Network Working Group
Internet-Draft
Intended status: Standards Track
Expires: June 24, 2018

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December 21, 2017

RPKI Validation Reconsidered
draft-ietf-sidr-rpki-validation-reconsidered-10

Abstract

This document specifies an alternative to the certificate validation procedure specified in RFC 6487 that reduces aspects of operational fragility in the management of certificates in the RPKI, while retaining essential security features.

Where the procedure specified in RFC 6487 requires that Resource Certificates are rejecting entirely if they are found to over-claim any resources not contained on the issuing certificate, the validation process defined here allows an issuing Certificate Authority to chose to communicate that such Resource Certificates should be accepted for the intersection of their resources and the issuing certificate.

It should be noted that the validation process defined here considers validation under a single Trust Anchor only. In particular, concerns regarding over-claims where multiple configured Trust Anchors claim overlapping resources are considered out of scope for this document.

This choice is signalled by form of a set of alternative Object Identifiers (OIDs) of RFC 3779 X.509 Extensions for IP Addresses and AS Identifiers, and certificate policy for the Resource Public Key Infrastructure (RFC 6484). It should be noted that in case these OIDs are not used for any certificate under a Trust Anchor, the validation procedure defined here has the same outcome as the procedure defined in RFC 6487

Furthermore this document provides an alternative to ROA (RFC 6482), and BGPSec Router Certificate (BGPSec PKI Profiles - publication requested) validation.

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Table of Contents

1. Requirements notation

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].

2. Certificate Validation in the RPKI

As currently defined in section 7.2 of [RFC6487], validation of PKIX certificates that conform to the RPKI profile relies on the use of a path validation process where each certificate in the validation path is required to meet the certificate validation criteria.

These criteria require, in particular, that the Internet Number Resources (INRs) of each certificate in the validation path are "encompassed" by INRs on the issuing certificate. The first certificate in the path is required to be a trust anchor, and its resources are considered valid by definition.

For example, in the following sequence:

```
Certificate 1 (trust anchor):
Issuer TA,
Subject TA,
Resources 192.0.2.0/24, 198.51.100.0/24,
      2001:db8::/32, AS64496-AS64500

Certificate 2:
Issuer TA,
Subject CA1,
Resources 192.0.2.0/24, 198.51.100.0/24, 2001:db8::/32

Certificate 3:
Issuer CA1,
Subject CA2,
Resources 192.0.2.0/24, 198.51.100.0/24, 2001:db8::/32

ROA 1:
Embedded Certificate 4 (EE certificate):
Issuer CA2,
Subject R1,
Resources 192.0.2.0/24

Prefix 192.0.2.0/24, Max Length 24, ASN 64496
```

All certificates in this scenario are considered valid since the INRs of each certificate are encompassed by those of the issuing certificate. ROA1 is valid because the specified prefix is encompassed by the embedded EE certificate, as required by [RFC6482].

3. Operational Considerations

The allocations recorded in the RPKI change as a result of resource transfers. For example, the CAs involved in transfer might choose to modify CA certificates in an order that causes some of these certificates to "over-claim" temporarily. A certificate is said to "over-claim" if it includes INRs not contained in the INRs of the CA that issued the certificate in question.

It may also happen that a child CA does not voluntarily request a shrunk resource certificate when resources are being transferred or reclaimed by the parent. Furthermore operational errors that may occur during management of RPKI databases also may create CA certificates that, temporarily, no longer encompass all of the INRs of subordinate certificates.

Consider the following sequence:

```
Certificate 1 (trust anchor):
Issuer TA,
Subject TA,
Resources 192.0.2.0/24, 198.51.100.0/24,
     2001:db8::/32, AS64496-AS64500

Certificate 2:
Issuer TA,
Subject CA1,
Resources 192.0.2.0/24, 2001:db8::/32

Certificate 3 (invalid):
Issuer CA1,
Subject CA2,
Resources 192.0.2.0/24, 198.51.100.0/24, 2001:db8::/32

ROA 1 (invalid):
Embedded Certificate 4 (EE certificate, invalid):
Issuer CA2,
Subject R1,
Resources 192.0.2.0/24

Prefix 192.0.2.0/24, Max Length 24, ASN 64496
```

Here Certificate 2 from the previous example was re-issued by TA to CA1 and the prefix 198.51.100.0/24 was removed. However, CA1 failed to re-issue a new Certificate 3 to CA2. As a result Certificate 3 is now over-claiming and considered invalid; by recursion the embedded Certificate 4 used for ROA1 is also invalid. And ROA1 is invalid because the specified prefix contained in the ROA is no longer encompassed by a valid embedded EE certificate, as required by [RFC6482]

However, it should be noted that ROA1 does not make use of any of the address resources that were removed from CA1's certificate, and thus it would be desirable if ROA1 could still be viewed as valid. Technically CA1 should re-issue a Certificate 3 to CA2 without 198.51.100.0/24, and then ROA1 would be considered valid according to [RFC6482]. But as long as CA1 does not take this action, ROA1 remains invalid. It would be preferable if ROA1 could be considered valid, since the assertion it makes was not affected by the reduced scope of CA1's certificate.

4. An Amended RPKI Certification Validation Process

4.1. Verified Resource Sets

The problem described above can be considered as a low probability problem today. However the potential impact on routing security would be high if an over-claiming occurred near the apex of the RPKI hierarchy, as this would invalidate the entirety of the sub-tree located below this point.

The changes specified here to the validation procedure in [RFC6487] do not change the probability of this problem, but they do limit the impact to just the over-claimed resources. This revised validation algorithm is intended to avoid causing CA certificates to be treated as completely invalid as a result of over-claims. However, these changes are designed to not degrade the security offered by the RPKI. Specifically, ROAs and router certificates will be treated as valid only if all of the resources contained in them are encompassed by all superior certificates along a path to a trust anchor.

The way this is achieved conceptually is by maintaining a Verified Resource Set (VRS) for each certificate that is separate from the INRs found in the [RFC3779] resource extension in the certificate.

4.2. Differences with existing standards

4.2.1. Certificate Policy (CP) for use with validation reconsidered in the Resource PKI (RPKI)

Note that section 1.2 of [RFC6484] defines the "Certificate Policy (CP) for the Resource PKI (RPKI)" with the following OID:

```
id-cp-ipAddr-asNumber OBJECT IDENTIFIER ::= { iso(1)
        identified-organization(3) dod(6) internet(1)
        security(5) mechanisms(5) pkix(7) cp(14) 2 }
```

This document requests an assignment of a new OID for an alternative "Certificate Policy (CP) for use with validation reconsidered in the Resource PKI (RPKI)" as follows:

```
id-cp-ipAddr-asNumber-v2 OBJECT IDENTIFIER ::= { iso(1)
        identified-organization(3) dod(6) internet(1)
        security(5) mechanisms(5) pkix(7) cp(14) TBD1 }
```

This alternative Certificate Policy is the same as the Certificate Policy described in [RFC6484], except that it is used to drive the decision in step 8 of the validation procedure described in Section 4.2.4.4.

4.2.2. An alternative to RFC3779 X.509 Extensions for IP Addresses and AS Identifiers

This document defines an alternative to [RFC3779]. All specifications and procedures described in [RFC3779] apply, with the following notable exceptions.

4.2.2.1. OID for id-pe-ipAddrBlocks-v2

This document request an OID for the extension id-pe-ipAddrBlocks-v2 (id-pe TBD2). This OID MUST only be used in conjunction with the alternative Certificate Policy OID defined in Section 4.2.1.

The following is an amended specification to be used as an alternative to the specification in section 2.2.1 of [RFC3779].

The OID for this extension is id-pe-ipAddrBlocks-v2.

```
id-pe-ipAddrBlocks-v2  OBJECT IDENTIFIER ::= { id-pe TBD2 }
```

where [RFC5280] defines:

```
id-pkix  OBJECT IDENTIFIER ::= { iso(1) identified-organization(3)
       dod(6) internet(1) security(5) mechanisms(5) pkix(7) }

id-pe    OBJECT IDENTIFIER ::= { id-pkix 1 }
```

4.2.2.2. Syntax for id-pe-ipAddrBlocks-v2

```
id-pe-ipAddrBlocks-v2      OBJECT IDENTIFIER ::= { id-pe TBD2 }

IPAddrBlocks        ::= SEQUENCE OF IPAddressFamily

IPAddressFamily     ::= SEQUENCE {    -- AFI & optional SAFI --
addressFamily        OCTET STRING (SIZE (2..3)),
ipAddressChoice      IPAddressChoice }

IPAddressChoice     ::= CHOICE {
inherit              NULL, -- inherit from issuer --
addressesOrRanges    SEQUENCE OF IPAddressOrRange }

IPAddressOrRange    ::= CHOICE {
addressPrefix        IPAddress,
addressRange         IPAddressRange }

IPAddressRange      ::= SEQUENCE {
min                  IPAddress,
max                  IPAddress }

IPAddress           ::= BIT STRING
```

Note that the descriptions of objects referenced in the syntax above are defined in sections 2.2.3.1 through 2.2.3.9 of [RFC3779].

4.2.2.3. OID for id-pe-autonomousSysIds-v2

This document request an OID for the extension id-pe-autonomousSysIds-v2 (id-pe TBD3). This OID MUST only be used in conjunction with the alternative Certificate Policy OID defined in Section 4.2.1.

The following is an amended specification to be used as an alternative to the specification in section 3.2.1 of [RFC3779].

The OID for this extension is id-pe-autonomousSysIds-v2.

```
id-pe-autonomousSysIds-v2  OBJECT IDENTIFIER ::= { id-pe TBD3 }
```

where [RFC5280] defines:

```
id-pkix  OBJECT IDENTIFIER ::= { iso(1) identified-organization(3)
       dod(6) internet(1) security(5) mechanisms(5) pkix(7) }

id-pe    OBJECT IDENTIFIER ::= { id-pkix 1 }
```

4.2.2.4. Syntax for id-pe-autonomousSysIds-v2

```
id-pe-autonomousSysIds-v2  OBJECT IDENTIFIER ::= { id-pe TBD3 }

ASIdentifiers       ::= SEQUENCE {
asnum               [0] EXPLICIT ASIdentifierChoice OPTIONAL,
rdi                 [1] EXPLICIT ASIdentifierChoice OPTIONAL}

ASIdentifierChoice  ::= CHOICE {
inherit              NULL, -- inherit from issuer --
asIdsOrRanges        SEQUENCE OF ASIdOrRange }

ASIdOrRange         ::= CHOICE {
id                  ASId,
range               ASRange }

ASRange             ::= SEQUENCE {
min                 ASId,
max                 ASId }

ASId                ::= INTEGER
```

4.2.2.5. Amended IP Address Delegation Extension Certification Path Validation

Certificate path validation is performed as specified in Section 4.2.4.4.

4.2.2.6. Amended Autonomous System Identifier Delegation Extension Certification Path Validation

Certificate path validation is performed as specified in Section 4.2.4.4.

4.2.2.7. Amended ASN.1 module

This document requests an OID for id-mod-ip-addr-and-as-ident-v2, as follows:

```
IPAddrAndASCertExtn-v2 { iso(1) identified-organization(3) dod(6)
   internet(1) security(5) mechanisms(5) pkix(7) mod(0)
   id-mod-ip-addr-and-as-ident-v2(TBD4) }
```

The following is an amended specification to be used as an alternative to the specification in section appendix A of [RFC3779].

This normative appendix describes the IP address and AS identifiers extensions used by conforming PKI components in ASN.1 syntax.

```
IPAddrAndASCertExtn-v2 { iso(1) identified-organization(3) dod(6)
   internet(1) security(5) mechanisms(5) pkix(7) mod(0)
   id-mod-ip-addr-and-as-ident-v2(TBD4) }

DEFINITIONS EXPLICIT TAGS ::=

BEGIN

-- EXPORTS ALL --

IMPORTS

-- PKIX specific OIDs and arcs --

id-pe FROM PKIX1Explicit88 { iso(1) identified-organization(3)
     dod(6) internet(1) security(5) mechanisms(5) pkix(7)
     id-mod(0) id-pkix1-explicit(18) }

-- IP Address Block and AS Identifiers Syntax --

IPAddrBlocks, ASIdentifiers FROM  IPAddrAndASCertExtn { iso(1)
   identified-organization(3) dod(6) internet(1) security(5)
   mechanisms(5) pkix(7) mod(0) id-mod-ip-addr-and-as-ident(30) }
;

-- Validation Reconsidered IP Address Delegation Extension OID --

id-pe-ipAddrBlocks-v2  OBJECT IDENTIFIER ::= { id-pe TBD2 }

-- Validation Reconsidered IP Address Delegation Extension Syntax --
-- Syntax is imported from [RFC3779] --

-- Validation Reconsidered Autonomous System Identifier --
--     Delegation Extension OID                          --

id-pe-autonomousSysIds-v2  OBJECT IDENTIFIER ::= { id-pe TBD3 }

-- Validation Reconsidered Autonomous System Identifier --
--     Delegation Extension Syntax                       --

-- Syntax is imported from [RFC3779] --

END
```

4.2.3. Addendum to RFC6268

This document requests an OID for id-mod-ip-addr-and-as-ident-2v2 as follows:

```
IPAddrAndASCertExtn-2010v2 { iso(1) identified-organization(3) dod(6)
         internet(1) security(5) mechanisms(5) pkix(7) mod(0)
         id-mod-ip-addr-and-as-ident-2v2(TBD5) }
```

[RFC6268] is an informational RFC that updates some auxiliary ASN.1 modules to conform to the 2008 version of ASN.1; the 1988 ASN.1 modules in Section 4.2.2.7 remain the normative version.

The following is an additional module confirming to the 2008 version of ASN.1 to be used with the extensions defined in Section 4.2.2.1 and Section 4.2.2.3.

```
IPAddrAndASCertExtn-2010v2 { iso(1) identified-organization(3) dod(6)
         internet(1) security(5) mechanisms(5) pkix(7) mod(0)
         id-mod-ip-addr-and-as-ident-2v2(TBD5) }

DEFINITIONS EXPLICIT TAGS ::=

BEGIN

   EXPORTS ALL;
   IMPORTS

   -- PKIX specific OIDs and arcs --

   id-pe
   FROM PKIX1Explicit-2009
     { iso(1) identified-organization(3) dod(6) internet(1)
       security(5) mechanisms(5) pkix(7) id-mod(0)
       id-mod-pkix1-explicit-02(51)}

   EXTENSION
   FROM PKIX-CommonTypes-2009
     { iso(1) identified-organization(3) dod(6) internet(1)
       security(5) mechanisms(5) pkix(7) id-mod(0)
       id-mod-pkixCommon-02(57)}

-- IP Address Block and AS Identifiers Syntax --

   IPAddrBlocks, ASIdentifiers
   FROM IPAddrAndASCertExtn-2010
      { iso(1) identified-organization(3) dod(6)
        internet(1) security(5) mechanisms(5) pkix(7) mod(0)
```

```
          id-mod-ip-addr-and-as-ident-2(72) }
    ;

    --
    -- Extensions contains the set of extensions defined in this
    -- module
    --
    -- These are intended to be placed in public key certificates
    -- and thus should be added to the CertExtensions extension
    -- set in PKIXImplicit-2009 defined for [RFC5280]
    --

    Extensions EXTENSION ::= {
       ext-pe-ipAddrBlocks-v2 | ext-pe-autonomousSysIds-v2
    }

    -- Validation Reconsidered IP Address Delegation Extension OID --

    ext-pe-ipAddrBlocks-v2 EXTENSION ::= {
      SYNTAX IPAddrBlocks
      IDENTIFIED BY id-pe-ipAddrBlocks-v2
    }

    id-pe-ipAddrBlocks-v2  OBJECT IDENTIFIER ::= { id-pe TBD2 }

    -- Validation Reconsidered IP Address Delegation --
    --      Extension Syntax                        --

    -- Syntax is imported from [RFC6268] --

    -- Validation Reconsidered Autonomous System Identifier --
    --      Delegation Extension OID                        --

    ext-pe-autonomousSysIds-v2 EXTENSION ::= {
      SYNTAX ASIdentifiers
      IDENTIFIED BY id-pe-autonomousSysIds-v2
    }

    id-pe-autonomousSysIds OBJECT IDENTIFIER ::= { id-pe TBD3 }

-- Validation Reconsidered Autonomous System Identifier --
--      Delegation Extension Syntax                     --

-- Syntax is imported from [RFC6268] --

END
```

4.2.4. An alternative to RFC6487 Profile for X.509 PKIX Resource Certificates

This document defines an alternative Profile for X.509 PKIX Resource Certificates. This profile follows all definitions and procedures described in [RFC6487] with the following notable exceptions.

4.2.4.1. Amended Certificate Policies

The following is an amended specification to be used in this profile, in place of section 4.8.9 of [RFC6487].

This extension MUST be present and MUST be marked critical. It MUST include exactly one policy of type id-cp-ipAddr-asNumber-v2, as specified in the updated RPKI CP in Section 4.2.1.

4.2.4.2. Amended IP Resources

The following is an amended specification to be used in this profile, in place of section 4.8.10 of [RFC6487].

Either the IP Resources extension, or the AS Resources extension, or both, MUST be present in all RPKI certificates, and if present, MUST be marked critical.

This extension contains the list of IP address resources as per Section 4.2.2.1. The value may specify the "inherit" element for a particular Address Family Identifier (AFI) value. In the context of resource certificates describing public number resources for use in the public Internet, the Subsequent AFI (SAFI) value MUST NOT be used.

This extension MUST either specify a non-empty set of IP address records, or use the "inherit" setting to indicate that the IP address resource set of this certificate is inherited from that of the certificate's issuer.

4.2.4.3. Amended AS Resources

The following is an amended specification to be used in this profile, in place of section 4.8.11 of [RFC6487].

Either the AS Resources extension, or the IP Resources extension, or both, MUST be present in all RPKI certificates, and if present, MUST be marked critical.

This extension contains the list of AS number resources as per Section 4.2.2.3, or it may specify the "inherit" element. Routing

Domain Identifier (RDI) values are NOT supported in this profile and MUST NOT be used.

This extension MUST either specify a non-empty set of AS number records, or use the "inherit" setting to indicate that the AS number resource set of this certificate is inherited from that of the certificate's issuer.

4.2.4.4. Amended Resource Certificate Path Validation

The following is an amended specification for path validation to be used in place of section 7.2 of [RFC6487] allowing for the validation of both certificates following the profile defined in [RFC6487], as well as certificates following the profile described above.

The following algorithm is employed to validate CA and EE resources certificates. It is modelled on the path validation algorithm from [RFC5280], but modified to make use of the IP Address Delegation and AS Identifier Delegation Extensions from [RFC3779].

There are two inputs to the validation algorithm:

1. a trust anchor

2. a certificate to be validated

The algorithm is initialized with two new variables for use in the RPKI: Validated Resource Set-IP (VRS-IP) and Validated Resource Set-AS (VRS-AS). These sets are used to track the set of INRs (IP address space and AS Numbers) that are considered valid for each CA certificate. The VRS-IP and VRS-AS sets are initially set to the IP Address Delegation and AS Identifier Delegation values, respectively, from the trust anchor used to perform validation.

This path validation algorithm verifies, among other things, that a prospective certification path (a sequence of n certificates) satisfies the following conditions:

a. for all 'x' in {1, ..., n-1}, the subject of certificate 'x' is the issuer of certificate ('x' + 1);

b. certificate '1' is issued by a trust anchor;

c. certificate 'n' is the certificate to be validated; and

d. for all 'x' in {1, ..., n}, certificate 'x' is valid.

Certificate validation requires verifying that all of the following conditions hold, in addition to the certification path validation criteria specified in Section 6 of [RFC5280].

1. The signature of certificate x (x>1) is verified using the public key of the issuer's certificate (x-1), using the signature algorithm specified for that public key (in certificate x-1).

2. The current time lies within the interval defined by the NotBefore and NotAfter values in the Validity field of certificate x.

3. The Version, Issuer, and Subject fields of certificate x satisfy the constraints established in Section 4.1-4.7 of this specification.

4. If certificate x uses the Certificate Policy defined in section 4.8.9 of [RFC6487], then the certificate MUST contain all extensions defined in section 4.8 of [RFC6487] that must be present. The value(s) for each of these extensions MUST satisfy the constraints established for each extension in the respective sections. Any extension not thus identified MUST NOT appear in certificate x.

5. If certificate x uses the Certificate Policy defined in Section 4.2.4.1, then all extensions defined in section 4.8 of [RFC6487], except sections 4.8.9, 4.8.10 and 4.8.10 MUST be present. The certificate MUST contain an extension as defined in Section 4.2.4.2 or Section 4.2.4.3, or both. The value(s) for each of these extensions MUST satisfy the constraints established for each extension in the respective sections. Any extension not thus identified MUST NOT appear in certificate x.

6. Certificate x MUST NOT have been revoked, i.e., it MUST NOT appear on a CRL issued by the CA represented by certificate x-1

7. Compute the VRS-IP and VRS-AS set values as indicated below:

   * If the IP Address Delegation extension is present in certificate x and x=1, set the VRS-IP to the resources found in this extension.

   * If the IP Address Delegation extension is present in certificate x and x>1, set the VRS-IP to the intersection of the resources between this extension and the value of the VRS-IP computed for certificate x-1.

* If the IP Address Delegation extension is absent in certificate x, set the VRS-IP to NULL.

* If the IP Address Delegation extension is present in certificate x and x=1, set the VRS-IP to the resources found in this extension.

* If the AS Identifier Delegation extension is present in certificate x and x>1, set the VRS-AS to the intersection of the resources between this extension and the value of the VRS-AS computed for certificate x-1

* If the AS Identifier Delegation extension is absent in certificate x, set the VRS-AS to NULL.

8. If there is any difference in resources in the VRS-IP and the IP Address Delegation extension on certificate x, or the VRS-AS and the AS Identifier Delegation extension on certificate x, then:

   * If certificate x uses the Certificate Policy defined in Section 4.2.4.1 a warning listing the over-claiming resources for certificate x SHOULD be issued.

   * If certificate x uses the Certificate Policy defined in section 4.8.9 of [RFC6487], then certificate x MUST be rejected.

These rules allow a CA certificate to contain resources that are not present in (all of) the certificates along the path from the trust anchor to the CA certificate. If none of the resources in the CA certificate are present in all certificates along the path, no subordinate certificates could be valid. However, the certificate is not immediately rejected as this may be a transient condition. Not immediately rejecting the certificate does not result in a security problem because the associated VRS sets accurately reflect the resources validly associated with the certificate in question.

4.2.5. An alternative ROA validation RFC6482

Section 4 of [RFC6482] currently has the following text on the validation of resources on a ROA:

o The IP address delegation extension [RFC3779] is present in the end-entity (EE) certificate (contained within the ROA), and each IP address prefix(es) in the ROA is contained within the set of IP addresses specified by the EE certificate's IP address delegation extension.

If the end-entity certificate uses the Certificate Policy defined in Section 4.2.4.1, then the following approach must be used instead.

- The amended IP address delegation extension described in Section 4.2.4.2 is present in the end-entity (EE) certificate (contained within the ROA), and each IP address prefix(es) in the ROA is contained within the VRS-IP set that is specified as an outcome of EE certificate validation described in Section 4.2.4.4.

Note that this ensures that ROAs can be valid only, if all IP address prefixes in the ROA are encompassed by the VRS-IP of all certificates along the path to the trust anchor used to verify it.

Operators MAY issue separate ROAs for each IP address prefix, so that the loss of one or more IP address prefixes from the VRS-IP of any certificate along the path to the trust anchor would not invalidate authorizations for other IP address prefixes.

4.2.6. An alternative to BGPSec Router Certificate Validation

If a BGPsec Router Certificate ([I-D.ietf-sidr-bgpsec-pki-profiles]) uses the Certificate Policy defined in Section 4.2.4.1, then in addition to the BGPsec Router Certificate Validation defined in section 3.3 of [I-D.ietf-sidr-bgpsec-pki-profiles], the following constraint MUST be met:

- The VRS-AS of BGPsec Router Certificates MUST encompass all ASNs in the AS Resource Identifier Delegation extension.

Operators MAY issue separate BGPsec Router Certificates for different ASNs, so that the loss of on ASN from the VRS-AS of any certificate along the path to the trust anchor would not invalidate router keys for other ASNs.

5. Validation examples

In this section we will demonstrate the outcome of RPKI validation performed using the algorithm and procedures described in Section 4.2.4.4, Section 4.2.5 and Section 4.2.6, under three deployment scenarios:

- An RPKI tree consisting of certificates using the old OIDs only

- An RPKI tree consisting of certificates using the new OIDs only

- An RPKI tree consisting of a mix of certificates using either the old or the new OIDs

In this context we refer to a certificate as using the 'old' OIDs, if the certificate uses a combination of the OIDs defined in section 4.8.9 of [RFC6487], section 2.2.1 of [RFC3779] and/or section 3.2.1 od [RFC3779]. We refer to a certificate as using the 'new' OIDS, if the certificate uses a combination of OIDs defined in Section 4.2.4.1, Section 4.2.2.1 and/or Section 4.2.2.3.

5.1. Example 1 - An RPKI tree using the old OIDs only

Consider the following example:

```
  Certificate 1 (trust anchor):
   Issuer: TA,
   Subject: TA,
   OIDs: OLD,
   Resources: 0/0, ::0, AS0-4294967295 (ALL Resources)

    Verified Resource Set: 0/0, ::0, AS0-4294967295 (ALL Resources)
    Warnings: none

  Certificate 2:
   Issuer: TA,
   Subject: CA1,
   OIDs: OLD,
   Resources: 192.0.2.0/24, 2001:db8::/32, AS64496

    Verified Resource Set: 192.0.2.0/24,
                           2001:db8::/32, AS64496
    Warnings: none

  Certificate 3 (invalid):
   Issuer: CA1,
   Subject: CA2,
   OIDs: OLD,
   Resources: 192.0.2.0/24, 198.51.100.0/24, AS64496

    Verified Resource Set: 192.0.2.0/24, AS64496

    Certificate 3 is considered invalid because "Resources:"
    contains 198.51.100.0/24 which is not found in the
    Verified Resource Set.

  ROA 1 (invalid):
   Embedded Certificate 4 (EE certificate invalid):
    Issuer: CA2,
    Subject: R1,
    OIDs: OLD,
    Resources: 192.0.2.0/24
```

```
        Prefix 192.0.2.0/24, Max Length 24, ASN 64496

      ROA1 is considered invalid because Certificate 3 is invalid.

    ROA 2 (invalid):
     Embedded Certificate 5 (EE certificate invalid):
      Issuer: CA2,
      Subject: R2,
      OIDs: OLD,
      Resources: 198.51.100.0/24
       Prefix 198.51.100.0/24, Max Length 24, ASN 64496

      ROA2 is considered invalid because Certificate 3 is invalid.

    BGPSec Certificate 1 (invalid):
     Issuer: CA2,
     Subject: ROUTER-64496,
     OIDs: NEW,
     Resources: AS64496

      BGPSec Certificate 1 is invalid because Certificate 3 is invalid.

    BGPSec Certificate 2 (invalid):
     Issuer: CA2,
     Subject: ALL-ROUTERS,
     OIDs: NEW,
     Resources: AS64496-AS64497

      BGPSec Certificate 2 is invalid because Certificate 3 is invalid.
```

5.2. Example 2 - An RPKI tree using the new OIDs only

Consider the following example under the amended approach:

```
    Certificate 1 (trust anchor):
     Issuer: TA,
     Subject: TA,
     OIDs: NEW,
     Resources: 0/0, ::0, AS0-4294967295 (ALL Resources)

      Verified Resource Set: 0/0, ::0, AS0-4294967295 (ALL Resources)
      Warnings: none

    Certificate 2:
     Issuer: TA,
     Subject: CA1,
     OIDs: NEW,
     Resources: 192.0.2.0/24, 2001:db8::/32, AS64496
```

```
       Verified Resource Set: 192.0.2.0/24,
                              2001:db8::/32, AS64496
       Warnings: none

     Certificate 3:
      Issuer: CA1,
      Subject: CA2,
      OIDs: NEW,
      Resources: 192.0.2.0/24, 198.51.100.0/24, AS64496

       Verified Resource Set: 192.0.2.0/24, AS64496
       Warnings: over-claim for 198.51.100.0/24

     ROA 1 (valid):
      Embedded Certificate 4 (EE certificate):
       Issuer: CA2,
       Subject: R1,
       OIDs: NEW,
       Resources: 192.0.2.0/24
        Prefix 192.0.2.0/24, Max Length 24, ASN 64496

        Verified Resource Set: 192.0.2.0/24
        Warnings: none

       ROA1 is considered valid because the prefix matches the Verified
       Resource Set on the embedded EE certificate.

     ROA 2 (invalid):
      Embedded Certificate 5 (EE certificate invalid):
       Issuer: CA2,
       Subject: R2,
       OIDs: NEW,
       Resources: 198.51.100.0/24
         Prefix 198.51.100.0/24, Max Length 24, ASN 64496

         Verified Resource Set: none (empty set)
         Warnings: 198.51.100.0/24

       ROA2 is considered invalid because the ROA prefix 198.51.100.0/24
       is not contained in the Verified Resource Set.

     BGPSec Certificate 1 (valid):
      Issuer: CA2,
      Subject: ROUTER-64496,
      OIDs: NEW,
      Resources: AS64496

       Verified Resource Set: AS64496
```

```
      Warnings: none

    BGPSec Certificate 2 (invalid):
     Issuer: CA2,
     Subject: ALL-ROUTERS,
     OIDs: NEW,
     Resources: AS64496-AS64497

      Verified Resource Set: AS64496

     BGPSec Certificate 2 is invalid because not all of its Resources
     are contained in the Verified Resource Set.

     Note that this problem can be mitigated by issuing separate
     certificates for each AS number.
```

5.3. Example 3 - An RPKI tree using a mix of old and new OIDs

In the following example new OIDs are used only for CA certificates where the issuing CA anticipates that an over-claim could occur, and has a desire to limit the impact of this to just the over-claimed resources in question:

```
 Certificate 1 (trust anchor):
  Issuer: TA,
  Subject: TA,
  OIDs: OLD,
  Resources: 0/0, ::0, AS0-4294967295 (ALL Resources)

   Verified Resource Set: 0/0, ::0, AS0-4294967295 (ALL Resources)
   Warnings: none

   Note that a Trust Anchor certificate cannot be found to over-claim.
   So, using the new OIDs here would not change anything with regards
   to the validity of this certificate.

 Certificate 2:
  Issuer: TA,
  Subject: CA1,
  OIDs: OLD,
  Resources: 192.0.2.0/24, 2001:db8::/32, AS64496

   Verified Resource Set: 192.0.2.0/24,
                          2001:db8::/32, AS64496
   Warnings: none

   Note that since the TA certificate claims all resources, it is
   impossible to issue a certificate below it that could be found
```

to be over-claiming. Therefore there is no benefit in using the new OIDs for Certificate 2.

Certificate 3:
Issuer: CA1,
Subject: CA2,
OIDs: NEW,
Resources: 192.0.2.0/24, 198.51.100.0/24, AS64496

Verified Resource Set: 192.0.2.0/24, AS64496
Warnings: over-claim for 198.51.100.0/24

Note that CA1 anticipated that it might invalid Certificate 3 issued to CA2, if its own resources on Certificate 2 were modified and OLD OIDs would have been used on Certificate 3.

ROA 1 (valid):
Embedded Certificate 4 (EE certificate):
Issuer: CA2,
Subject: R1,
OIDs: OLD,
Resources: 192.0.2.0/24
Prefix 192.0.2.0/24, Max Length 24, ASN 64496

Verified Resource Set: 192.0.2.0/24
Warnings: none

ROA1 is considered valid because the prefix matches the Verified Resource Set on the embedded EE certificate.

ROA 2 (invalid):
Embedded Certificate 5 (EE certificate invalid):
Issuer: CA2,
Subject: R2,
OIDs: OLD,
Resources: 198.51.100.0/24
Prefix 198.51.100.0/24, Max Length 24, ASN 64496

Verified Resource Set: none (empty set)

ROA2 is considered invalid because "Resources:" on its EE certificate contains 198.51.100.0/24, which is not contained in its Verified Resource Set.

Note that if new OIDs were used here (as in example 2) ROA 2 would be considered invalid because the Prefix is not contained in the Verified Resource Set.

So, if there is no difference in the validity outcome one could argue that using old OIDs here is clearest, because any over-claim of ROA prefixes MUST result in it being considered invalid (as described in section 4.2.5).

BGPSec Certificate 1 (valid):
Issuer: CA2,
Subject: ROUTER-64496,
OIDs: OLD,
Resources: AS64496

Verified Resource Set: AS64496
Warnings: none

BGPSec Certificate 2 (invalid):
Issuer: CA2,
Subject: ALL-ROUTERS,
OIDs: OLD,
Resources: AS64496-AS64497

Verified Resource Set: AS64496

BGPSec Certificate 2 is consider invalid because "Resources:" contains AS64497, which is not contained in its Verified Resource Set.

Note that if new OIDs were used here (as in example 2) BGPSec Certificate 2 would be considered invalid because the Prefix is not contained in the Verified Resource Set.

So, if there is no difference in the validity outcome one could argue that using old OIDs here is the clearest, because any over-claim on this certificate MUST result in it being considered invalid (as described in section 4.2.6).

Also note that as in example 2 this problem can be mitigated by issuing separate certificates for each AS number.

6. Deployment Considerations

This document defines an alternative RPKI validation algorithm, but it does not dictate how this algorithm will be deployed. This should be discussed as a separate effort. That said, the following observations may help this discussion.

Because this document introduces new OIDs and an alternative to the Profile for X.509 PKIX Resource Certificates described in [RFC6487], the use of such certificates in the global RPKI will lead to the

rejection of such certificates by Relying Party tools that do not (yet) implement the alternative profile described in this document.

For this reason it is important that such tools are updated before Certificate Authorities start to use this specification.

However, because the OIDs are defined in each RPKI certificate, there is no strict requirement for all Certificate Authorities to migrate to the new OIDs at the same time, or even for all the certificates they issue. The example in Section 5.3 illustrates a possible deployment where the new OIDs are used only when issuing CA certificates where an accidental over-claim may occur.

7. Security Considerations

The authors believe that the revised validation algorithm introduces no new security vulnerabilities into the RPKI, because it cannot lead to any ROA and/or Router Certificates to be accepted if they contain resources that are not held by the issuer.

8. IANA Considerations

IANA is to add the following to the SMI Security for PKIX Certificate Policies registry:

Decimal	Description	References
TBD1	id-cp-ipAddr-asNumber-v2	[section 4.2.1]

IANA is to add the following to the SMI Security for PKIX Certificate Extension registry:

Decimal	Description	References
TBD2	id-pe-ipAddrBlocks-v2	[section 4.2.2.1]
TBD3	id-pe-autonomousSysIds-v2	[section 4.2.2.3]

IANA is to add the following to the SMI Security for PKIX Module Identifier registry:

Decimal	Description	References
TBD4	id-mod-ip-addr-and-as-ident-v2	[section 4.2.2.7]
TBD5	id-mod-ip-addr-and-as-ident-2v2	[section 4.2.3]

9. Acknowledgements

The authors would like to thank Stephen Kent for reviewing and contributing to this document. We would like to thank Rob Austein for suggesting that separate OIDs should be used to make the behaviour of Relying Party tools deterministic, and we would like to thank Russ Hously, Sean Turner and Tom Petch for their contributions on OID and ASN.1 updates. Finally we would like to thank Tom Harrison for a general review of this document.

10. References

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10.2. Informative References

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