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Enhanced Feasible-Path Unicast Reverse Path Filtering
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Abstract

This document identifies a need for improvement of the unicast Reverse Path Filtering techniques (uRPF) (see BCP 84) for detection and mitigation of source address spoofing (see BCP 38). The strict uRPF is inflexible about directionality, the loose uRPF is oblivious to directionality, and the current feasible-path uRPF attempts to strike a balance between the two (see BCP 84). However, as shown in this draft, the existing feasible-path uRPF still has shortcomings. This document describes an enhanced feasible-path uRPF technique, which aims to be more flexible (in a meaningful way) about directionality than the feasible-path uRPF. It can potentially alleviate ISPs' concerns about the possibility of disrupting service for their customers, and encourage greater deployment of uRPF techniques.

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1. Introduction

Source Address Validation (SAV) refers to the detection and mitigation of source address spoofing [RFC2827]. This document identifies a need for improvement of the unicast Reverse Path Filtering (uRPF) techniques [RFC3704] for SAV. The strict uRPF is inflexible about directionality (see [RFC3704] for definitions), the loose uRPF is oblivious to directionality, and the current feasible-path uRPF attempts to strike a balance between the two [RFC3704]. However, as shown in this draft, the existing feasible-path uRPF still has shortcomings. Even with the feasible-path uRPF, ISPs are often apprehensive that they may be dropping customers' data packets with legitimate source addresses.

This document describes an enhanced feasible-path uRPF technique, which aims to be more flexible (in a meaningful way) about directionality than the feasible-path uRPF. It is based on the principle that if BGP updates for multiple prefixes with the same origin AS were received on different interfaces (at border routers), then incoming data packets with source addresses in any of those prefixes should be accepted on any of those interfaces (presented in Section 3). For some challenging ISP-customer scenarios (see Section 3.3), this document also describes a more relaxed version of the enhanced feasible-path uRPF technique (presented in Section 3.4). Implementation and operations considerations are discussed in Section 3.6.

Definition of Reverse Path Filtering (RPF) list: The list of permissible source address prefixes for incoming data packets on a given interface.

Throughout this document, the routes under consideration are assumed to have been vetted based on prefix filtering [RFC7454] and possibly (in the future) origin validation [RFC6811].

The enhanced feasible-path uRPF methods described here are expected to add greater operational robustness and efficacy to uRPF, while minimizing ISPs' concerns about accidental service disruption for their customers. It is expected that this will encourage more deployment of uRPF to help realize its DDoS prevention benefits network wide.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Review of Existing Source Address Validation Techniques

There are various existing techniques for mitigation against DDoS attacks with spoofed addresses [RFC2827] [RFC3704]. Source address validation (SAV) is performed in network edge devices such as border routers, Cable Modem Termination Systems (CMTS) [RFC4036], and Packet Data Network (PDN) gateways in mobile networks [Firmin]. Ingress Access Control List (ACL) and unicast Reverse Path Filtering (uRPF) are techniques employed for implementing SAV [RFC2827] [RFC3704] [ISOC].

2.1. SAV using Access Control List

Ingress/egress Access Control Lists (ACLs) are maintained which list acceptable (or alternatively, unacceptable) prefixes for the source addresses in the incoming/outgoing Internet Protocol (IP) packets. Any packet with a source address that does not match the filter is dropped. The ACLs for the ingress/egress filters need to be maintained to keep them up to date. Updating the ACLs is an operator driven manual process, and hence operationally difficult or infeasible.

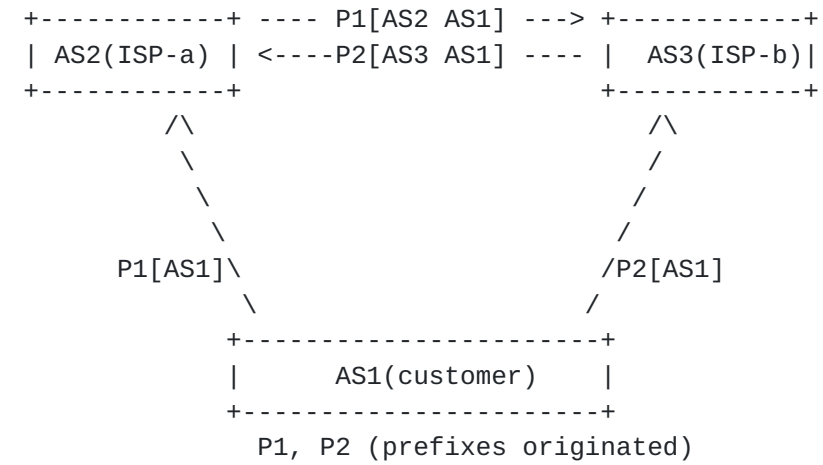
Typically, the egress ACLs in access aggregation devices (e.g. CMTS, DSLAM) permit source addresses only from the address spaces (prefixes) that are associated with the interface on which the customer network is connected. Ingress ACLs are typically deployed on border routers, and drop ingress packets when the source address is spoofed (e.g., belongs to obviously disallowed prefix blocks, IANA special-purpose prefixes [SPAR-v4][SPAR-v6], provider's own prefixes, etc.).

2.2. SAV using Strict Unicast Reverse Path Filtering

Note: In the figures (scenarios) that follow, the following terminology is used: "fails" means drops packets with legitimate source addresses; "works (but not desirable)" means passes all packets with legitimate source addresses but is oblivious to directionality; "works best" means passes all packets with legitimate source addresses with no (or minimal) compromise of directionality. Further, the notation Pi[ASn ASm ...] denotes a BGP update with prefix Pi and an AS_PATH as shown in the square brackets.

In the strict unicast Reverse Path Filtering (uRPF) method, an ingress packet at border router is accepted only if the Forwarding Information Base (FIB) contains a prefix that encompasses the source address, and forwarding information for that prefix points back to the interface over which the packet was received. In other words, the reverse path for routing to the source address (if it were used

as a destination address) should use the same interface over which the packet was received. It is well known that this method has limitations when networks are multi-homed, routes are not symmetrically announced to all transit providers, and there is asymmetric routing of data packets. Asymmetric routing occurs (see Figure 1) when a customer AS announces one prefix (P1) to one transit provider (ISP-a) and a different prefix (P2) to another transit provider (ISP-b), but routes data packets with source addresses in the second prefix (P2) to the first transit provider (ISP-a) or vice versa.



P1, P2 (prefixes originated)

Consider data packets received at AS2
(1) from AS1 with source address in P2, or
(2) from AS3 that originated from AS1
with source address in P1:

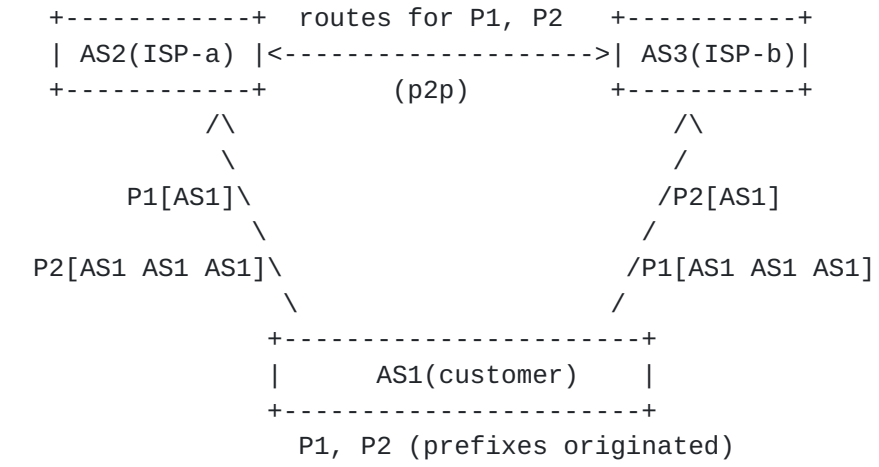
* Strict uRPF fails
* Feasible-path uRPF fails
* Loose uRPF works (but not desirable)
* Enhanced Feasible-path uRPF works best

Figure 1: Scenario 1 for illustration of efficacy of uRPF schemes.

2.3. SAV using Feasible-Path Unicast Reverse Path Filtering

The feasible-path uRPF technique helps partially overcome the problem identified with the strict uRPF in the multi-homing case. The feasible-path uRPF is similar to the strict uRPF, but in addition to inserting the best-path prefix, additional prefixes from alternative announced routes are also included in the RPF list. This method relies on either (a) announcements for the same prefixes (albeit some may be prepended to effect lower preference) propagating to all transit providers performing feasible-path uRPF checks, or (b) announcement of an aggregate less specific prefix to all transit providers while announcing more specific prefixes (covered by the

less specific prefix) to different transit providers as needed for traffic engineering. As an example, in the multi-homing scenario (see Figure 2), if the customer AS announces routes for both prefixes (P1, P2) to both transit providers (with suitable prepends if needed for traffic engineering), then the feasible-path uRPF method works. It should be mentioned that the feasible-path uRPF works in this scenario only if customer routes are preferred at AS2 and AS3 over a shorter non-customer route. However, the feasible-path uRPF method has limitations as well. One form of limitation naturally occurs when the recommendation (a) or (b) mentioned above regarding propagation of prefixes is not followed. Another form of limitation can be described as follows. In Scenario 2 (described above, illustrated in Figure 2), it is possible that the second transit provider (ISP-b or AS3) does not propagate the prepended route for prefix P1 to the first transit provider (ISP-a or AS2). This is because AS3's decision policy permits giving priority to a shorter route to prefix P1 via a lateral peer (AS2) over a longer route learned directly from the customer (AS1). In such a scenario, AS3 would not send any route announcement for prefix P1 to AS2 (over the p2p link). Then a data packet with source address in prefix P1 that originates from AS1 and traverses via AS3 to AS2 will get dropped at AS2.



Consider data packets received at AS2 via AS3
that originated from AS1 and have source address in P1:
* Feasible-path uRPF works (if customer route to P1
  is preferred at AS3 over shorter path)
* Feasible-path uRPF fails (if shorter path to P1
  is preferred at AS3 over customer route)
* Loose uRPF works (but not desirable)
* Enhanced Feasible-path uRPF works best

Figure 2: Scenario 2 for illustration of efficacy of uRPF schemes.

2.4. SAV using Loose Unicast Reverse Path Filtering

In the loose unicast Reverse Path Filtering (uRPF) method, an ingress packet at the border router is accepted only if the FIB has one or more prefixes that encompass the source address. That is, a packet is dropped if no route exists in the FIB for the source address. Loose uRPF sacrifices directionality. It only drops packets if the spoofed address is unreachable in the current FIB (e.g., IANA special-purpose prefixes [SPAR-v4][SPAR-v6], unallocated, allocated but currently not routed).

2.5. SAV using VRF Table

The Virtual Routing and Forwarding (VRF) technology allows a router to maintain multiple routing table instances, separate from the global Routing Information Base (RIB) [Juniper][RFC4364]. External BGP (eBGP) peering sessions send specific routes to be stored in a dedicated VRF table. The uRPF process queries the VRF table (instead of the FIB) for source address validation. A VRF table can be dedicated per eBGP peer and used for uRPF for only that peer, resulting in strict mode operation. For implementing loose uRPF on an interface, the corresponding VRF table would be global, i.e., contains the same routes as in the FIB.

3. SAV using Enhanced Feasible-Path uRPF

3.1. Description of the Method

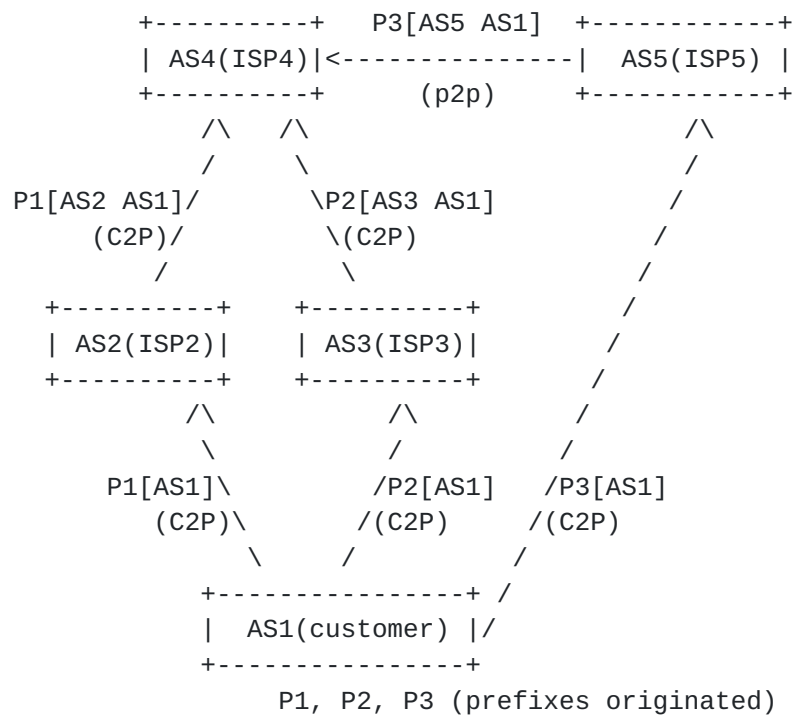
Enhanced feasible-path uRPF (EFP-uRPF) method adds greater operational robustness and efficacy to existing uRPF methods discussed in Section 2. That is because it avoids dropping legitimate data packets and avoids compromising directionality. The method is based on the principle that if BGP updates for multiple prefixes with the same origin AS were received on different interfaces (at border routers), then incoming data packets with source addresses in any of those prefixes should be accepted on any of those interfaces. The EFP-uRPF method can be best explained with an example as follows:

Let us say, a border router of ISP-A has in its Adj-RIB-Ins [RFC4271] the set of prefixes {Q1, Q2, Q3} each of which has AS-x as its origin and AS-x is in ISP-A's customer cone. In this set, the border router received the route for prefix Q1 over a customer facing interface, while it learned the routes for prefixes Q2 and Q3 from a lateral peer and an upstream transit provider, respectively. In this example scenario, the enhanced feasible-path uRPF method requires Q1, Q2, and Q3 be included in the RPF list for the customer interface under consideration.

Thus, the enhanced feasible-path uRPF (EFP-uRPF) method gathers feasible paths for customer interfaces in a more precise way (as compared to feasible-path uRPF) so that all legitimate packets are accepted while the directionality property is not compromised.

The above described EFP-uRPF method is recommended to be applied on customer interfaces. It can be extended to design the RPF lists for lateral peer interfaces also. That is, the EFP-uRPF method can be applied (and loose uRPF avoided) on lateral peer interfaces. That will help avoid compromise of directionality for lateral peer interfaces (which is inevitable with loose uRPF; see Section 2.4).

Looking back at Scenarios 1 and 2 (Figure 1 and Figure 2), the enhanced feasible-path uRPF (EFP-uRPF) method works better than the other uRPF methods. Scenario 3 (Figure 3) further illustrates the enhanced feasible-path uRPF method with a more concrete example. In this scenario, the focus is on operation of the feasible-path uRPF at ISP4 (AS4). ISP4 learns a route for prefix P1 via a customer-to-provider (C2P) interface from customer ISP2 (AS2). This route for P1 has origin AS1. ISP4 also learns a route for P2 via another C2P interface from customer ISP3 (AS3). Additionally, AS4 learns a route for P3 via a lateral peer-to-peer (p2p) interface from ISP5 (AS5). Routes for all three prefixes have the same origin AS (i.e., AS1). Using the enhanced feasible-path uRPF scheme, given the commonality of the origin AS across the routes for P1, P2 and P3, AS4 includes all of these prefixes to the RPF list for the customer interfaces (from AS2 and AS3).



Consider that data packets (sourced from AS1)
may be received at AS4 with source address
in P1, P2 or P3 via any of the neighbors (AS2, AS3, AS5):
* Feasible-path uRPF fails
* Loose uRPF works (but not desirable)
* Enhanced Feasible-path uRPF works best

Figure 3: Scenario 3 for illustration of efficacy of uRPF schemes.

3.1.1. Algorithm A: Enhanced Feasible-Path uRPF

The underlying algorithm in the solution method described above can be specified as follows (to be implemented in a transit AS):

1. Create the list of unique origin ASes considering only the routes in the Adj-RIB-Ins of customer interfaces. Call it Set A = {AS1, AS2, ..., ASn}.

2. Considering all routes in Adj-RIB-Ins for all interfaces (customer, lateral peer, and transit provider), form the set of unique prefixes that have a common origin AS1. Call it Set X1.

3. Include set X1 in Reverse Path Filter (RPF) list on all customer interfaces on which one or more of the prefixes in set X1 were received.

4. Repeat Steps 2 and 3 for each of the remaining ASes in Set A (i.e., for ASi, where i = 2, ..., n).

The above algorithm can be extended to apply EFP-uRPF method to lateral peer interfaces also. However, it is left up to the operator to decide whether they should apply EFP-uRPF or loose uRPF method on lateral peer interfaces. The loose uRPF method is recommended to be applied on transit provider interfaces.

3.2. Operational Recommendations

The following operational recommendations will make the operation of the enhanced feasible-path uRPF robust:

For multi-homed stub AS:

- A multi-homed stub AS SHOULD announce at least one of the prefixes it originates to each of its transit provider ASes. (It is understood that a single-homed stub AS would announce all prefixes it originates to its sole transit provider AS.)

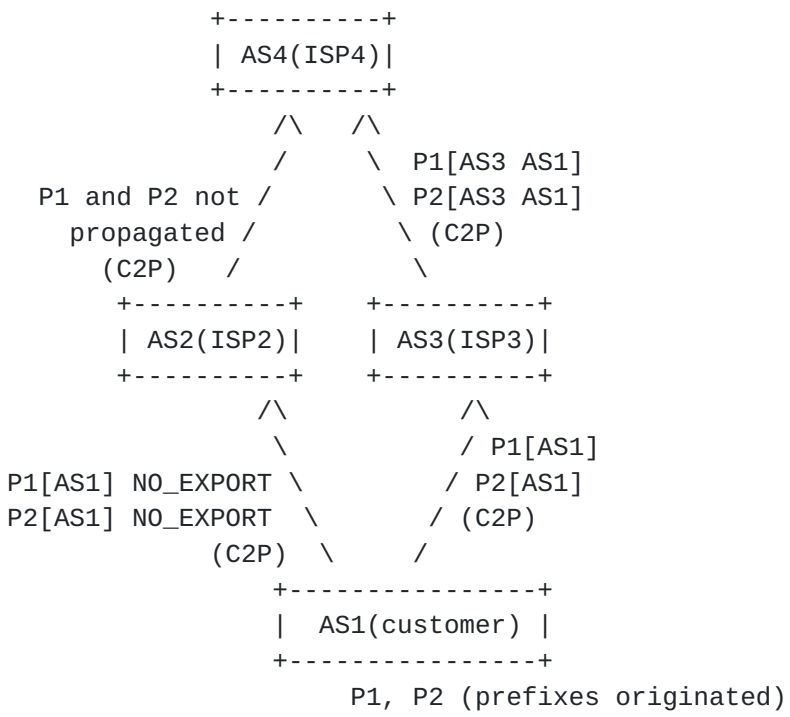
For non-stub AS:

- A non-stub AS SHOULD also announce at least one of the prefixes it originates to each of its transit provider ASes.

- Additionally, from the routes it has learned from customers, a non-stub AS SHOULD announce at least one route per origin AS to each of its transit provider ASes.

3.3. A Challenging Scenario

It should be observed that in the absence of ASes adhering to above recommendations, the following example scenario may be constructed which poses a challenge for the enhanced feasible-path uRPF (as well as for traditional feasible-path uRPF). In the scenario illustrated in Figure 4, since routes for neither P1 nor P2 are propagated on the AS2-AS4 interface (due to the presence of NO_EXPORT Community), the enhanced feasible-path uRPF at AS4 will reject data packets received on that interface with source addresses in P1 or P2. (For a little more complex example scenario see slide #10 in [sriram-urpf].)



Consider that data packets (sourced from AS1)
may be received at AS4 with source address
in P1 or P2 via AS2:
* Feasible-path uRPF fails
* Loose uRPF works (but not desirable)
* Enhanced Feasible-path uRPF with Algorithm A fails
* Enhanced Feasible-path uRPF with Algorithm B works best

Figure 4: Illustration of a challenging scenario.

3.4. Algorithm B: Enhanced Feasible-Path uRPF with Additional Flexibility Across Customer Cone

Adding further flexibility to the enhanced feasible-path uRPF method can help address the potential limitation identified above using the scenario in Figure 4 (Section 3.3). In the following, "route" refers to a route currently existing in the Adj-RIB-in. Including the additional degree of flexibility, the modified algorithm (implemented in a transit AS) can be described as follows (we call this Algorithm B):

1. Create the set of all directly-connected customer interfaces. Call it Set I = {I1, I2, ..., Ik}.

2. Create the set of all unique prefixes for which routes exist in Adj-RIB-Ins for the interfaces in Set I. Call it Set P = {P1, P2, ..., Pm}.

3. Create the set of all unique origin ASes seen in the routes that exist in Adj-RIB-Ins for the interfaces in Set I. Call it Set A = {AS1, AS2, ..., ASn}.

4. Create the set of all unique prefixes for which routes exist in Adj-RIB-Ins of all lateral peer and transit provider interfaces such that each of the routes has its origin AS belonging in Set A. Call it Set Q = {Q1, Q2, ..., Qj}.

5. Then, Set Z = Union(P,Q) is the RPF list that is applied for every customer interface in Set I.

When Algorithm B (which is more flexible than Algorithm A) is employed on customer interfaces, the type of limitation identified in Figure 4 (Section 3.3) is overcome and the method works. The directionality property is minimally compromised, but still the proposed EFP-uRPF method with Algorithm B is a much better choice (for the scenario under consideration) than applying the loose uRPF method which is oblivious to directionality.

So, applying EFP-uRPF method with Algorithm B is recommended on customer interfaces for the challenging scenarios such as those described in Section 3.3. Further, it is recommended that loose uRPF method for SAV should be applied on lateral peer and transit provider interfaces.

3.5. Augmenting RPF Lists with ROA and IRR Data

It is worth emphasizing that an indirect part of the proposal in the draft is that RPF filters may be augmented from secondary sources. Hence, the construction of RPF lists using a method proposed in this document (Algorithm A or B) can be augmented with data from Route Origin Authorization (ROA) [RFC6482] as well as Internet Routing Registry (IRR) data. Prefixes from registered ROAs and IRR route objects that include ASes in an ISP's customer cone SHOULD be used to augment the appropriate RPF lists. (Note: The ASes in a customer cone are obtained in Step 3 of Algorithm B in Section 3.4.) This will help make the RPF lists more robust about source addresses that may be legitimately used by customers of the ISP.

3.6. Implementation and Operations Considerations

3.6.1. Impact on FIB Memory Size Requirement

The existing RPF checks in edge routers take advantage of existing line card implementations to perform the RPF functions. For implementation of the enhanced feasible-path uRPF, the general necessary feature would be to extend the line cards to take arbitrary

RPF lists that are not necessarily the same as the existing FIB contents. In the algorithms (Section 3.1.1 and Section 3.4) described here, the RPF lists are constructed by applying a set of rules to all received BGP routes (not just those selected as best path and installed in FIB). The concept of uRPF querying an RPF list (instead of the FIB) is similar to uRPF querying a VRF table (see (Section 2.5).

The techniques described in this document require that there should be additional memory (i.e., TCAM) available to store the RPF lists in line cards. For an ISP's AS, the RPF list size for each line card will roughly and conservatively equal the total number of prefixes in its customer cone (assuming Algorithm B in Section 3.4 is used). (Note: Most ISP customer cone scenarios would not require Algorithm B, but instead be served best by Algorithm A (see Section 3.1.1) which requires much less FIB memory. This is because Algorithm B is applicable for the less common scenarios such as Scenario 4 in Figure 4 while Algorithm A is applicable for the more common scenarios such as Scenario 3 in Figure 3.)

The following table shows the measured customer cone sizes for various types of ISPs [sriram-ripe63]:

Type of ISP	Measured Customer Cone Size in # Prefixes (in turn this is an estimate for RPF list size on line card)
Very Large Global ISP	32392
Very Large Global ISP	29528
Large Global ISP	20038
Mid-size Global ISP	8661
Regional ISP (in Asia)	1101

Table 1: Customer cone sizes (# prefixes) for various types of ISPs.

For some super large global ISPs that are at the core of the Internet, the customer cone size (# prefixes) can be as high as a few hundred thousand [CAIDA]. But uRPF is most effective when deployed at ASes at the edges of the Internet where the customer cone sizes are smaller as shown in Table 1.

A very large global ISP's router line card is likely to have a FIB size large enough to accommodate 2 to 6 million routes [Cisco1]. Similarly, the line cards in routers corresponding to a large global ISP, a mid-size global ISP, and a regional ISP are likely to have FIB sizes large enough to accommodate about 1 million, 0.5 million, and 100K routes, respectively [Cisco2]. Comparing these FIB size numbers with the corresponding RPF list size numbers in Table 1, it can be surmised that the conservatively estimated RPF list size is only a small fraction of the anticipated FIB memory size under relevant ISP scenarios. What is meant here by relevant ISP scenarios is that only smaller ISPs (and possibly some mid-size and regional ISPs) are expected to implement the proposed EFP-uRPF method since it is most effective closer to the edges of the Internet.

3.6.2. Coping with BGP's Transient Behavior

BGP routing announcements can exhibit transient behavior. Routes may be withdrawn temporarily and then re-announced due to transient conditions such as BGP session reset or link failure-recovery. To cope with this, hysteresis should be introduced in the maintenance of the RPF lists. Deleting entries from the RPF lists SHOULD be delayed by a pre-determined amount (the value based on operational experience) when responding to route withdrawals. This should help suppress the effects due to the transients in BGP.

3.7. Summary of Recommendations

Depending on the scenario, an ISP or enterprise AS operator should follow one of the following recommendations concerning uRPF/SAV:

1. For directly connected networks, i.e., subnets directly connected to the AS and not multi-homed, the AS under consideration SHOULD perform ACL-based source address validation (SAV).

2. For a directly connected single-homed stub AS (customer), the AS under consideration SHOULD perform SAV based on the strict uRPF method.

3. For all other scenarios:

   * If the scenario does not involve complexity such as NO_EXPORT of routes (see Section 3.3, Figure 4), then the enhanced feasible-path uRPF method in Algorithm A (see Section 3.1.1) SHOULD be applied on customer interfaces.

   * Else, if the scenario involves the complexity then the enhanced feasible-path uRPF method in Algorithm B (see Section 3.4) SHOULD be applied on customer interfaces.

* In general, loose uRPF method for SAV SHOULD be applied on lateral peer and transit provider interfaces. However, for lateral peer interfaces, in some cases an operator MAY apply EFP-uRPF method with Algorithm A if they deem it suitable.

It is also recommended that prefixes from registered ROAs and IRR route objects that include ASes in an ISP's customer cone SHOULD be used to augment the appropriate RPF lists.

4. Security Considerations

The security considerations in BCP 38 [RFC2827] and BCP 84 [RFC3704] apply for this document as well. In addition, AS operator should apply the uRPF method that performs best (i.e., with zero or insignificant possibility of dropping legitimate data packets) for the type of peer (customer, transit provider, etc.) and the nature of customer cone scenario that apply (see Section 3.1.1 and Section 3.4).

5. IANA Considerations

This document does not request new capabilities or attributes. It does not create any new IANA registries.

6. Acknowledgements

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