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Benchmarking Methodology for Intra-domain and Inter-domain Source Address Validation
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Abstract

This document defines methodologies for benchmarking the performance of intra-domain and inter-domain source address validation (SAV) mechanisms. SAV mechanisms are utilized to generate SAV rules to prevent source address spoofing, and have been implemented with many various designs in order to perform SAV in the corresponding scenarios. This document takes the approach of considering a SAV device to be a black box, defining the methodology in a manner that is agnostic to the mechanisms. This document provides a method for measuring the performance of existing and new SAV implementations.

Status of This Memo

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1. Introduction

Source address validation (SAV) is significantly important to prevent source address spoofing. Operators are suggested to deploy different SAV mechanisms [RFC3704] [RFC8704] based on their deployment network environments. In addition, existing intra-domain (intra-AS) and inter-domain (inter-AS) SAV mechanisms have problems in operational overhead and SAV accuracy under various scenarios [intra-domain-ps] [inter-domain-ps]. Intra-domain and inter-domain SAVNET architectures [intra-domain-arch] [inter-domain-arch] are proposed to guide the design of new intra-domain and inter-domain SAV mechanisms to solve the problems. The benchmarking methodology defined in this document will help operators to get a more accurate idea of the SAV performance when their deployed devices enable SAV and will also help vendors to test the performance of SAV implementation for their devices.

This document provides generic methodologies for benchamarking SAV mechanism performance. To achieve the desired functionality, a SAV device may support multiple SAV mechanisms, allowing operators to enable those most suitable for their specific network environments. This document considers a SAV device to be a black box, regardless of the design and implementation. The tests defined in this document can be used to benchmark a SAV device for SAV accuracy (i.e., false positive and false negative rates), SAV protocol convergence performance, and control plane and data plane forwarding performance. These tests can be performed on a hardware router, a software router, a virtual machine (VM) instance, or a container instance, which runs as a SAV device. This document outlines methodologies for assessing SAV device performance and comparing various SAV mechanisms and implementations.

1.1. Goal and Scope

The benchmarking methodology outlined in this draft focuses on two objectives:

* Assessing “which SAV mechanism performs best” over a set of well-defined scenarios.

* Measuring the contribution of sub-systems to the overall SAV systems’ performance (also known as “micro-benchmark”).

This benchmark evaluates the SAV performance of individual devices (e.g., hardware/software routers) by comparing different SAV mechanisms under specific network scenarios. The results help determine the appropriate SAV deployment for real-world network scenarios.

1.2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Terminology

SAV Control Plane: The SAV control plane consists of processes including gathering and communicating SAV-related information.

SAV Data Plane: The SAV data plane stores the SAV rules within a specific data structure and validates each incoming packet to determine whether to permit or discard it.

Host-facing Router: An intra-domain router facing an intra-domain host network.

Customer-facing Router: An intra-domain router facing an intra-domain customer network which includes routers and runs the routing protocol.

AS Border Router: An intra-domain router facing an external AS.

3. Test Methodology

3.1. Test Setup

The test setup in general is compliant with [RFC2544]. The Device Under Test (DUT) is connected to a Tester and other network devices to construct the network topology introduced in Section 5. The Tester is a traffic generator to generate network traffic with various source and destination addresses in order to emulate the spoofing or legitimate traffic. It is OPTIONAL to choose various proportions of traffic and it is needed to generate the traffic with line speed to test the data plane forwarding performance.

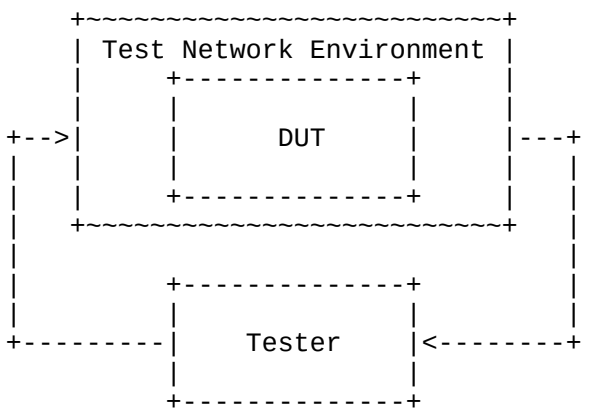


Figure 1: Test Setup.

Figure 1 illustrates the test configuration for the Device Under Test (DUT). Within the test network environment, the DUT can be interconnected with other devices to create a variety of test scenarios. The Tester may establish a direct connection with the DUT or link through intermediary devices. The nature of the connection between them is dictated by the benchmarking tests outlined in Section 5. Furthermore, the Tester has the capability to produce both spoofed and legitimate traffic to evaluate the SAV accuracy of the DUT in relevant scenarios, and it can also generate traffic at line rate to assess the data plane forwarding performance of the DUT. Additionally, the DUT is required to support logging functionalities to document all test outcomes.

3.2. Network Topology and Device Configuration

The positioning of the DUT within the network topology has an impact on SAV performance. Therefore, the benchmarking process MUST include evaluating the DUT at multiple locations across the network to ensure a comprehensive assessment.

The routing configurations of network devices may differ, and the resulting SAV rules depend on these settings. It is essential to clearly document the specific device configurations used during testing.

Furthermore, the role of each device, such as host-facing router, customer-facing router, or AS border router in an intra-domain network, SHOULD be clearly identified. In an inter-domain context, the business relationships between ASes MUST also be specified.

When evaluating data plane forwarding performance, the traffic generated by the Tester must be characterized by defined traffic rates, the ratio of spoofed to legitimate traffic, and the distribution of source addresses, as all of these factors can influence test results.

4. SAV Performance Indicators

This section lists key performance indicators (KPIs) of SAV for overall benchmarking tests. All KPIs SHOULD be measured in the bencharking scenarios described in Section 5. Also, the KPIs SHOULD be measured from the result output of the DUT.

4.1. False Positive Rate

The proportion of legitimate traffic which is determined to be spoofing traffic by the DUT across all the legitimate traffic, and this can reflect the SAV accuracy of the DUT.

4.2. False Negative Rate

The proportion of spoofing traffic which is determined to be legitimate traffic by the DUT across all the spoofing traffic, and this can reflect the SAV accuracy of the DUT.

4.3. Protocol Convergence Time

The control protocol convergence time represents the period during which the SAV control plane protocol converges to update the SAV rules when routing changes happen, and it is the time elapsed from the begining of routing change to the completion of SAV rule update. This KPI can indicate the convergence performance of the SAV protocol.

4.4. Protocol Message Processing Throughput

The protocol message processing throughput measures the throughput of processing the packets for communicating SAV-related information on the control plane, and it can indicate the SAV control plane performance of the DUT.

4.5. Data Plane SAV Table Refreshing Rate

The data plane SAV table refreshing rate refers to the rate at which a DUT updates its SAV table with new SAV rules, and it can reflect the SAV data plane performance of the DUT.

4.6. Data Plane Forwarding Rate

The data plane forwarding rate measures the SAV data plane forwarding throughput for processing the data plane traffic, and it can indicate the SAV data plane performance of the DUT.

4.7. Resource Utilization

The resource utilization refers to the CPU and memory usage of the SAV processes within the DUT.

5. Benchmarking Tests

5.1. Intra-domain SAV

5.1.1. False Positive and False Negative Rates

Objective: Evaluate the false positive rate and false negative rate of the DUT in processing both legitimate and spoofed traffic across various intra-domain network scenarios. These scenarios include SAV implementations for customer/host networks, Internet-facing networks, and aggregation-router-facing networks.

In the following, this document introduces the test scenarios for evaluating intra-domain SAV on the DUT.

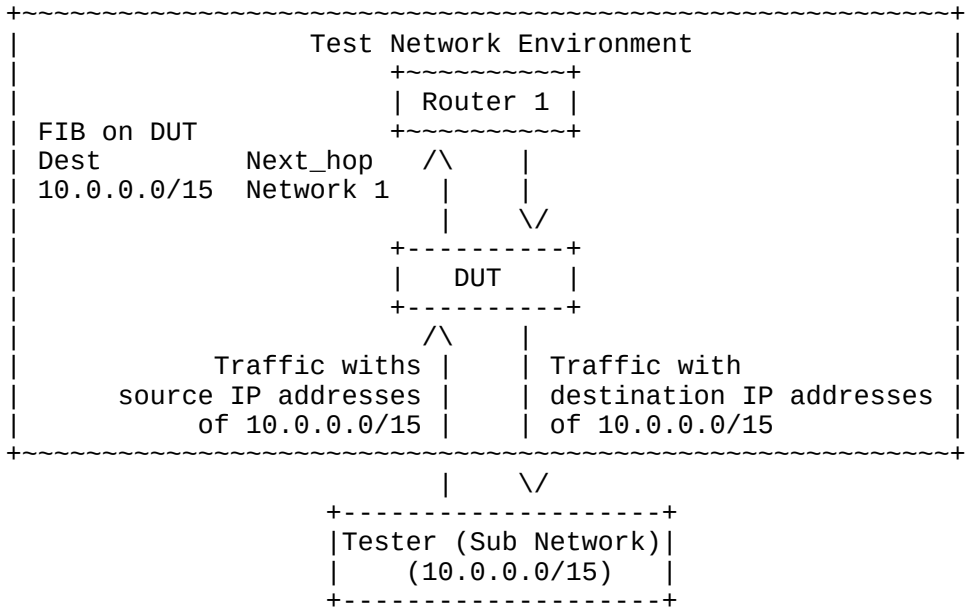


Figure 2: SAV for customer or host network in intra-domain symmetric routing scenario.

SAV for Customer or Host Network: Figure 2 illustrates an intra-domain symmetric routing scenario in which SAV is deployed for a customer or host network. The DUT performs SAV as a customer/host-facing router and connects to Router 1 for Internet access. A sub network, which resides within the AS and uses the prefix 10.0.0.0/15, is connected to the DUT. The Tester emulates a sub network by advertising this prefix in the control plane and generating both spoofed and legitimate traffic in the data plane. In this setup, the Tester is configured so that inbound traffic destined for 10.0.0.0/15 arrives via the DUT. The DUT learns the route to 10.0.0.0/15 from the Tester, while the Tester sends outbound traffic with source addresses within 10.0.0.0/15 to the DUT, simulating a symmetric routing scenario between the two. The IP addresses used in this test case are optional; users may substitute them with other addresses, as applies equally to other test cases.

The *procedure* for testing SAV in this intra-domain symmetric routing scenario is as follows:

1. To verify whether the DUT can generate accurate SAV rules for customer or host network under symmetric routing conditions, construct a testbed as depicted in Figure 2. The Tester is connected to the DUT and acts as a sub network.

2. Configure the DUT and Router 1 to establish a symmetric routing environment..

3. The Tester generates both legitimate traffic (with source addresses in 10.0.0.0/15) and spoofed traffic (with source addresses in 10.2.0.0/15) toward the DUT. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and allows legitimate traffic originating from the sub network.

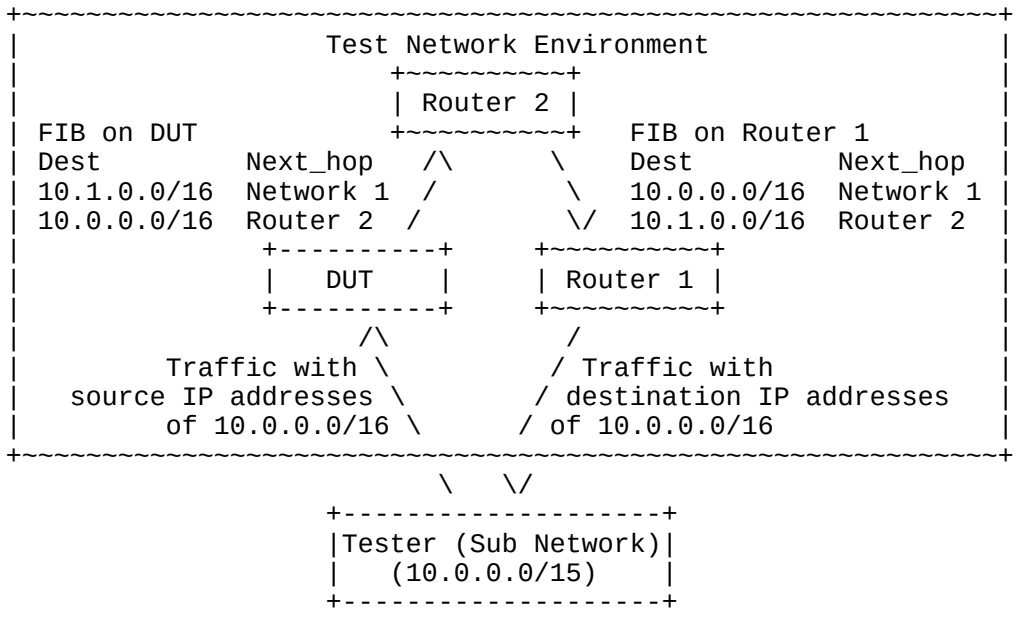


Figure 3: SAV for customer or host network in intra-domain asymmetric routing scenario.

SAV for Customer or Host Network: Figure 3 illustrates an intra-domain asymmetric routing scenario in which SAV is deployed for a customer or host network. The DUT performs SAV as a customer/host-facing router. A sub network, i.e., a customer/host network within the AS, is connected to both the DUT and Router 1, and uses the prefix 10.0.0.0/15. The Tester emulates a sub network and handles both its control plane and data plane functions. In this setup, the Tester is configured so that inbound traffic destined for 10.1.0.0/16 is received only from the DUT, while inbound traffic for 10.0.0.0/16 is received only from Router 1. The DUT learns the route to prefix 10.1.0.0/16 from the Tester, and Router 1 learns the route to 10.0.0.0/16 from the Tester. Both the DUT and Router 1 then advertise their respective learned prefixes to Router 2. Consequently, the DUT learns the route to 10.0.0.0/16 from Router 2, and Router 1 learns the route to 10.1.0.0/16 from Router 2. The Tester sends outbound traffic with source addresses in 10.0.0.0/16 to the DUT, simulating an asymmetric routing scenario between the Tester and the DUT.

The *procedure* for testing SAV in this intra-domain asymmetric routing scenario is as follows:

1. To determine whether the DUT can generate accurate SAV rules under asymmetric routing conditions, set up the test environment as shown in Figure 3. The Tester is connected to both the DUT and Router 1 and emulates the functions of a sub network.

2. Configure the DUT, Router 1, and Router 2 to establish the asymmetric routing scenario.

3. The Tester generates both spoofed traffic (using source addresses in 10.1.0.0/16) and legitimate traffic (using source addresses in 10.0.0.0/16) toward the DUT. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic originating from the sub network.

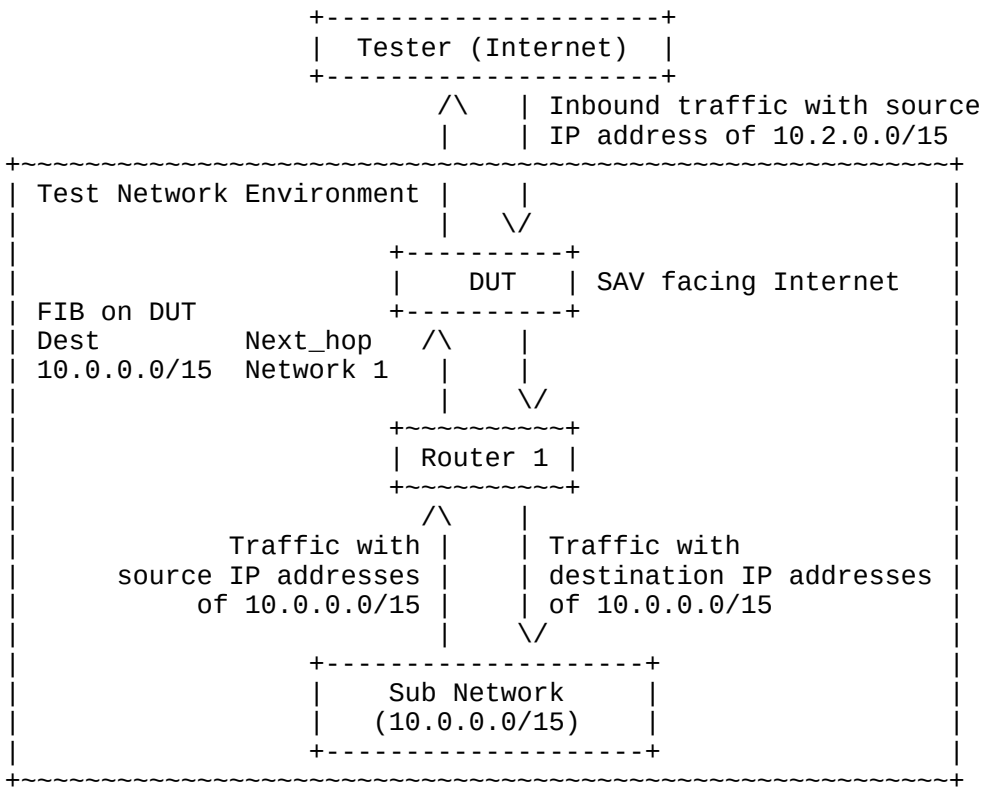


Figure 4: SAV for Internet-facing network in intra-domain symmetric routing scenario.

SAV for Internet-facing Network: Figure 4 illustrates the test scenario for SAV in an Internet-facing network under intra-domain symmetric routing conditions. The network topology resembles that of Figure 2, with the key difference being the positioning of the DUT. In this case, the DUT is connected to Router 1 and the Internet, while the Tester emulates the Internet. The DUT performs SAV from an Internet-facing perspective, as opposed to a customer/host-facing role.

The *procedure* for testing SAV for an Internet-facing network in an intra-domain symmetric routing scenario is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules for Internet-facing SAV under symmetric routing, set up the test environment as depicted in Figure 4. The Tester is connected to the DUT and emulates the Internet.

2. Configure the DUT and Router 1 to establish a symmetric routing environment.

3. The Tester generates both spoofed traffic (using source addresses in 10.0.0.0/15) and legitimate traffic (using source addresses in 10.2.0.0/15) toward the DUT. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and allows legitimate traffic originating from the Internet.

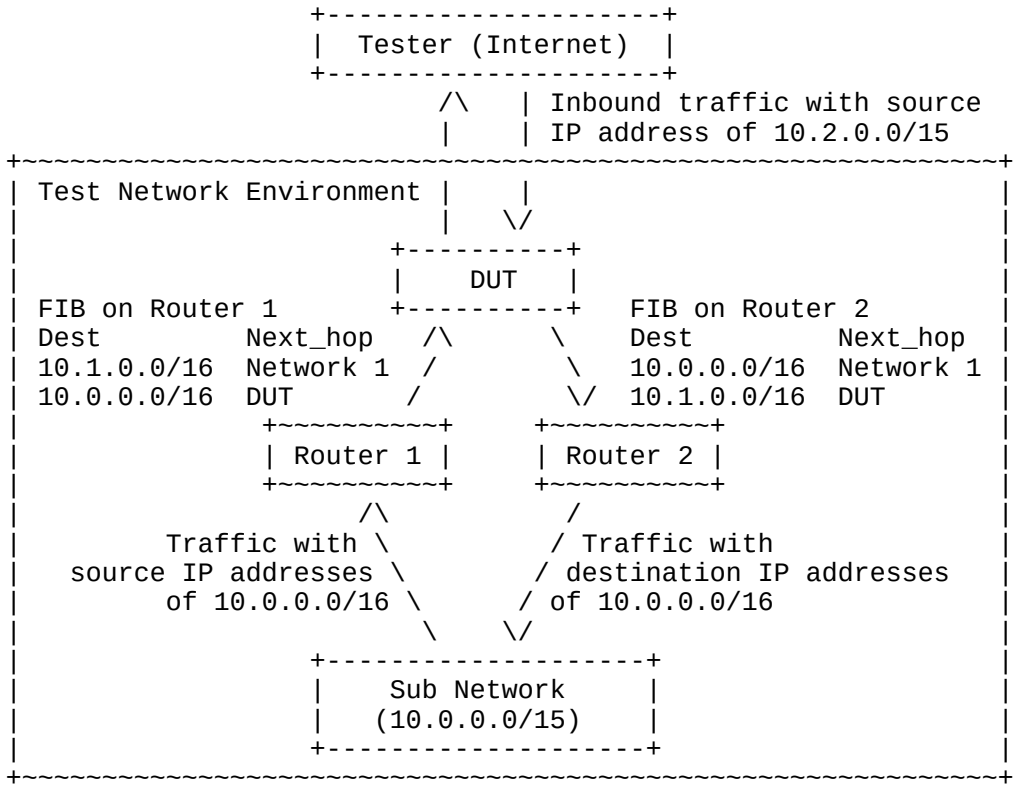


Figure 5: SAV for Internet-facing network in intra-domain asymmetric routing scenario.

SAV for Internet-facing Network: Figure 5 illustrates a test case for SAV in an Internet-facing network under intra-domain asymmetric routing conditions. The network topology is identical to that of Figure 3, with the key distinction being the placement of the DUT. In this scenario, the DUT is connected to Router 1 and Router 2 within the same AS, as well as to the Internet. The Tester emulates the Internet, and the DUT performs Internet-facing SAV rather than customer/host-network-facing SAV.

The *procedure* for testing SAV in this intra-domain asymmetric routing scenario is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules for Internet-facing SAV under asymmetric routing, construct the test environment as shown in Figure 5. The Tester is connected to the DUT and emulates the Internet.

2. Configure the DUT, Router 1, and Router 2 to establish the asymmetric routing scenario.

3. The Tester generates both spoofed traffic (using source addresses in 10.0.0.0/15) and legitimate traffic (using source addresses in 10.2.0.0/15) toward the DUT. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic originating from the Internet.

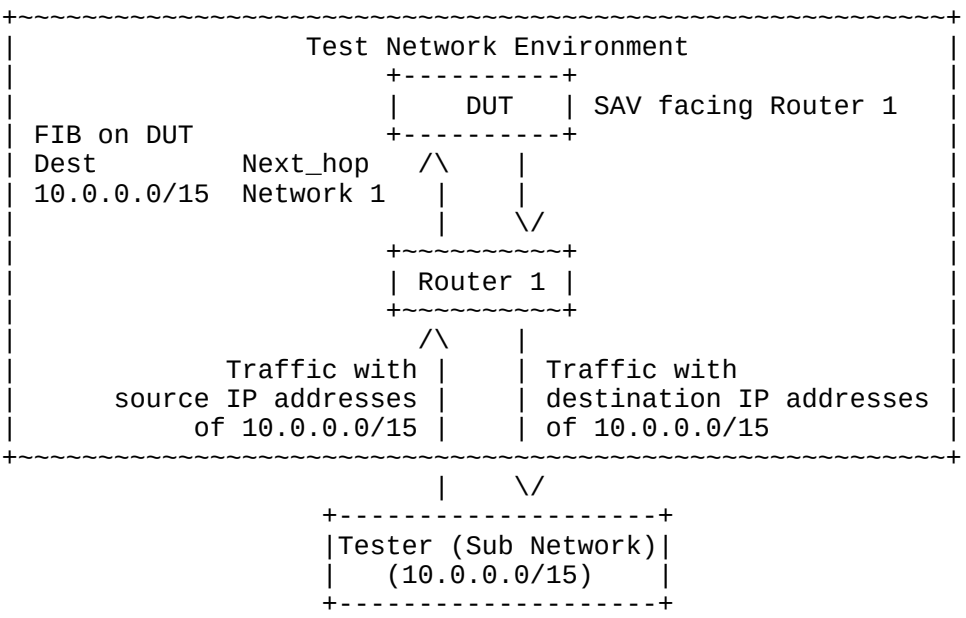


Figure 6: SAV for aggregation-router-facing network in intra-domain symmetric routing scenario.

SAV for Aggregation-router-facing Network: Figure 6 depicts the test scenario for SAV in an aggregation-router-facing network under intra-domain symmetric routing conditions. The network topology in Figure 6 is identical to that of Figure 4. The Tester is connected to Router 1 to emulate a sub network, enabling evaluation of the DUT’s false positive and false negative rates when facing Router 1.

The *procedure* for testing SAV in this aggregation-router-facing scenario is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules for aggregation-router-facing SAV under symmetric routing, construct the test environment as shown in Figure 6. The Tester is connected to Router 1 and emulates a sub network.

2. Configure the DUT and Router 1 to establish a symmetric routing environment.

3. The Tester generates both legitimate traffic (using source addresses in 10.1.0.0/15) and spoofed traffic (using source addresses in 10.2.0.0/15) toward Router 1. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic originating from the direction of Router 1.

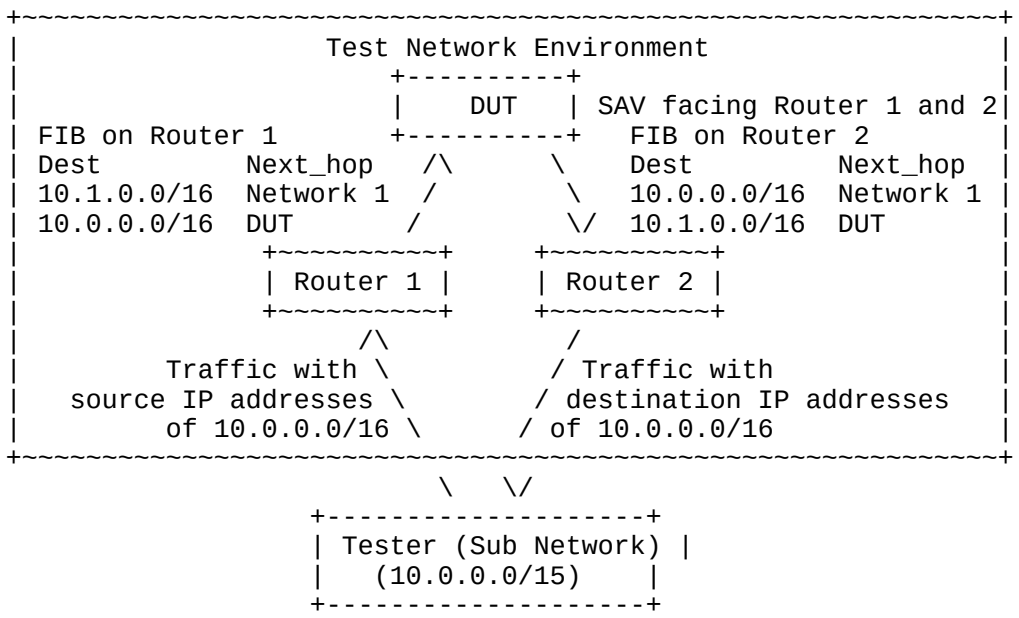


Figure 7: SAV for aggregation-router-facing network in intra-domain asymmetric routing scenario.

SAV for Aggregation-router-facing Network: Figure 7 illustrates the test case for SAV in an aggregation-router-facing network under intra-domain asymmetric routing conditions. The network topology in Figure 7 is identical to that of Figure 5. The Tester is connected to both Router 1 and Router 2 to emulate a sub network, enabling evaluation of the DUT's false positive and false negative rates when facing Router 1 and Router 2.

The *procedure* for testing SAV in this aggregation-router-facing asymmetric routing scenario is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules under asymmetric routing conditions, construct the test environment as shown in Figure 7. The Tester is connected to Router 1 and Router 2 and emulates the functions of a sub network.

2. Configure the DUT, Router 1, and Router 2 to establish an asymmetric routing environment.

3. The Tester generates both spoofed traffic (using source addresses in 10.1.0.0/16) and legitimate traffic (using source addresses in 10.0.0.0/16) toward Router 1. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic originating from the direction of Router 1 and Router 2.

5.1.2. Control Plane Performance

Objective: Measure the control plane performance of the DUT, including both protocol convergence performance and protocol message processing performance in response to route changes caused by network failures or operator configurations. Protocol convergence performance is quantified by the convergence time, defined as the duration from the onset of a routing change until the completion of the corresponding SAV rule update. Protocol message processing performance is measured by the processing throughput, represented by the total size of protocol messages processed per second.

Figure 8: Test setup for protocol convergence performance measurement.

Protocol Convergence Performance: Figure 8 illustrates the test setup for measuring protocol convergence performance. The convergence process of the DUT, during which SAV rules are updated, is triggered by route changes resulting from network failures or operator configurations. In Figure 8, the Tester is directly connected to the DUT and simulates these route changes by adding or withdrawing prefixes to initiate the DUT's convergence procedure.

The *procedure* for testing protocol convergence performance is as follows:

1. To measure the protocol convergence time of the DUT, set up the test environment as depicted in Figure 8, with the Tester directly connected to the DUT.

2. The Tester withdraws a specified percentage of the total prefixes supported by the DUT, for example, 10%, 20%, up to 100%.

3. The protocol convergence time is calculated based on DUT logs that record the start and completion times of the convergence process.

Please note that for IGP, proportional prefix withdrawal can be achieved by selectively shutting down interfaces. For instance, if the Tester is connected to ten emulated devices through ten interfaces, each advertising a prefix, withdrawing 10% of prefixes can be accomplished by randomly disabling one interface. Similarly, 20% withdrawal corresponds to shutting down two interfaces, and so forth. This is one suggested method, and other approaches that achieve the same effect should be also acceptable.

The protocol convergence time, defined as the duration required for the DUT to complete the convergence process, should be measured from the moment the last "hello" message is received from the emulated device on the disabled interface until SAV rule generation is finalized. To ensure accuracy, the DUT should log the timestamp of the last hello message received and the timestamp when SAV rule updates are complete. The convergence time is the difference between these two timestamps.

It is recommended that if the emulated device sends a "goodbye hello" message during interface shutdown, using the receipt time of this message, rather than the last standard hello, as the starting point will provide a more precise measurement, as advised in [RFC4061].

Protocol Message Processing Performance: The test for protocol message processing performance uses the same setup illustrated in Figure 8. This performance metric evaluates the protocol message

processing throughput, the rate at which the DUT processes protocol messages. The Tester varies the sending rate of protocol messages, ranging from 10% to 100% of the total link capacity between the Tester and the DUT. The DUT records both the total size of processed protocol messages and the corresponding processing time.

The *procedure* for testing protocol message processing performance is as follows:

1. To measure the protocol message processing throughput of the DUT, set up the test environment as shown in Figure 8, with the Tester directly connected to the DUT.

2. The Tester sends protocol messages at varying rates, such as 10%, 20%, up to 100%, of the total link capacity between the Tester and the DUT.

3. The protocol message processing throughput is calculated based on DUT logs that record the total size of processed protocol messages and the total processing time.

To compute the protocol message processing throughput, the DUT logs MUST include the total size of the protocol messages processed and the total time taken for processing. The throughput is then derived by dividing the total message size by the total processing time.

5.1.3. Data Plane Performance

Objective: Evaluate the data plane performance of the DUT, including both data plane SAV table refresh performance and data plane forwarding performance. Data plane SAV table refresh performance is quantified by the refresh rate, which indicates how quickly the DUT updates its SAV table with new SAV rules. Data plane forwarding performance is measured by the forwarding rate, defined as the total size of packets forwarded by the DUT per second.

Data Plane SAV Table Refreshing Performance: The evaluation of data plane SAV table refresh performance uses the same test setup shown in Figure 8. This metric measures the rate at which the DUT refreshes its SAV table with new SAV rules. The Tester varies the transmission rate of protocol messages, from 10% to 100% of the total link capacity between the Tester and the DUT, to influence the proportion of updated SAV rules and corresponding SAV table entries. The DUT records the total number of updated SAV table entries and the time taken to complete the refresh process.

The *procedure* for testing data plane SAV table refresh performance is as follows:

1. To measure the data plane SAV table refresh rate of the DUT, set up the test environment as depicted in Figure 8, with the Tester directly connected to the DUT.

2. The Tester sends protocol messages at varying percentages of the total link capacity, for example, 10%, 20%, up to 100%.

3. The data plane SAV table refresh rate is calculated based on DUT logs that record the total number of updated SAV table entries and the total refresh time.

To compute the refresh rate, the DUT logs MUST capture the total number of updated SAV table entries and the total time required for refreshing. The refresh rate is then derived by dividing the total number of updated entries by the total refresh time.

Data Plane Forwarding Performance: The evaluation of data plane forwarding performance uses the same test setup shown in Figure 8. The Tester transmits a mixture of spoofed and legitimate traffic at a rate matching the total link capacity between the Tester and the DUT, while the DUT maintains a fully populated SAV table. The ratio of spoofed to legitimate traffic can be varied within a range, for example, from 1:9 to 9:1. The DUT records the total size of forwarded packets and the total duration of the forwarding process.

The procedure for testing data plane forwarding performance is as follows:

1. To measure the data plane forwarding rate of the DUT, set up the test environment as depicted in Figure 8, with the Tester directly connected to the DUT.

2. The Tester sends a mix of spoofed and legitimate traffic to the DUT at the full link capacity between the Tester and the DUT. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

3. The data plane forwarding rate is calculated based on DUT logs that record the total size of forwarded traffic and the total forwarding time.

To compute the forwarding rate, the DUT logs must include the total size of forwarded traffic and the total time taken for forwarding. The forwarding rate is then derived by dividing the total traffic size by the total forwarding time.

5.2. Inter-domain SAV

5.2.1. False Positive and False Negative Rates

Objective: Measure the false positive rate and false negative rate of the DUT when processing legitimate and spoofed traffic across multiple inter-domain network scenarios, including SAV implementations for both customer-facing ASes and provider-/peer-facing ASes.

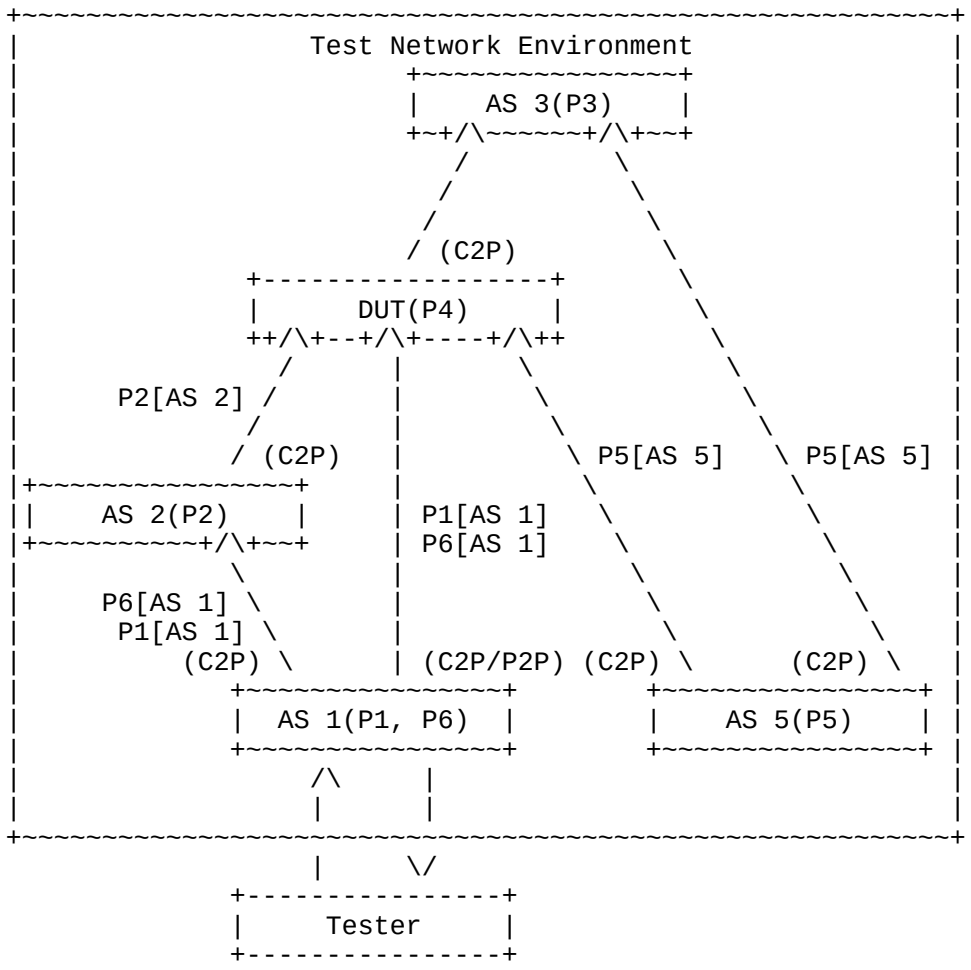


Figure 9: SAV for customer-facing ASes in inter-domain symmetric routing scenario.

SAV for Customer-facing ASes: Figure 9 presents a test case for SAV in customer-facing ASes under an inter-domain symmetric routing scenario. In this setup, AS 1, AS 2, AS 3, the DUT, and AS 5 form

the test network environment, with the DUT performing SAV at the AS level. AS 1 is a customer of both AS 2 and the DUT; AS 2 is a customer of the DUT, which in turn is a customer of AS 3; and AS 5 is a customer of both AS 3 and the DUT. AS 1 advertises prefixes P1 and P6 to AS 2 and the DUT, respectively. AS 2 then propagates routes for P1 and P6 to the DUT, enabling the DUT to learn these prefixes from both AS 1 and AS 2. In this test, the legitimate path for traffic with source addresses in P1 and destination addresses in P4 is AS 1->AS 2->DUT->AS 4. The Tester is connected to AS 1 to evaluate the DUT's SAV performance for customer-facing ASes.

The *procedure* for testing SAV in this scenario is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules for customer-facing ASes under symmetric inter-domain routing, construct the test environment as shown in Figure 9. The Tester is connected to AS 1 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to establish a symmetric routing environment.

3. The Tester sends both legitimate traffic (with source addresses in P1 and destination addresses in P4) and spoofed traffic (with source addresses in P5 and destination addresses in P4) to the DUT via AS 2. The ratio of spoofed to legitimate traffic may vary, for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic received from the direction of AS 2.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 9 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.

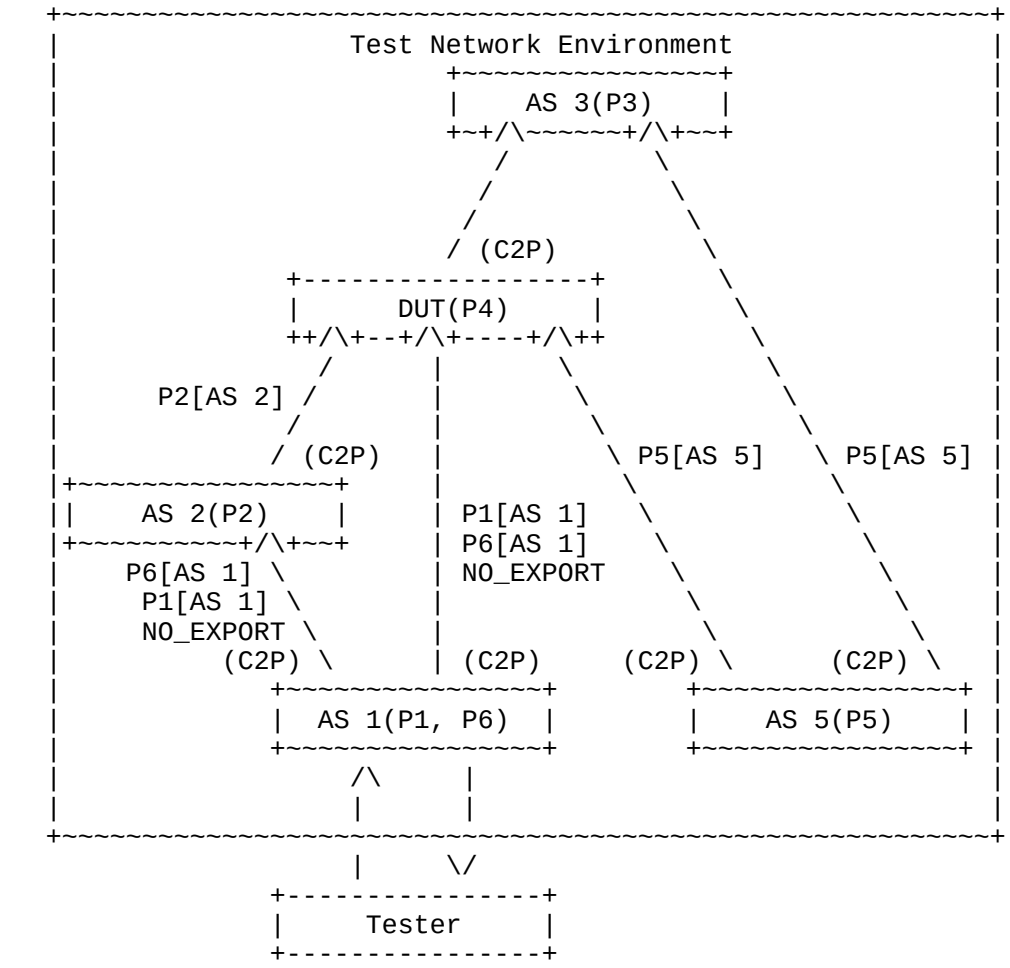


Figure 10: SAV for customer-facing ASes in inter-domain asymmetric routing scenario caused by NO_EXPORT.

SAV for Customer-facing ASes: Figure 10 presents a test case for SAV in customer-facing ASes under an inter-domain asymmetric routing scenario induced by NO_EXPORT community configuration. In this setup, AS 1, AS 2, AS 3, the DUT, and AS 5 form the test network, with the DUT performing SAV at the AS level. AS 1 is a customer of both AS 2 and the DUT; AS 2 is a customer of the DUT, which is itself a customer of AS 3; and AS 5 is a customer of both AS 3 and the DUT. AS 1 advertises prefix P1 to AS 2 with the NO_EXPORT community attribute, preventing AS 2 from propagating the route for P1 to the DUT. Similarly, AS 1 advertises prefix P6 to the DUT with the NO_EXPORT attribute, preventing the DUT from propagating this route

to AS 3. As a result, the DUT learns the route for prefix P1 only from AS 1. The legitimate path for traffic with source addresses in P1 and destination addresses in P4 is AS 1->AS 2->DUT. The Tester is connected to AS 1 to evaluate the DUT's SAV performance for customer-facing ASes.

The *procedure* for testing SAV in this asymmetric routing scenario is as follows:

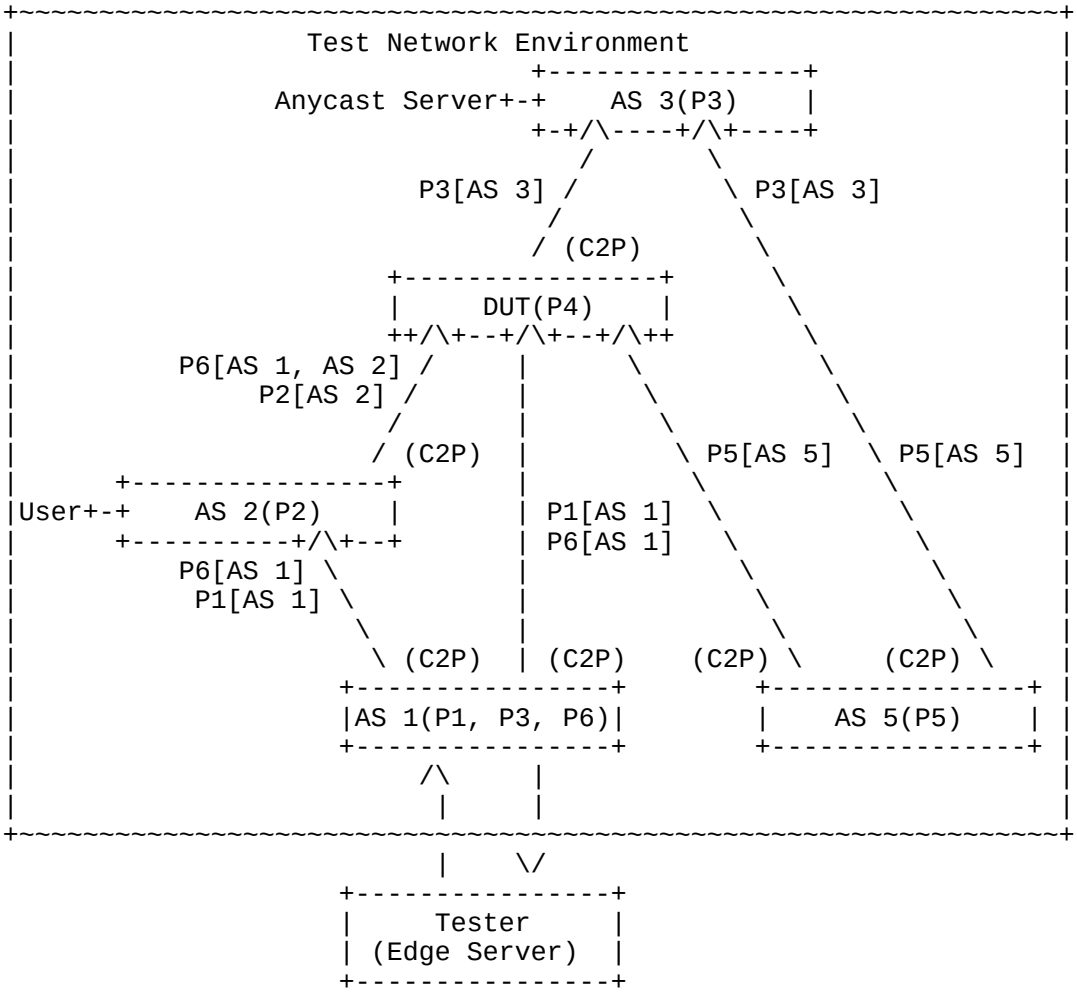
1. To evaluate whether the DUT can generate accurate SAV rules under NO_EXPORT-induced asymmetric routing, construct the test environment as shown in Figure 10. The Tester is connected to AS 1 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to establish the asymmetric routing scenario.

3. The Tester sends both legitimate traffic (with source addresses in P1 and destination addresses in P4) and spoofed traffic (with source addresses in P5 and destination addresses in P4) to the DUT via AS 2. The ratio of spoofed to legitimate traffic may vary— for example, from 1:9 to 9:1.

The *expected results* for this test case are that the DUT blocks spoofed traffic and permits legitimate traffic received from the direction of AS 2.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 10 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.



Within the test network environment, P3 is the anycast prefix and is only advertised by A S 3 through BGP.

Figure 11: SAV for customer-facing ASes in the scenario of direct server return (DSR).

SAV for Customer-facing ASes: Figure 11 presents a test case for SAV in customer-facing ASes under a Direct Server Return (DSR) scenario. In this setup, AS 1, AS 2, AS 3, the DUT, and AS 5 form the test network, with the DUT performing SAV at the AS level. AS 1 is a customer of both AS 2 and the DUT; AS 2 is a customer of the DUT, which is itself a customer of AS 3; and AS 5 is a customer of both AS 3 and the DUT. When users in AS 2 send requests to an anycast destination IP, the forwarding path is AS 2->DUT->AS 3.

Anycast servers in AS 3 receive the requests and tunnel them to edge servers in AS 1. The edge servers then return content to the users with source addresses in prefix P3. If the reverse forwarding path is AS 1->DUT->AS 2, the Tester sends traffic with source addresses in P3 and destination addresses in P2 along the path AS 1->DUT->AS 2. Alternatively, if the reverse forwarding path is AS 1->AS 2, the Tester sends traffic with source addresses in P3 and destination addresses in P2 along the path AS 1->AS 2. In this case, AS 2 may serve as the DUT.

The *procedure* for testing SAV in this DSR scenario is as follows:

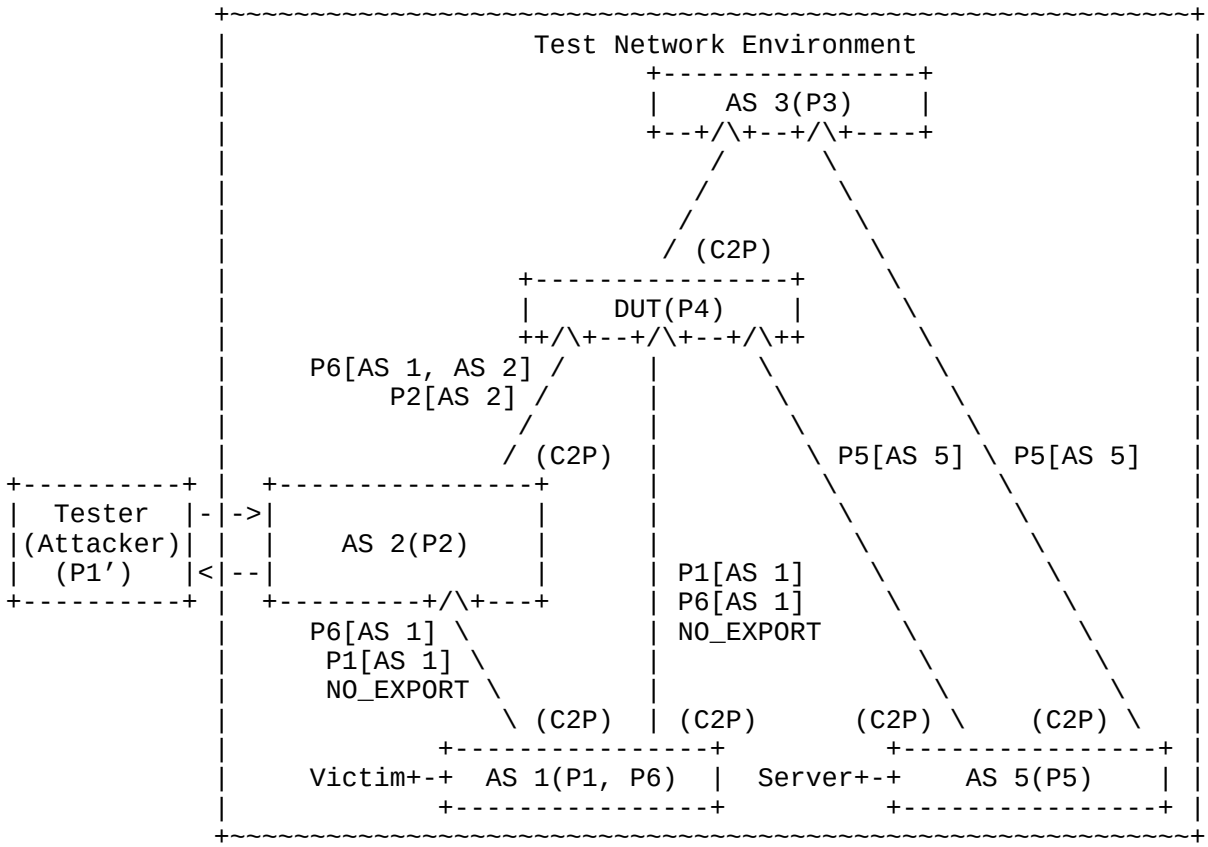
1. To evaluate whether the DUT can generate accurate SAV rules under DSR conditions, construct the test environment as shown in Figure 11. The Tester is connected to AS 1 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to establish the DSR scenario.

3. The Tester sends legitimate traffic (with source addresses in P3 and destination addresses in P2) to AS 2 via the DUT.

The *expected results* for this test case are that the DUT permits legitimate traffic with source addresses in P3 received from the direction of AS 1.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 11 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.



P1' is the spoofed source prefix P1 by the attacker which is inside of AS 2 or connected to AS 2 through other ASes.

Figure 12: SAV for customer-facing ASes in the scenario of reflection attacks.

SAV for Customer-facing ASes: Figure 12 illustrates a test case for SAV in customer-facing ASes under a reflection attack scenario. In this scenario, a reflection attack using source address spoofing occurs within the DUT's customer cone. The attacker spoofs the victim's IP address (P1) and sends requests to server IP addresses (P5) that are configured to respond to such requests. The Tester emulates the attacker by performing source address spoofing. The arrows in Figure 12 indicate the business relationships between ASes: AS 3 serves as the provider for both the DUT and AS 5, while the DUT acts as the provider for AS 1, AS 2, and AS 5. Additionally, AS 2 is the provider for AS 1.

The *procedure* for testing SAV under reflection attack conditions is as follows:

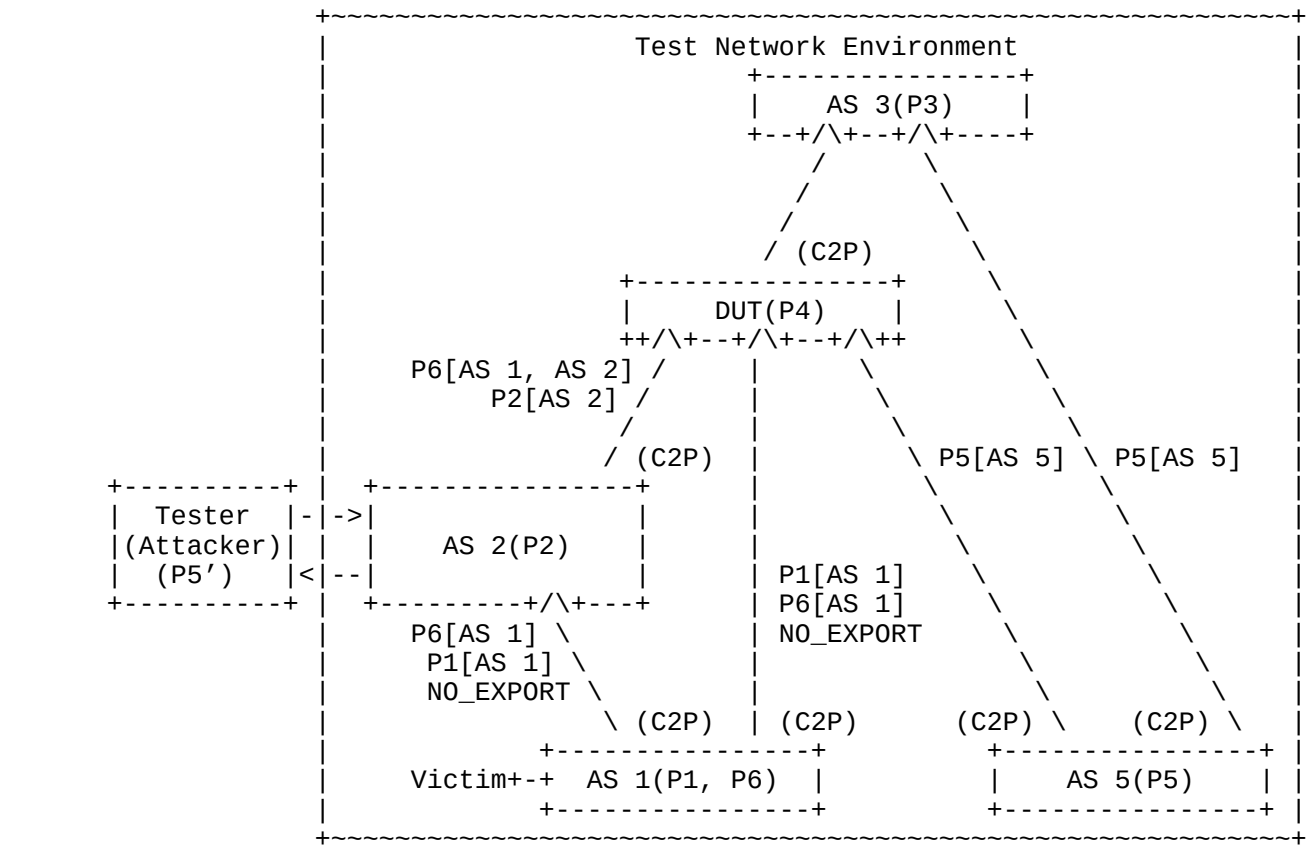
1. To evaluate whether the DUT can generate accurate SAV rules in a reflection attack scenario, construct the test environment as shown in Figure 12. The Tester is connected to AS 2 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to simulate the reflection attack scenario.

3. The Tester sends spoofed traffic (with source addresses in P1 and destination addresses in P5) toward AS 5 via the DUT.

The *expected results* for this test case are that the DUT blocks spoofed traffic with source addresses in P1 received from the direction of AS 2.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 12 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.



P5' is the spoofed source prefix P5 by the attacker which is inside of AS 2 or connected to AS 2 through other ASes.

Figure 13: SAV for customer-facing ASes in the scenario of direct attacks.

SAV for Customer-facing ASes: Figure 13 presents a test case for SAV in customer-facing ASes under a direct attack scenario. In this scenario, a direct attack using source address spoofing occurs within the DUT's customer cone. The attacker spoofs a source address (P5) and directly targets the victim's IP address (P1), aiming to overwhelm its network resources. The Tester emulates the attacker by performing source address spoofing. The arrows in Figure 13 indicate the business relationships between ASes: AS 3 serves as the provider for both the DUT and AS 5, while the DUT acts as the provider for AS 1, AS 2, and AS 5. Additionally, AS 2 is the provider for AS 1.

The *procedure* for testing SAV under direct attack conditions is as follows:

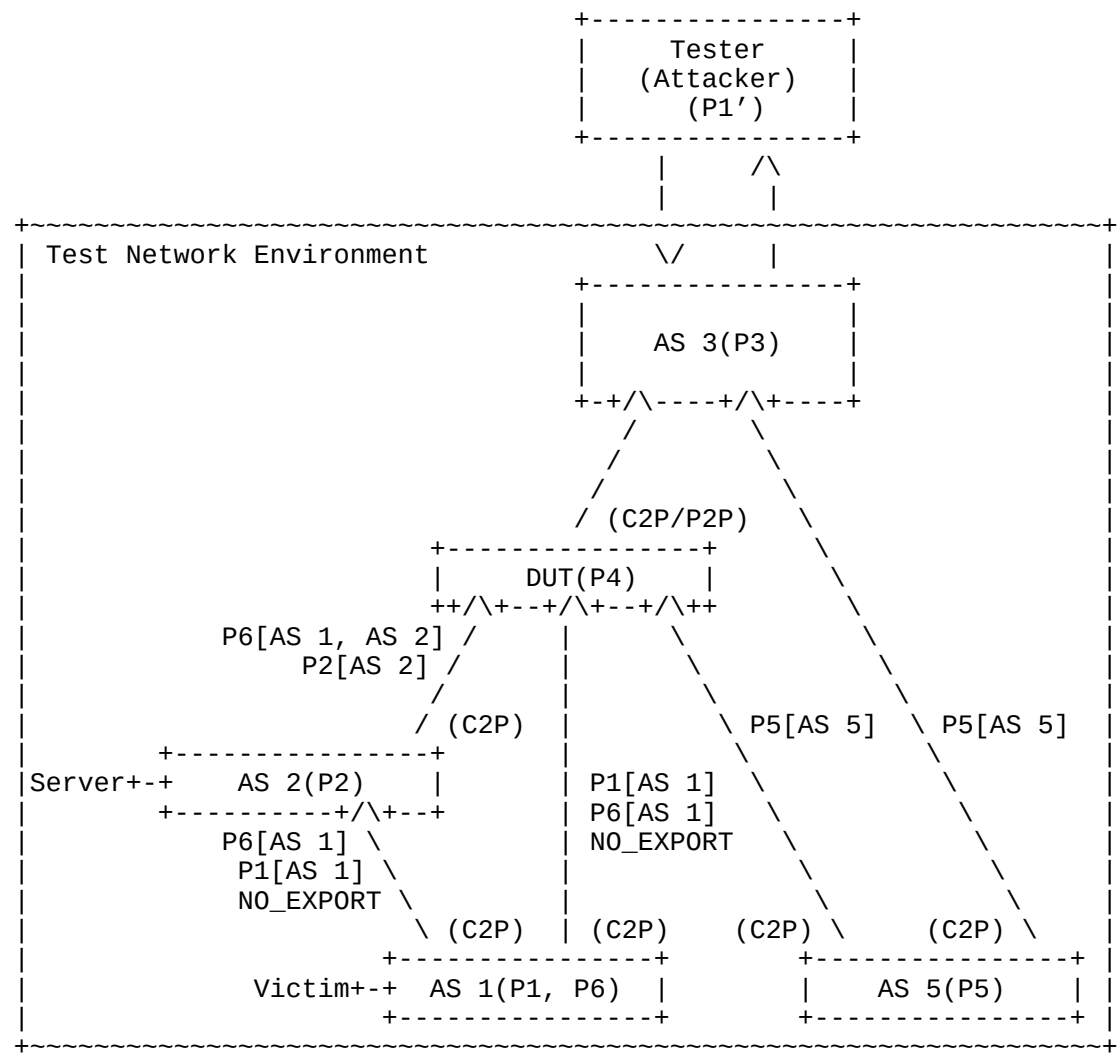
1. To evaluate whether the DUT can generate accurate SAV rules in a direct attack scenario, construct the test environment as shown in Figure 13. The Tester is connected to AS 2 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to simulate the direct attack scenario.

3. The Tester sends spoofed traffic (with source addresses in P5 and destination addresses in P1) toward AS 1 via the DUT.

The *expected results* for this test case are that the DUT blocks spoofed traffic with source addresses in P5 received from the direction of AS 2.

Note that DUT may also be placed at AS 1 or AS 2 in Figure 13 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.



P1' is the spoofed source prefix P1 by the attacker which is inside of AS 3 or connected to AS 3 through other ASes.

Figure 14: SAV for provider-facing ASes in the scenario of reflection attacks.

SAV for Provider/Peer-facing ASes: Figure 14 illustrates a test case for SAV in provider/peer-facing ASes under a reflection attack scenario. In this scenario, the attacker spoofs the victim's IP address (P1) and sends requests to server IP addresses (P2) that are configured to respond. The Tester emulates the attacker by performing source address spoofing. The servers then send

overwhelming responses to the victim, exhausting its network resources. The arrows in Figure 14 represent the business relationships between ASes: AS 3 acts as either a provider or a lateral peer of the DUT and is the provider for AS 5, while the DUT serves as the provider for AS 1, AS 2, and AS 5. Additionally, AS 2 is the provider for AS 1.

The *procedure* for testing SAV under reflection attack conditions is as follows:

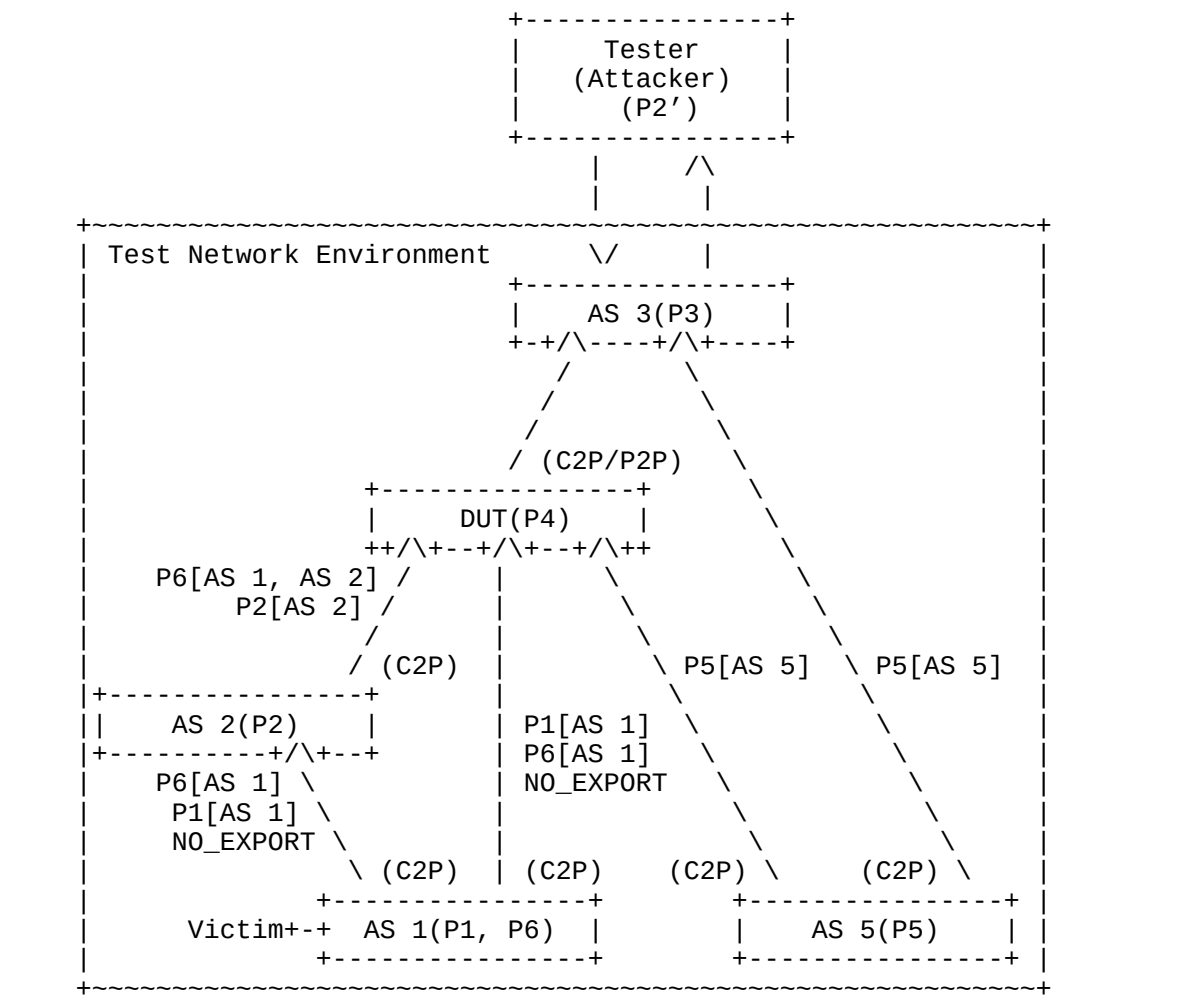
1. To evaluate whether the DUT can generate accurate SAV rules for provider/peer-facing ASes in a reflection attack scenario, construct the test environment as shown in Figure 14. The Tester is connected to AS 3 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to simulate the reflection attack scenario.

3. The Tester sends spoofed traffic (with source addresses in P1 and destination addresses in P2) toward AS 2 via AS 3 and the DUT.

The *expected results* for this test case are that the DUT blocks spoofed traffic with source addresses in P1 received from the direction of AS 3.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 14 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.



P2' is the spoofed source prefix P2 by the attacker which is inside of AS 3 or connected to AS 3 through other ASes.

Figure 15: SAV for provider-facing ASes in the scenario of direct attacks.

Figure 15 presents a test case for SAV in provider-facing ASes under a direct attack scenario. In this scenario, the attacker spoofs a source address (P2) and directly targets the victim's IP address (P1), overwhelming its network resources. The arrows in Figure 15 represent the business relationships between ASes: AS 3 acts as either a provider or a lateral peer of the DUT and is the provider for AS 5, while the DUT serves as the provider for AS 1, AS 2, and AS 5. Additionally, AS 2 is the provider for AS 1.

The procedure for testing SAV under direct attack conditions is as follows:

1. To evaluate whether the DUT can generate accurate SAV rules for provider-facing ASes in a direct attack scenario, construct the test environment as shown in Figure 15. The Tester is connected to AS 3 and generates test traffic toward the DUT.

2. Configure AS 1, AS 2, AS 3, the DUT, and AS 5 to simulate the direct attack scenario.

3. The Tester sends spoofed traffic (with source addresses in P2 and destination addresses in P1) toward AS 1 via AS 3 and the DUT.

The *expected results* for this test case are that the DUT blocks spoofed traffic with source addresses in P2 received from the direction of AS 3.

Note that the DUT may also be placed at AS 1 or AS 2 in Figure 15 to evaluate its false positive and false negative rates using the same procedure. In these configurations, the DUT is expected to effectively block spoofed traffic.

5.2.2. Control Plane Performance

The test setup, procedure, and metrics for evaluating protocol convergence performance and protocol message processing performance can refer to Section 5.1.2.

5.2.3. Data Plane Performance

The test setup, procedure, and metrics for evaluating data plane SAV table refresh performance and data plane forwarding performance can refer to Section 5.1.3.

5.3. Resource Utilization

When evaluating the DUT for both intra-domain (Section 5.1) and inter-domain SAV (Section 5.2) functionality, CPU utilization (for both control and data planes) and memory utilization (for both control and data planes) MUST be recorded. These metrics SHOULD be collected separately per plane to facilitate granular performance analysis.

6. Reporting Format

Each test follows a reporting format comprising both global, standardized components and individual elements specific to each test. The following parameters for test configuration and SAV mechanism settings MUST be documented in the test report.

Test Configuration Parameters:

1. Test device hardware and software versions
2. Network topology
3. Test traffic attributes
4. System configuration (e.g., physical or virtual machine, CPU, memory, caches, operating system, interface capacity)
5. Device configuration (e.g., symmetric routing, NO_EXPORT)
6. SAV mechanism

7. IANA Considerations

This document has no IANA actions.

8. Security Considerations

The benchmarking tests outlined in this document are confined to evaluating the performance of SAV devices within a controlled laboratory environment, utilizing isolated networks.

The network topology employed for benchmarking must constitute an independent test setup. It is imperative that this setup remains disconnected from any devices that could potentially relay test traffic into an operational production network.

9. References

9.1. Normative References

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