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The Use of Maxlength in the RPKI
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Abstract

This document recommends ways to reduce forged-origin attack surface by prudently limiting the address space that is included in Route Origin Authorizations (ROAs). One recommendation is to avoid using the maxLength attribute in ROAs except in some specific cases. The recommendations complement and extend those in RFC 7115. The document also discusses creation of ROAs for facilitating Distributed Denial of Service (DDoS) mitigation services. Considerations related to ROAs and origin validation for the case of destination-based Remote Triggered Black Hole (RTBH) filtering are also highlighted.

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1. Introduction

The RPKI [RFC6480] uses Route Origin Authorizations (ROAs) to create a cryptographically verifiable mapping from an IP prefix to a set of autonomous systems (ASes) that are authorized to originate this prefix. Each ROA contains a set of IP prefixes, and an AS number of an AS authorized to originate all the IP prefixes in the set [RFC6482]. The ROA is cryptographically signed by the party that holds a certificate for the set of IP prefixes.

The ROA format also supports a maxLength attribute. According to [RFC6482], "When present, the maxLength specifies the maximum length of the IP address prefix that the AS is authorized to advertise." Thus, rather than requiring the ROA to list each prefix the AS is authorized to originate, the maxLength attribute provides a shorthand that authorizes an AS to originate a set of IP prefixes.

However, measurements of current RPKI deployments have found that use of the maxLength in ROAs tends to lead to security problems. Specifically, measurements have shown that 84% of the prefixes specified in ROAs that use the maxLength attribute, are vulnerable to a forged-origin subprefix hijack [HARMFUL]. The forged-origin prefix or subprefix hijack involves inserting the legitimate AS (as specified in the ROA) as the origin AS, and can be launched against any IP prefix/subprefix that has a ROA. Consider a prefix/subprefix that has a ROA but is unused, i.e., not announced in BGP by a legitimate AS. A forged-origin hijack involving such a prefix/subprefix can propagate widely throughout the Internet. On the other hand, if the prefix/subprefix were announced by the legitimate AS, then the propagation of the forged-origin hijack is somewhat limited because of its increased path length relative to the legitimate announcement. Of course, forged-origin hijacks are harmful in both cases but the extent of harm is greater for unannounced prefixes.

For this reason, this document recommends that, whenever possible, operators SHOULD use "minimal ROAs" that include only those IP prefixes that are actually originated in BGP, and no other prefixes. Further, it recommends ways to reduce forged-origin attack surface by prudently limiting the address space that is included in Route Origin Authorizations (ROAs). One recommendation is to avoid using the maxLength attribute in ROAs except in some specific cases. The recommendations complement and extend those in [RFC7115]. The document also discusses creation of ROAs for facilitating Distributed Denial of Service (DDoS) mitigation services. Considerations related to ROAs and origin validation for the case of destination-based Remote Triggered Black Hole (RTBH) filtering are also highlighted.

One ideal place to implement the ROA related recommendations is in the user interfaces for configuring ROAs. Thus, this document further recommends that designers and/or providers of such user interfaces SHOULD provide warnings to draw the user's attention to the risks of using the maxLength attribute.

Best current practices described in this document require no changes to the RPKI specification and will not increase the number of signed ROAs in the RPKI, because ROAs already support lists of IP prefixes [RFC6482].

1.1. Requirements

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 [RFC2119].

1.2. Documentation Prefixes

The documentation prefixes recommended in [RFC5737] are insufficient for use as example prefixes in this document. Therefore, this document uses [RFC1918] address space for constructing example prefixes.

2. Suggested Reading

It is assumed that the reader understands BGP [RFC4271], RPKI [RFC6480], Route Origin Authorizations (ROAs) [RFC6482], RPKI-based Prefix Validation [RFC6811], and BGPsec [RFC8205].

3. Forged-Origin Subprefix Hijack

A detailed description and discussion of forged-origin subprefix hijack are presented here, especially considering the case when the subprefix is not announced in BGP. The forged-origin subprefix hijack is relevant to a scenario in which (1) the RPKI [RFC6480] is deployed, and (2) routers use RPKI origin validation to drop invalid routes [RFC6811], but (3) BGPsec [RFC8205] (or any similar method to validate the truthfulness of the BGP AS_PATH attribute) is not deployed.

The forged-origin subprefix hijack [RFC7115] [GCHSS] is described here using a running example.

Consider the IP prefix 192.168.0.0/16 which is allocated to an organization that also operates AS 64496. In BGP, AS 64496 originates the IP prefix 192.168.0.0/16 as well as its subprefix 192.168.225.0/24. Therefore, the RPKI should contain a ROA authorizing AS 64496 to originate these two IP prefixes. That is, the ROA should be

ROA:(192.168.0.0/16, 192.168.225.0/24, AS 64496)

This ROA is "minimal" because it includes only those IP prefixes that AS 64496 originates in BGP, but no other IP prefixes [RFC6907].

Now suppose an attacking AS 64511 originates a BGP announcement for a subprefix 192.168.0.0/24. This is a standard "subprefix hijack".

In the absence of the minimal ROA above, AS 64511 could intercept traffic for the addresses in 192.168.0.0/24. This is because routers perform a longest-prefix match when deciding where to forward IP packets, and 192.168.0.0/24 originated by AS 64511 is a longer prefix than 192.168.0.0/16 originated by AS 64496.

However, the minimal ROA renders AS 64511's BGP announcement invalid, because (1) this ROA "covers" the attacker's announcement (since 192.168.0.0/24 is a subprefix of 192.168.0.0/16), and (2) there is no ROA "matching" the attacker's announcement (there is no ROA for AS 64511 and IP prefix 192.168.0.0/24) [RFC6811]. If routers ignore invalid BGP announcements, the minimal ROA above ensures that the subprefix hijack will fail.

Now suppose that the "minimal ROA" was replaced with a "loose ROA" that used maxLength as a shorthand for set of IP prefixes that AS 64496 is authorized to originate. The "loose ROA" would be:

> ROA:(192.168.0.0/16-24, AS 64496)

This "loose ROA" authorizes AS 64496 to originate any subprefix of 192.168.0.0/16, up to length /24. That is, AS 64496 could originate 192.168.225.0/24 as well as all of 192.168.0.0/17, 192.168.128.0/17, ..., 192.168.255.0/24 but not 192.168.0.0/25.

However, AS 64496 only originates two prefixes in BGP: 192.168.0.0/16 and 192.168.255.0/24. This means that all other prefixes authorized by the "loose ROA" (for instance, 192.168.0.0/24), are vulnerable to the following forged-origin subprefix hijack [RFC7115] [GCHSS]:

> The hijacker AS 64511 sends a BGP announcement "192.168.0.0/24: AS 64511, AS 64496", falsely claiming that AS 64511 is a neighbor of AS 64496 and falsely claiming that AS 64496 originates the IP prefix 192.168.0.0/24. In fact, the IP prefix 192.168.0.0/24 is not originated by AS 64496.

The hijacker's BGP announcement is valid according to the RPKI, since the ROA (192.168.0.0/16-24, AS 64496) authorizes AS 64496 to originate BGP routes for 192.168.0.0/24. Because AS 64496 does not actually originate a route for 192.168.0.0/24, the hijacker's route is the *only* route to the 192.168.0.0/24. Longest-prefix-match routing ensures that the hijacker's route to the subprefix 192.168.0.0/24 is always preferred over the legitimate route to 192.168.0.0/16 originated by AS 64496. Thus, the hijacker's route propagates through the Internet, the traffic destined for IP addresses in 192.168.0.0/24 will be delivered to the hijacker.

The forged-origin *subprefix* hijack would have failed if the "minimal ROA" described above was used instead of the "loose ROA". If the "minimal ROA" had been used instead, the attacker would be forced to launch a forged-origin *prefix* hijack in order to attract traffic, as follows:

The hijacker AS 64511 sends a BGP announcement "192.168.0.0/16: AS 64511, AS 64496", falsely claiming that AS 64511 is a neighbor of AS 64496.

This forged-origin *prefix* hijack is significantly less damaging than the forged-origin *subprefix* hijack. AS 64496 legitimately originates 192.168.0.0/16 in BGP, so the hijacker AS 64511 is not presenting the *only* route to 192.168.0.0/16. Moreover, the path originated by AS 64511 is one hop longer than the path originated by the legitimate origin AS 64496. As discussed in [LSG16], this means that the hijacker will attract less traffic than he would have in the forged-origin *subprefix* hijack, where the hijacker presents the *only* route to the hijacked subprefix.

In summary, a forged-origin subprefix hijack has the same impact as a regular subprefix hijack. A forged-origin *subprefix* hijack is also more damaging than forged-origin *prefix* hijack.

4. Measurements of Today's RPKI

Network measurements have shown that 12% of the IP prefixes authorized in ROAs have a maxLength longer than their prefix length. The vast majority of these (84%) are vulnerable to forged-origin subprefix hijacks. These subprefixes are not announced in BGP by the legitimate AS. Even large providers are vulnerable to these attacks. See [GSG17] for details.

These measurements suggest that operators commonly misconfigure the maxLength attribute, and unwittingly open themselves up to forged-origin subprefix hijacks. That is, they are exposing a much larger attack surface for forged-origin hijacks than necessary.

5. Recommendations about Minimal ROAs and Maxlength

Operators SHOULD avoid using the maxLength attribute in their ROAs except in some special cases. One such exception may be when all more specific prefixes permitted by the maxLength are actually announced by the AS in the ROA. Another exception for use of maxLength is when (a) the maxLength is substantially larger compared to the specified prefix length in the ROA, and (b) a large number of more specific prefixes in that range is announced by the AS in the ROA. This case should occur rarely in practice (if at all). Operator discretion is necessary in this case.

Operators SHOULD use "minimal ROAs" whenever possible. A minimal ROA contains only those IP prefixes that are actually originated by an AS in BGP, and no other IP prefixes. (See Section 3 for an example.)

This practice requires no changes to the RPKI specification and will not increase the number of signed ROAs in the RPKI, because ROAs already support lists of IP prefixes [RFC6482]. See also [GSG17] for further discussion of why this practice will have minimal impact on the performance of the RPKI ecosystem.

5.1. Creation of ROAs Facilitating DDoS Mitigation Service

Sometimes, it is not possible to use a "minimal ROA", because an operator wants to issue a ROA that includes an IP prefix that is sometimes (but not always) originated in BGP.

In this case, the ROA SHOULD include (1) the set of IP prefixes that are always originated in BGP, and (2) the set IP prefixes that are sometimes, but not always, originated in BGP. The ROA SHOULD NOT include any IP prefixes that the operator knows will not be originated in BGP. Whenever possible, the ROA SHOULD also avoid the use of the maxLength attribute.

The running example is now extended to illustrate one situation where it is not possible to issue a minimal ROA.

Consider the following scenario prior to deployment of RPKI. Suppose AS 64496 announced 192.168.0.0/16 and has a contract with a Distributed Denial of Service (DDoS) mitigation service provider that holds AS 64500. Further, assume that the DDoS mitigation service contract applies to all IP addresses covered by 192.168.0.0/22. When a DDoS attack is detected and reported by AS 64496, AS 64500 immediately originates 192.168.0.0/22, thus attracting all the DDoS traffic to itself. The traffic is scrubbed at AS 64500 and then sent back to AS 64496 over a backhaul data link. Notice that, during a DDoS attack, the DDoS mitigation service provider AS 64500 originates a /22 prefix that is longer than AS 64496's /16 prefix, and so all the traffic (destined to addresses in 192.168.0.0/22) that normally goes to AS 64496 goes to AS 64500 instead.

First, suppose the RPKI only had the minimal ROA for AS 64496, as described in Section 3. But if there is no ROA authorizing AS 64500 to announce the /22 prefix, then the DDoS mitigation (and traffic scrubbing) scheme would not work. That is, if AS 64500 originates the /22 prefix in BGP during DDoS attacks, the announcement would be invalid [RFC6811].

Therefore, the RPKI should have two ROAs: one for AS 64496 and one for AS 64500.

ROA:(192.168.0.0/16, 192.168.225.0/24, AS 64496)

ROA:(192.168.0.0/22, AS 64500)

Neither ROA uses the maxLength attribute. But the second ROA is not "minimal" because it contains a /22 prefix that is not originated by anyone in BGP during normal operations. The /22 prefix is only originated by AS 64500 as part of its DDoS mitigation service during a DDoS attack.

Notice, however, that this scheme does not come without risks. Namely, all IP addresses in 192.168.0.0/22 are vulnerable to a forged-origin subprefix hijack during normal operations, when the /22 prefix is not originated. (The hijacker AS 64511 would send the BGP announcement "192.168.0.0/22: AS 64511, AS 64500", falsely claiming that AS 64511 is a neighbor of AS 64500 and falsely claiming that AS 64500 originates 192.168.0.0/22.)

In some situations, the DDoS mitigation service at AS 64500 might want to limit the amount of DDoS traffic that it attracts and scrubs. Suppose that a DDoS attack only targets IP addresses in 192.168.0.0/24. Then, the DDoS mitigation service at AS 64500 only wants to attract the traffic designated for the /24 prefix that is under attack, but not the entire /22 prefix. To allow for this, the RPKI should have two ROAs: one for AS 64496 and one for AS 64500.

ROA:(192.168.0.0/16, 192.168.225.0/24, AS 64496)

ROA:(192.168.0.0/22-24, AS 64500)

The second ROA uses the maxLength attribute because it is designed to explicitly enable AS 64500 to originate *any* /24 subprefix of 192.168.0.0/22.

As before, the second ROA is not "minimal" because it contains prefixes that are not originated by anyone in BGP during normal operations. As before, all IP addresses in 192.168.0.0/22 are vulnerable to a forged-origin subprefix hijack during normal operations, when the /22 prefix is not originated.

The use of maxLength in this second ROA also comes with an additional risk. While it permits the DDoS mitigation service at AS 64500 to originate prefix 192.168.0.0/24 during a DDoS attack in that space, it also makes the *other* /24 prefixes covered by the /22 prefix (i.e., 192.168.1.0/24, 192.168.2.0/24, 192.168.3.0/24) vulnerable to a forged-origin subprefix attacks.

There is another entirely different way of managing ROAs for DDoS mitigation service. In this scheme, ROAs are not pre-created for the DDoS mitigation service but are created on the fly when the DDoS

mitigation service request is made. Further, the BGP announcements for actuating the DDoS mitigation service will not be made until the ROAs propagate fully through the RPKI system. Hence, there would be a latency involved in DDoS mitigation service going into effect. This method would be effective only if the latency is guaranteed to be within some acceptable limit. This calls for mechanisms to be in place for RPKI data propagation to occur very fast. Thus, this scheme of managing ROAs for DDoS mitigation service helps with eliminating the attack surface for prefixes requiring this service. However, the viability of this scheme depends on future work related to achieving fast ROA propagation in the global RPKI system.

6. ROAs and Origin Validation for RTBH Filtering Scenario

Considerations related to ROAs and origin validation [RFC6811] for the case of destination-based Remote Triggered Black Hole (RTBH) filtering are addressed here. In RTBH filtering, highly specific prefixes (greater than /24 in IPv4 and greater than /48 in IPv6; possibly even /32 (IPv4) and /128 (IPv6)) are announced in BGP. These announcements are tagged with a BLACKHOLE Community [RFC7999]. It is obviously not desirable to use large maxlength or include any such highly specific prefixes in the ROAs to accommodate destination-based RTBH filtering. Therefore, operators SHOULD accommodate this scenario by accepting BGP announcements tagged with BLACKHOLE Community only if the following conditions are met: (1) the announcement is received on a BGP session on which there is agreement to accept BLACKHOLE Community, and (2) the origin AS number in the announcement matches the neighbor (customer) AS number associated with the BGP session, and (3) the prefix in the announcement is subsumed by a less-specific prefix that the neighbor (customer) AS is authorized to announce per RPKI/ROA. Additional details can be found in Section 5.5 in [NIST-800-189].

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