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Authors: J. Snijders B. Maddison M. Lepinski
 Fastly Workonline Carleton College
 D. Kong S. Kent
 Raytheon Independent
 A Profile for Route Origin Authorizations (ROAs)

Abstract

This document defines a standard profile for Route Origin Authorizations (ROAs). A ROA is a digitally signed object that provides a means of verifying that an IP address block holder has authorized an Autonomous System (AS) to originate routes to one or more prefixes within the address block. This document obsoletes RFC 6482.

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.

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1. Introduction

The primary purpose of the Resource Public Key Infrastructure (RPKI) is to improve routing security. (See [[RFC6480](#)] for more

information.) As part of this system, a mechanism is needed to allow entities to verify that an AS has been given permission by an IP address block holder to advertise routes to one or more prefixes within that block. A ROA provides this function.

The ROA makes use of the template for RPKI digitally signed objects [RFC6488], which defines a Cryptographic Message Syntax (CMS) [RFC5652] wrapper for the ROA content as well as a generic validation procedure for RPKI signed objects. Therefore, to complete the specification of the ROA (see Section 4 of [RFC6488]), this document defines:

- *The OID that identifies the signed object as being a ROA. (This OID appears within the eContentType in the encapContentInfo object as well as the content-type signed attribute in the signerInfo object).
- *The ASN.1 syntax for the ROA eContent. (This is the payload that specifies the AS being authorized to originate routes as well as the prefixes to which the AS may originate routes.) The ROA eContent is ASN.1 encoded using the Distinguished Encoding Rules (DER) [X.690].
- *Additional steps required to validate ROAs (in addition to the validation steps specified in [RFC6488]).

1.1. Changes from RFC6482

This section summarizes the significant changes between [RFC6482] and the profile described in this document.

- *Clarified the requirements for the IP Addresses and AS Identifiers X.509 certificate extensions.
- *Strengthened the ASN.1 formal notation and definitions.
- *Incorporated RFC 6482 Errata.
- *Added an example ROA eContent payload and an ROA.
- *Specified a canonicalization procedure for the content of ipAddrBlocks.

2. Related Work

It is assumed that the reader is familiar with the terms and concepts described in "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile" [RFC5280] and "X.509 Extensions for IP Addresses and AS Identifiers" [RFC3779].

Additionally, this document makes use of the RPKI signed object profile [[RFC6488](#)]; thus, familiarity with that document is assumed. Note that the RPKI signed object profile makes use of certificates adhering to the RPKI Resource Certificate Profile [[RFC6487](#)]; thus, familiarity with that profile is also assumed.

3. The ROA ContentType

The content-type for a ROA is defined as routeOriginAuthz and has the numerical value of 1.2.840.113549.1.9.16.1.24.

This OID MUST appear both within the eContentType in the encapContentInfo object as well as the ContentType signed attribute in the signerInfo object (see [[RFC6488](#)]).

4. The ROA eContent

The content of a ROA identifies a single AS that has been authorized by the address space holder to originate routes and a list of one or more IP address prefixes that will be advertised. If the address space holder needs to authorize multiple ASes to advertise the same set of address prefixes, the holder issues multiple ROAs, one per AS number. A ROA is formally defined as:

```

RPKI-ROA-2023 { iso(1) member-body(2) us(840) rsadsi(113549)
  pkcs(1) pkcs9(9) smime(16) mod(0) id-mod-rpkiROA-2023(TBD) }

DEFINITIONS EXPLICIT TAGS ::=
BEGIN

IMPORTS
  CONTENT-TYPE
  FROM CryptographicMessageSyntax-2010 -- in [RFC6268]
  { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) smime(16) modules(0) id-mod-cms-2009(58) } ;

ct-routeOriginAttestation CONTENT-TYPE ::=
  { TYPE RouteOriginAttestation
    IDENTIFIED BY id-ct-routeOriginAuthz }

id-ct-routeOriginAuthz OBJECT IDENTIFIER ::=
  { iso(1) member-body(2) us(840) rsadsi(113549) pkcs(1)
    pkcs-9(9) id-smime(16) id-ct(1) routeOriginAuthz(24) }

RouteOriginAttestation ::= SEQUENCE {
  version [0]    INTEGER DEFAULT 0,
  asID           ASID,
  ipAddrBlocks  SEQUENCE (SIZE(1..2)) OF ROAIPAddressFamily }

ASID ::= INTEGER (0..4294967295)

ROAIPAddressFamily ::= SEQUENCE {
  addressFamily ADDRESS-FAMILY.&afi ({AddressFamilySet}),
  addresses      ADDRESS-FAMILY.&Addresses ({AddressFamilySet}@addressFa

ADDRESS-FAMILY ::= CLASS {
  &afi          OCTET STRING (SIZE(2)) UNIQUE,
  &Addresses
} WITH SYNTAX { AFI &afi ADDRESSES &Addresses }

AddressFamilySet ADDRESS-FAMILY ::=
  { addressFamilyIPv4 | addressFamilyIPv6 }

addressFamilyIPv4 ADDRESS-FAMILY ::=
  { AFI afi-IPv4 ADDRESSES ROAAddressesIPv4 }
addressFamilyIPv6 ADDRESS-FAMILY ::=
  { AFI afi-IPv6 ADDRESSES ROAAddressesIPv6 }

afi-IPv4 OCTET STRING ::= '0001'H
afi-IPv6 OCTET STRING ::= '0002'H

ROAAddressesIPv4 ::= SEQUENCE (SIZE(1..MAX)) OF ROAIPAddress{32}
ROAAddressesIPv6 ::= SEQUENCE (SIZE(1..MAX)) OF ROAIPAddress{128}

```

```
ROAIPAddress {INTEGER: len} ::= SEQUENCE {  
    address      BIT STRING (SIZE(0..len)),  
    maxLength    INTEGER (0..len) OPTIONAL }
```

END

4.1. Element version

The version number of the RouteOriginAttestation MUST be 0.

4.2. Element asID

The asID element contains the AS number that is authorized to originate routes to the given IP address prefixes.

4.3. Element ipAddrBlocks

The ipAddrBlocks element encodes the set of IP address prefixes to which the AS is authorized to originate routes. Note that the syntax here is more restrictive than that used in the IP Address Delegation extension defined in [[RFC3779](#)]. That extension can represent arbitrary address ranges, whereas ROAs need to represent only IP prefixes.

4.3.1. Type ROAIPAddressFamily

Within the ROAIPAddressFamily structure, the addressFamily element contains the Address Family Identifier (AFI) of an IP address family. This specification only supports IPv4 and IPv6, therefore addressFamily MUST be either 0001 or 0002. IPv4 prefixes MUST NOT appear as IPv4-Mapped IPv6 Addresses (section 2.5.5.2 of [[RFC4291](#)]).

There MUST be only one instance of ROAIPAddressFamily per unique AFI in the ROA. Thus, the ROAIPAddressFamily structure MUST NOT appear more than twice.

The addresses element represents IP prefixes as a sequence of type ROAIPAddress.

4.3.2. Type ROAIPAddress

A ROAIPAddress structure is a sequence containing an address element of type IPAddress and an optional maxLength element of type INTEGER. See section 2.2.3.8 of [[RFC3779](#)] for more details on type IPAddress.

4.3.2.1. Element address

The address element is of type IPAddress and represents a single IP address prefix.

4.3.2.2. Element maxLength

When present, the maxLength specifies the maximum length of the IP address prefix that the AS is authorized to advertise. The maxLength element SHOULD NOT be encoded if the maximum length is equal to the prefix length. Certification Authorities SHOULD anticipate that

future Relying Parties will become increasingly stringent in considering the presence of superfluous maxLength elements an encoding error.

If present, the maxLength MUST be:

- *an integer greater than or equal to the length of the accompanying prefix, and

- *less than or equal to the maximum length (in bits) of an IP address in the applicable address family: 32 in case of IPv4 and 128 in case of IPv6.

For example, if the IP address prefix is 203.0.113.0/24 and the maxLength is 26, the AS is authorized to advertise any more specific prefix with a maximum length of 26. In this example, the AS would be authorized to advertise 203.0.113.0/24, 203.0.113.128/25, or 203.0.113.192/26; but not 203.0.113.0/27. See [[RFC9319](#)] for more information on the use of maxLength.

When the maxLength is not present, the AS is only authorized to advertise the exact prefix specified in the ROAIPAddress' address element.

4.3.2.3. Note on overlapping or superfluous information encoding

Note that a valid ROA may contain an IP address prefix (within a ROAIPAddress element) that is encompassed by another IP address prefix (within a separate ROAIPAddress element). For example, a ROA may contain the prefix 203.0.113.0/24 with maxLength 26, as well as the prefix 203.0.113.0/28 with maxLength 28. This ROA would authorize the indicated AS to advertise any prefix beginning with 203.0.113 with a minimum length of 24 and a maximum length of 26, as well as the specific prefix 203.0.113.0/28.

Additionally, a ROA MAY contain two ROAIPAddress elements, where the IP address prefix is identical in both cases. However, this is NOT RECOMMENDED as, in such a case, the ROAIPAddress with the shorter maxLength grants no additional privileges to the indicated AS and thus can be omitted without changing the meaning of the ROA.

4.3.3. Canonical form for ipAddrBlocks

As the data structure described by the ROA ASN.1 module allows for many different ways to represent the same set of IP address information, a canonical form is defined such that every set of IP address information has a unique representation. In order to produce and verify this canonical form, the process described in this section SHOULD be used to ensure information elements are unique with respect to one another and sorted in ascending order.

Certification Authorities SHOULD anticipate that future Relying Parties will impose a strict requirement for the ipAddrBlocks field to be in this canonical form. This canonicalization procedure builds upon the canonicalization procedure specified in section 2.2.3.6 of [\[RFC3779\]](#).

In order to semantically compare, sort, and deduplicate the contents of the ipAddrBlocks field, each ROAIPAddress element is mapped to an abstract data element composed of four integer values:

afi The AFI value appearing in the addressFamily field of the containing ROAIPAddressFamily as an integer.

addr The first IP address of the IP prefix appearing in the ROAIPAddress address field, as a 32-bit (IPv4) or 128-bit (IPv6) integer value.

plen The prefix length of the IP prefix appearing in the ROAIPAddress address field as an integer value.

mLen The value appearing in the maxLength field of the ROAIPAddress, if present, otherwise the above prefix length value.

Thus, the equality or relative order of two ROAIPAddress elements can be tested by comparing their abstract representations.

4.3.3.1. Comparator

The set of ipAddrBlocks is totally ordered. The order of two ipAddrBlocks is determined by the first non-equal comparison in the following list.

1. Data elements with a lower afi value precede data elements with a higher afi value.
2. Data elements with a lower addr value precede data elements with a higher addr value.
3. Data elements with a lower plen value precede data elements with a higher plen value.
4. Data elements with a lower mlen value precede data elements with a higher mlen value.

Data elements for which all four values compare equal are duplicates of one another.

4.3.3.2. Example implementations

A sorting implementation [[roasort-c](#)] in ISO/IEC 9899:1999 ("ANSI C99").

A sorting implementation [[roasort-rs](#)] in Rust 2021 Edition.

5. ROA Validation

Before a relying party can use a ROA to validate a routing announcement, the relying party MUST first validate the ROA. To validate a ROA, the relying party MUST perform all the validation checks specified in [[RFC6488](#)] as well as the following additional ROA-specific validation steps:

- *The IP Address Delegation extension [[RFC3779](#)] is present in the end-entity (EE) certificate (contained within the ROA), and every IP address prefix in the ROA payload is contained within the set of IP addresses specified by the EE certificate's IP Address Delegation extension.

- *The EE certificate's IP Address Delegation extension MUST NOT contain "inherit" elements described in [[RFC3779](#)].

- *The Autonomous System Identifier Delegation Extension described in [[RFC3779](#)] is not used in Route Origin Authorizations and MUST NOT be present in the EE certificate.

- *The ROA content fully conforms with all requirements specified in [Section 3](#) and [Section 4](#).

If any of the above checks fail, the ROA in its entirety MUST be considered invalid and an error SHOULD be logged.

6. Security Considerations

There is no assumption of confidentiality for the data in a ROA; it is anticipated that ROAs will be stored in repositories that are accessible to all ISPs, and perhaps to all Internet users. There is no explicit authentication associated with a ROA, since the PKI used for ROA validation provides authorization but not authentication. Although the ROA is a signed, application-layer object, there is no intent to convey non-repudiation via a ROA.

The purpose of a ROA is to convey authorization for an AS to originate a route to the prefix(es) in the ROA. Thus, the integrity of a ROA MUST be established. The ROA specification makes use of the RPKI signed object format; thus, all security considerations in [[RFC6488](#)] also apply to ROAs. Additionally, the signed object profile uses the CMS signed message format for integrity; thus, ROAs

inherit all security considerations associated with that data structure.

The right of the ROA signer to authorize the target AS to originate routes to the prefix(es) is established through use of the address space and AS number PKI described in [[RFC6480](#)]. Specifically, one MUST verify the signature on the ROA using an X.509 certificate issued under this PKI, and check that the prefix(es) in the ROA are contained within those in the certificate's IP Address Delegation Extension.

7. IANA Considerations

7.1. SMI Security for S/MIME CMS Content Type (1.2.840.113549.1.9.16.1)

The IANA is requested to update the id-ct-routeOriginAuthz entry in the "SMI Security for S/MIME CMS Content Type (1.2.840.113549.1.9.16.1)" registry as follows:

Decimal	Description	References
24	id-ct-routeOriginAuthz	[RFC-to-be]

Upon publication of this document, IANA is requested to reference the RFC publication instead of this draft.

7.2. RPKI Signed Objects sub-registry

The IANA is requested to update the entry for the Route Origination Authorization in the "RPKI Signed Objects" registry created by [[RFC6488](#)] as follows:

Name	OID	Specificati
Route Origination Authorization	1.2.840.113549.1.9.16.1.24	[RFC-to-be]

7.3. File Extension

The IANA is requested to update the entry for the ROA file extension in the "RPKI Repository Name Schemes" registry created by [[RFC6481](#)] as follows:

Filename Extension	RPKI Object	Reference
.roa	Route Origination Authorization	[RFC-to-be]

Upon publication of this document, IANA is requested to make this addition permanent and to reference the RFC publication instead of this draft.

7.4. SMI Security for S/MIME Module Identifier (1.2.840.113549.1.9.16.0)

The IANA is requested to allocate for this document in the "SMI Security for S/MIME Module Identifier (1.2.840.113549.1.9.16.0)" registry:

Decimal	Description	Reference
TBD	id-mod-rpkiROA-2023	[RFC-to-be]

7.5. Media Type

The IANA is requested to update the media type application/rpki-roa in the "Media Type" registry as follows:

Type name: application
Subtype name: rpki-roa
Required parameters: N/A
Optional parameters: N/A
Encoding considerations: binary
Security considerations: Carries an RPKI ROA [RFC-to-be].
 This media type contains no active content. See
 Section 6 of [RFC-to-be] for further information.
Interoperability considerations: None
Published specification: [RFC-to-be]
Applications that use this media type: RPKI operators
Additional information:
 Content: This media type is a signed object, as defined
 in [RFC6488], which contains a payload of a list of
 prefixes and an AS identifier as defined in [RFC-to-be].
 Magic number(s): None
 File extension(s): .roa
 Macintosh file type code(s):
Person & email address to contact for further information:
 Job Snijders <job@fastly.com>
Intended usage: COMMON
Restrictions on usage: None
Change controller: IETF

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Appendix A. Acknowledgements

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Appendix B. Example ROA eContent Payload

Below an example of a DER encoded ROA eContent is provided with annotation following the '#' character.

```

$ echo 302402023CCA301E301C04020002301630090307002001067C208C30090307002
| xxd -r -ps \
| openssl asn1parse -i -dump -inform DER
  0:d=0  hl=2 l= 36 cons: SEQUENCE                # RouteOriginAtt
  2:d=1  hl=2 l=  2 prim: INTEGER                  :3CCA # asID 15562
  6:d=1  hl=2 l= 30 cons: SEQUENCE                # ipAddrBlocks
  8:d=2  hl=2 l= 28 cons: SEQUENCE                # ROAIPAddressF
10:d=3  hl=2 l=  2 prim: OCTET STRING            # addressFamIl
    0000 - 00 02 .. # IPv6
14:d=3  hl=2 l= 22 cons: SEQUENCE                # addresses
16:d=4  hl=2 l=  9 cons: SEQUENCE                # ROAIPAdres
18:d=5  hl=2 l=  7 prim: BIT STRING              # address
    0000 - 00 20 01 06 7c 20 8c . . . | . # 2001:67c:
27:d=4  hl=2 l=  9 cons: SEQUENCE                # ROAIPAdres
29:d=5  hl=2 l=  7 prim: BIT STRING              # address
    0000 - 00 2a 0e b2 40 . * . . @ # 2a0e:b240
    0007 - <SPACES/NULS>

```

Below is a complete [Base64](#) [[RFC4648](#)] encoded RPKI ROA Signed Object.

Object
SHA256 hash: 13afbad09ed59b315efd8722d38b09fd02962e376e4def32
Size: 1807 octets

CMS signing time: Fri 17 Jun 2022 00:24:22 +0000

X.509 end-entity certificate

Subject key id: A3D964245749BB6DD5AB1F2E830E33A6C5146E8F
Authority key id: 38E14F92FDC7CCFBFC182361523AE27D697E952F
Issuer: /CN=38e14f92fdc7ccfbfc182361523ae27d697e952f
Serial: 86F9
Not before: Fri 17 Jun 2022 00:24:22 +0000
Not after: Sat 01 Jul 2023 00:00:00 +0000
IP address delegation: 2001:67c:208c::/48, 2a0e:b240::/48

eContent

asID: 15562
addresses: 2001:67c:208c::/48, 2a0e:b240::/48

Authors' Addresses

Job Snijders
Fastly
Amsterdam
Netherlands

Email: job@fastly.com

Ben Maddison
Workonline
Cape Town
South Africa

Email: benm@workonline.africa

Matthew Lepinski
Carleton College

Email: mlepinski@carleton.edu

Derrick Kong
Raytheon

Email: derrick.kong@raytheon.com

Stephen Kent
Independent

Email: kent@alum.mit.edu