged networks prevent loops and select forwarding topologies.

3.1 Bridge IDs, path cost, and root selection

Bridge IDs, path cost, and root selection is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Calculate root bridge, root ports, designated ports, blocked roles, and path changes. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for bridge ids, path cost, and root selection.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating bridge ids, path cost, and root selection as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for bridge ids, path cost, and root selection.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

3.2 RSTP and MSTP behavior

RSTP and MSTP behavior is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Explain rapid transitions, proposals, agreements, edge ports, shared links, regions, instances, and interoperability. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for rstp and mstp behavior.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

Treating rstp and mstp behavior as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for rstp and mstp behavior.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

3.3 Topology change and MAC flushing

Topology change and MAC flushing is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Trace topology-change propagation, forwarding database updates, transient flooding, and application impact. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for topology change and mac flushing.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating topology change and mac flushing as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for topology change and mac flushing.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

3.4 Root placement and deterministic design

Root placement and deterministic design is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Align primary and secondary roots with gateway location, traffic paths, redundancy, and operational intent. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for root placement and deterministic design.
- Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating root placement and deterministic design as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for root placement and deterministic design.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 03 laboratory and review

Practical laboratory
Build redundant triangles under RSTP or MSTP, predict every role before convergence, fail each link, and measure packet loss and reconvergence.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Compare spanning-tree resilience with routed access, SPB, TRILL history, and EVPN multihoming.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 04

Loop and edge protection

Prevent accidental or malicious conditions from destabilizing a bridged domain.

Chapter operating position
Prevent accidental or malicious conditions from destabilizing a bridged domain.

4.1 BPDU Guard, Root Guard, and Loop Guard

BPDU Guard, Root Guard, and Loop Guard is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Choose protections by port role and understand their distinct trigger and recovery behavior. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for bpdu guard, root guard, and loop guard.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating bpdu guard, root guard, and loop guard as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for bpdu guard, root guard, and loop guard.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

4.2 UDLD and unidirectional-link detection

UDLD and unidirectional-link detection is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Detect one-way fiber or forwarding faults that can defeat normal bidirectional assumptions. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for udld and unidirectional-link detection.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

Treating udld and unidirectional-link detection as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for udld and unidirectional-link detection.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

4.3 Storm control and rate protection

Storm control and rate protection is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Bound broadcast, multicast, and unknown-unicast impact without masking legitimate bursts. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing,

tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for storm control and rate protection.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating storm control and rate protection as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for storm control and rate protection.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

4.4 Port security and control-plane protection

Port security and control-plane protection is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Limit identity, MAC movement, spoofing, discovery abuse, and protocol-plane resource exhaustion. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for port security and control-plane protection.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating port security and control-plane protection as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for port security and control-plane protection.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 04 laboratory and review

Practical laboratory
Inject a rogue switch, superior BPDU, unidirectional link, and broadcast storm. Verify each control activates as designed and does not create unacceptable collateral impact.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Explore per-stream filtering, deterministic Ethernet, cryptographic link identity, and autonomous loop containment.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 05

Link aggregation and LACP

Engineer bundles as stateful systems with member eligibility, hashing, and asymmetric failure behavior.

Chapter operating position
Engineer bundles as stateful systems with member eligibility, hashing, and asymmetric failure behavior.

5.1 Static bundles and LACP state

Static bundles and LACP state is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Understand actor and partner state, system identifiers, keys, timers, collecting, distributing, and minimum-links behavior. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for static bundles and lacp state.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating static bundles and lacp state as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for static bundles and lacp state.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

5.2 Hashing and flow distribution

Hashing and flow distribution is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Model source and destination fields, polarization, elephant flows, entropy, and per-flow bandwidth limits. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for hashing and flow distribution.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

- Treating hashing and flow distribution as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for hashing and flow distribution.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

5.3 Failure, recovery, and partial connectivity

Failure, recovery, and partial connectivity is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Test member loss, one-way faults, mismatched bundles, suspended links, and recovery sequencing. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for failure, recovery, and partial connectivity.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating failure, recovery, and partial connectivity as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for failure, recovery, and partial connectivity.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

5.4 Operational visibility

Operational visibility is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Correlate logical bundle state, member counters, LACP PDUs, forwarding decisions, and application flows. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for operational visibility.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating operational visibility as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for operational visibility.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 05 laboratory and review

Practical laboratory
Build a four-member LACP bundle, generate diverse and single-flow traffic, remove members, create a mismatch, and validate minimum-links behavior.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Evaluate resilient hashing, adaptive load balancing, 400/800G breakout, and optical member diversity.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 06

MLAG and multichassis resilience

Understand the proprietary and standards-adjacent mechanisms that make two switches appear as one attachment system.

Chapter operating position
Understand the proprietary and standards-adjacent mechanisms that make two switches appear as one attachment system.

6.1 Peer links, keepalives, and state synchronization

Peer links, keepalives, and state synchronization is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Identify what state crosses each channel and what happens when only one channel fails. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for peer links, keepalives, and state synchronization.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating peer links, keepalives, and state synchronization as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for peer links, keepalives, and state synchronization.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

6.2 Orphan ports and dual-attached endpoints

Orphan ports and dual-attached endpoints is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Model local forwarding, peer-link use, active-active attachment, and isolation under failures. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for orphan ports and dual-attached endpoints.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

Treating orphan ports and dual-attached endpoints as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for orphan ports and dual-attached endpoints.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

6.3 Split brain and dual-primary prevention

Split brain and dual-primary prevention is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Define detection, role selection, port shutdown, recovery, and risks of inconsistent state. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing,

tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for split brain and dual-primary prevention.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating split brain and dual-primary prevention as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for split brain and dual-primary prevention.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

6.4 Routing over MLAG

Routing over MLAG is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Understand first-hop redundancy, anycast gateway, routing adjacencies, peer-gateway behavior, and asymmetric traffic. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for routing over mlag.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating routing over mlag as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for routing over mlag.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 06 laboratory and review

Practical laboratory

Test peer-link failure, keepalive failure, total isolation, one chassis loss, orphan traffic, and dual-attached traffic. Record expected and observed actions.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Compare MLAG with EVPN Ethernet segments, all-active multihoming, distributed anycast gateways, and controller-assisted fabrics.

Review gate

Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 07

Layer-2 security and observability

Make segmentation and resilience measurable, reviewable, and resistant to common abuse.

Chapter operating position
Make segmentation and resilience measurable, reviewable, and resistant to common abuse.

7.1 DHCP snooping and source validation

DHCP snooping and source validation is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Build trusted boundaries, binding databases, option handling, rate limits, and interactions with mobility. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for dhcp snooping and source validation.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating dhcp snooping and source validation as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for dhcp snooping and source validation.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

7.2 ARP inspection and IPv6 first-hop security

ARP inspection and IPv6 first-hop security is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Validate address ownership, neighbor advertisements, router advertisements, and exception handling. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for arp inspection and ipv6 first-hop security.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

- Treating arp inspection and ipv6 first-hop security as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for arp inspection and ipv6 first-hop security.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

7.3 Telemetry and change evidence

Telemetry and change evidence is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Collect MAC, VLAN, STP, LACP, interface, error, topology, and configuration state with stable time and identity. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing,

tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for telemetry and change evidence.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating telemetry and change evidence as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for telemetry and change evidence.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

7.4 Baseline and anomaly detection

Baseline and anomaly detection is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Detect unexpected roots, MAC churn, VLAN propagation, loops, storms, and member imbalance. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for baseline and anomaly detection.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating baseline and anomaly detection as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for baseline and anomaly detection.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 07 laboratory and review

Practical laboratory
Enable first-hop protections and telemetry in a lab. Attempt rogue DHCP, ARP spoofing, RA spoofing, and rapid MAC movement while preserving evidence.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Extend assurance with streaming telemetry, graph models, digital twins, and programmable switch verification.

Review gate
Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

CHAPTER 08

Design, migration, and failure assurance

Choose bounded Layer-2 patterns and prove behavior under realistic lifecycle changes.

Chapter operating position
Choose bounded Layer-2 patterns and prove behavior under realistic lifecycle changes.

8.1 Failure-domain sizing

Failure-domain sizing is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Limit VLAN scope, spanning-tree diameter, endpoint count, broadcast rate, and shared dependencies. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for failure-domain sizing.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating failure-domain sizing as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for failure-domain sizing.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

8.2 Routed access and EVPN migration

Routed access and EVPN migration is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Identify triggers for moving segmentation and redundancy into Layer 3 or overlay control planes. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for routed access and evpn migration.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Implementation sketch

```
interfaces:
  uplink_bundle:
    mode: lacp-active
    minimum_links: 1
    members: [ethernet1, ethernet2]
  access_profile:
    mode: access
    vlan: 120
    protections:
      bpdu_guard: true
      storm_control_percent: 1
      dhcp_snooping: true
validation:
  - root_and_port_roles
  - lacp_actor_partner_state
  - mac_learning_and_move
  - member_failure_and_recovery
```

Failure patterns

- Treating routed access and evpn migration as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.
- Assuming an established adjacency or installed route proves end-to-end forwarding.
- Changing multiple variables before preserving the original failure evidence.
- Using vendor-default timers, trust, or policy without documenting the resulting behavior.
- Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for routed access and evpn migration.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

8.3 Change planning and rollback

Change planning and rollback is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Validate VLAN additions, root changes, bundle changes, software upgrades, and staged migrations. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

- Document the authoritative design intent, ownership, and scope for change planning and rollback.
- Predict protocol and forwarding state before implementation or troubleshooting.
- Validate control-plane state, installed forwarding state, and real traffic independently.
- Test normal, boundary, degraded, failed, recovery, and rollback conditions.
- Retain packet, configuration, counter, log, topology, timing, and service evidence.
- Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

- Treating change planning and rollback as a configuration recipe without understanding protocol state.
- Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for change planning and rollback.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

8.4 Acceptance and resilience testing

Acceptance and resilience testing is an operational mechanism with observable inputs, state transitions, forwarding consequences, and failure signatures. Define positive traffic, denied traffic, convergence, split-brain, storm, and recovery tests. The engineer should be able to predict the expected state before opening a command line, then compare that prediction with device, endpoint, packet, and service evidence.

In this guide, the subject is traced through the bridging, forwarding, and failure-domain chain. Configuration alone is not accepted as proof: intended state must be reconciled with protocol state, installed forwarding state, traffic counters, packet behavior, and the application or receiver outcome. This prevents a healthy control plane from concealing a broken data plane, and prevents a working test flow from concealing an unsafe policy.

A production implementation begins by defining authority, scope, identifiers, timers, capacity, security boundaries, telemetry, and rollback. Establish a small known-good baseline; exercise normal operation; inject one failure at a time; preserve timestamps and raw evidence; and only then introduce optimization, automation, scale, or autonomous control. Every abstraction must retain a path back to the underlying protocol state.

Troubleshooting should identify the first point where observed behavior diverges from the expected transaction. Inspect both directions, distinguish absence from rejection, and account for caching, stale state, recursive dependencies, load sharing, tunneling, policy, and hardware offload. A final conclusion should state what failed, why it failed, what evidence proves it, what restored service, and what prevents recurrence.

Engineering practices

Document the authoritative design intent, ownership, and scope for acceptance and resilience testing.

Predict protocol and forwarding state before implementation or troubleshooting.

Validate control-plane state, installed forwarding state, and real traffic independently.

Test normal, boundary, degraded, failed, recovery, and rollback conditions.

Retain packet, configuration, counter, log, topology, timing, and service evidence.

Automate only after the manual behavior, invariants, and failure handling are understood.

Failure patterns

Treating acceptance and resilience testing as a configuration recipe without understanding protocol state.

Checking only the local device while ignoring the neighbor, endpoint, reverse path, or remote policy.

Assuming an established adjacency or installed route proves end-to-end forwarding.

Changing multiple variables before preserving the original failure evidence.

Using vendor-default timers, trust, or policy without documenting the resulting behavior.

Closing the incident after one successful probe without negative tests or recurrence monitoring.

Validation and evidence

Method	Expected evidence
Examine	Topology, addressing, policy, configuration, protocol state, counters, and source authority for acceptance and resilience testing.
Capture	Relevant packets or telemetry at enough observation points to distinguish sender, path, policy, and receiver behavior.
Test	Nominal traffic, invalid input, dependency loss, partial failure, convergence, restoration, and rollback.
Measure	Reachability, loss, latency, convergence, resource use, state scale, error rates, and application outcome.
Reconcile	Intended state against observed endpoint, control-plane, forwarding, security, and service evidence.

Chapter 08 laboratory and review

Practical laboratory

Design a campus or small fabric, document every Layer-2 boundary and failure case, then execute a migration from spanning-tree redundancy to routed or EVPN attachment.

Laboratory evidence package

- Architecture or topology showing boundaries, identities, dependencies, and authoritative inputs.
- Versioned configuration or code with explanatory comments and reproducible setup instructions.
- Nominal-path validation plus at least two injected failure or boundary conditions.
- Structured logs, traces, metrics, packet captures, test output, or other appropriate evidence.
- A concise decision record covering findings, limitations, residual risks, and next actions.

Frontier extension

Assess intent-driven fabrics, formally verified forwarding, photonic Ethernet, and autonomous remediation with bounded authority.

Review gate

Advance only when another engineer can reproduce the result, explain the architecture, identify the failure boundary, and distinguish measured evidence from assumptions or projections.

Integrated learning roadmap

The guide is intended to be revisited. First establish fluency, then build a small implementation, operate it under failure, automate repeatable work, and finally evaluate emerging techniques against a stable baseline. Progress is demonstrated through evidence rather than reading completion alone.

Stage	Demonstrated capability
Foundation	Explain the system from first principles and trace its critical path without relying on product terminology.
Build	Implement the smallest representative system with explicit contracts, identities, telemetry, and tests.
Operate	Diagnose injected failures, recover safely, and preserve evidence of the causal chain.
Automate	Convert a proven manual workflow into bounded, idempotent, observable automation.
Architect	Design for scale, resilience, security, interoperability, and lifecycle change.
Explore	Evaluate frontier techniques using stated hypotheses, limitations, and adoption gates.

Source authority register

Source policy
Official standards, specifications, and project documentation remain with their issuing organizations. Mythos Systems provides original engineering interpretation, synthesis, implementation guidance, and relationship mapping. Source verification dates do not guarantee that an authority has not changed since review.

01. IEEE Standards Association - IEEE 802.1Q-2022 - Bridges and Bridged Networks
Role: Bridging, VLAN, spanning-tree, and bridged-network authority.
Verified: 2026-07-26
Official source: https://standards.ieee.org/standard/802_1Q-2022.html

02. IEEE Standards Association - IEEE 802.1AX-2020 - Link Aggregation
Role: Link aggregation and distributed resilient interconnect authority.
Verified: 2026-07-26
Official source: https://standards.ieee.org/ieee/802.1AX/6768/

03. IETF / RFC Editor - RFC 826 - An Ethernet Address Resolution Protocol
Role: ARP behavior and IPv4-to-MAC resolution reference.
Verified: 2026-07-26
Official source: https://www.rfc-editor.org/info/rfc826

04. IETF / RFC Editor - RFC 4861 - Neighbor Discovery for IPv6
Role: IPv6 neighbor discovery, router discovery, and reachability authority.
Verified: 2026-07-26
Official source: https://www.rfc-editor.org/info/rfc4861

05. OpenConfig - OpenConfig Data Models
Role: Vendor-neutral configuration and telemetry model reference.
Verified: 2026-07-26
Official source: https://www.openconfig.net/projects/models/

06. OpenConfig - gNMI Specification
Role: Model-driven configuration and streaming telemetry specification.
Verified: 2026-07-26
Official source: https://www.openconfig.net/docs/gnmi/gnmi-specification/

Authority application and refresh triggers

Authority class	Required library action
Protocols and specifications	Recheck interoperability, security considerations, defaults, and migration guidance when a referenced specification changes.
Security and assurance frameworks	Update control mappings, evidence expectations, risk language, and assessment procedures after material framework revision.
Languages, runtimes, and projects	Re-run examples, tests, deprecation checks, and operational recommendations against supported releases.
Benchmarks and evaluations	Re-execute claims when workloads, methods, models, compilers, drivers, hardware, or scoring rules change.
Operational evidence	Incorporate validated incidents, failure tests, reader corrections, and measured implementation outcomes into the next revision.

Limitations, freshness, and revision control

Boundary	Statement
Publication limitation	This guide synthesizes broad engineering practice. It does not replace product documentation, legal advice, safety certification, or environment-specific design review.
Evidence limitation	Not every pattern is benchmarked in every environment. Examples illustrate engineering methods and must be validated against actual versions, workloads, hardware, policy, and failure conditions.
Freshness limitation	Vendor behavior, software libraries, AI models, security threats, and emerging standards can change quickly. Volatile claims require source revalidation before operational adoption.
Adoption limitation	Frontier content is not an implicit adoption recommendation. Adoption requires defined value, qualification gates, controlled proof, rollback, ownership, and residual-risk acceptance.
Status boundary	Candidate Focused Field Guide describes the publication, not certification of a product, implementation, engineer, or organization.

Revision record

Version	Revision statement
1.0.0-candidate	Initial candidate living-guide edition. Published 2026-07-26; scheduled review 2026-10-26.

Search and relationship metadata

Dimension	Engineering position
Primary domain	MYTHOS-NET - Network Engineering & Architecture
Secondary domain	MYTHOS-SEC; MYTHOS-DAT
Publication class	Field Guide / Canonical Living Overview Guide
Skill levels	L1 Foundational; L2 Practitioner; L3 Advanced; L4 Frontier
Tags	Ethernet, switching, VLAN, STP, RSTP, MSTP, LACP, MLAG, Layer 2, resilience
Canonical route	/library/field-guides/mythos-fg-net-0002/

Living publication

Corrections, expanded laboratories, improved diagrams, authority changes, and new engineering evidence should revise this permanent publication rather than create disconnected replacements.