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BGPsec Protocol Specification
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Abstract

This document describes BGPsec, an extension to the Border Gateway Protocol (BGP) that provides security for the path of autonomous systems through which a BGP update message passes. BGPsec is implemented via a new optional non-transitive BGP path attribute that carries a digital signature produced by each autonomous system that propagates the update message.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" are to be interpreted as described in RFC 2119 [1] only when they appear in all upper case. They may also appear in lower or mixed case as English words, without normative meaning.

Status of this Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on May 6, 2016.

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1. Introduction

This document describes BGPsec, a mechanism for providing path security for Border Gateway Protocol (BGP) [2] route advertisements. That is, a BGP speaker who receives a valid BGPsec update has cryptographic assurance that the advertised route has the following property: Every AS on the path of ASes listed in the update message has explicitly authorized the advertisement of the route to the subsequent AS in the path.

This document specifies a new optional (non-transitive) BGP path attribute, BGPsec_Path. It also describes how a BGPsec-compliant BGP speaker (referred to hereafter as a BGPsec speaker) can generate, propagate, and validate BGP update messages containing this attribute to obtain the above assurances.

BGPsec is intended to be used to supplement BGP Origin Validation [19] and when used in conjunction with origin validation, it is possible to prevent a wide variety of route hijacking attacks against BGP.

BGPsec relies on the Resource Public Key Infrastructure (RPKI) certificates that attest to the allocation of AS number and IP address resources. (For more information on the RPKI, see [12] and the documents referenced therein.) Any BGPsec speaker who wishes to send, to external (eBGP) peers, BGP update messages containing the BGPsec_Path needs to possess a private key associated with an RPKI router certificate [9] that corresponds to the BGPsec speaker's AS number. Note, however, that a BGPsec speaker does not need such a certificate in order to validate received update messages containing the BGPsec_Path attribute.

2. BGPsec Negotiation

This document defines a new BGP capability [6] that allows a BGP speaker to advertise to a neighbor the ability to send or to receive BGPsec update messages (i.e., update messages containing the BGPsec_Path attribute).

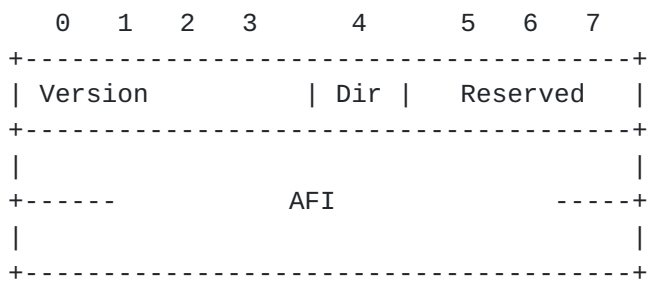
2.1. The BGPsec Capability

This capability has capability code : TBD

The capability length for this capability MUST be set to 3.

The three octets of the capability value are specified as follows.

BGPsec Send Capability Value:



The first four bits of the first octet indicate the version of BGPsec for which the BGP speaker is advertising support. This document defines only BGPsec version 0 (all four bits set to zero). Other versions of BGPsec may be defined in future documents. A BGPsec speaker MAY advertise support for multiple versions of BGPsec by including multiple versions of the BGPsec capability in its BGP OPEN message.

The fifth bit of the first octet is a direction bit which indicates whether the BGP speaker is advertising the capability to send BGPsec update messages or receive BGPsec update messages. The BGP speaker sets this bit to 0 to indicate the capability to receive BGPsec update messages. The BGP speaker sets this bit to 1 to indicate the capability to send BGPsec update messages.

The remaining three bits of the first octet are reserved for future use. These bits are set to zero by the sender of the capability and ignored by the receiver of the capability.

The second and third octets contain the 16-bit Address Family Identifier (AFI) which indicates the address family for which the BGPsec speaker is advertising support for BGPsec. This document only specifies BGPsec for use with two address families, IPv4 and IPv6, AFI values 1 and 2 respectively. BGPsec for use with other address families may be specified in future documents.

2.2. Negotiating BGPsec Support

In order to indicate that a BGP speaker is willing to send BGPsec update messages (for a particular address family), a BGP speaker sends the BGPsec Capability (see Section 2.1) with the Direction bit (the fifth bit of the first octet) set to 1. In order to indicate that the speaker is willing to receive BGP update messages containing the BGPsec_Path attribute (for a particular address family), a BGP speaker sends the BGPsec capability with the Direction bit set to 0. In order to advertise the capability to both send and receive BGPsec update messages, the BGP speaker sends two copies of the BGPsec capability (one with the direction bit set to 0 and one with the direction bit set to 1).

Similarly, if a BGP speaker wishes to use BGPsec with two different address families (i.e., IPv4 and IPv6) over the same BGP session, then the speaker includes two instances of this capability (one for each address family) in the BGP OPEN message. A BGP speaker MUST support the BGP multiprotocol extension [3]. Additionally, a BGP speaker MUST NOT advertise the capability of BGPsec support for a particular AFI unless it has also advertised the multiprotocol extension capability for the same AFI combination [3].

In a session where BGP session, a peer is permitted to send update messages containing the BGPsec_Path attribute if, and only if:

- The given peer sent the BGPsec capability for a particular version of BGPsec and a particular address family with the Direction bit set to 1; and

- The other peer sent the BGPsec capability for the same version of BGPsec and the same address family with the Direction bit set to 0.

In such a session, we say that the use of (the particular version of) BGPsec has been negotiated (for a particular address family). BGP update messages without the BGPsec_Path attribute MAY be sent within a session regardless of whether or not the use of BGPsec is successfully negotiated. However, if BGPsec is not successfully negotiated, then BGP update messages containing the BGPsec_Path attribute MUST NOT be sent.

This document defines the behavior of implementations in the case where BGPsec version zero is the only version that has been successfully negotiated. Any future document which specifies additional versions of BGPsec will need to specify behavior in the case that support for multiple versions is negotiated.

BGPsec cannot provide meaningful security guarantees without support for four-byte AS numbers. Therefore, any BGP speaker that announces the BGPsec capability, MUST also announce the capability for four-byte AS support [4]. If a BGP speaker sends the BGPsec capability but not the four-byte AS support capability then BGPsec has not been successfully negotiated, and update messages containing the BGPsec_Path attribute MUST NOT be sent within such a session.

Note that BGPsec update messages can be quite large, therefore any BGPsec speaker announcing the capability to receive BGPsec messages SHOULD also announce support for the capability to receive BGP extended messages [8].

3. The BGPsec_Path Attribute

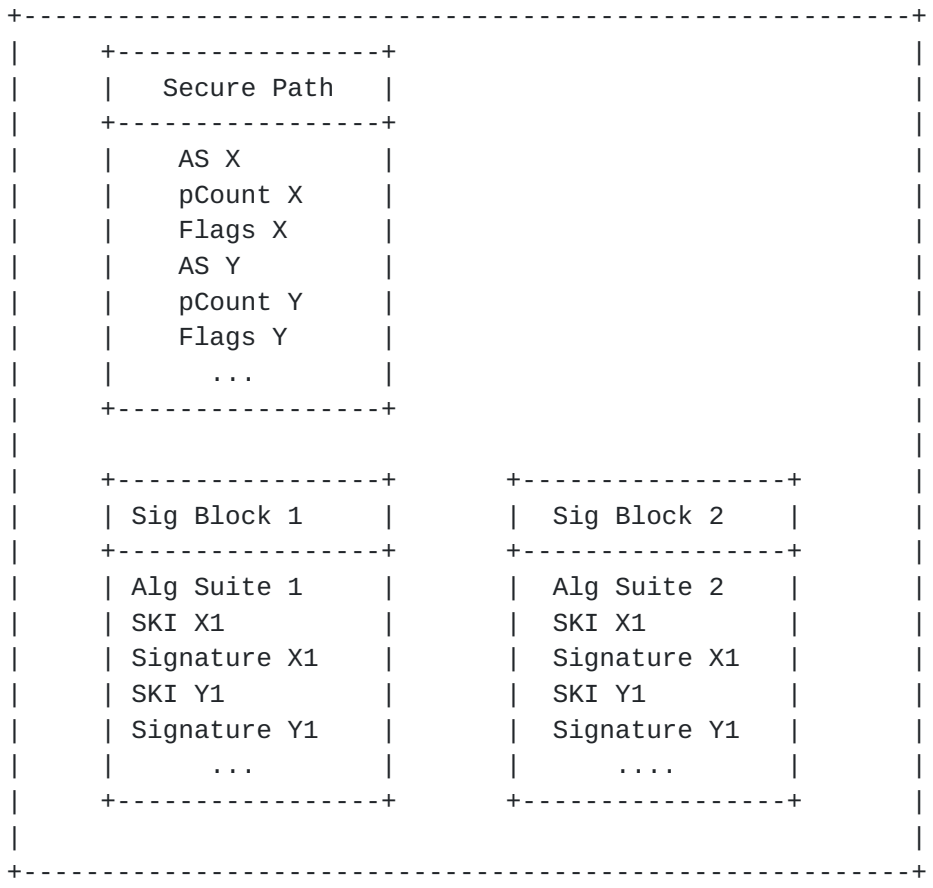
The BGPsec_Path attribute is a new optional non-transitive BGP path attribute.

This document registers a new attribute type code for this attribute : TBD

The BGPsec_Path attribute carries the secured information regarding the path of ASes through which an update message passes. This includes the digital signatures used to protect the path information. We refer to those update messages that contain the BGPsec_Path attribute as "BGPsec Update messages". The BGPsec_Path attribute replaces the AS_PATH attribute in a BGPsec update message. That is, update messages that contain the BGPsec_Path attribute MUST NOT contain the AS_PATH attribute, and vice versa.

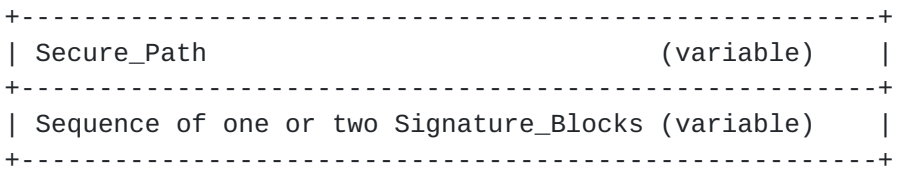
The BGPsec_Path attribute is made up of several parts. The following high-level diagram provides an overview of the structure of the BGPsec_Path attribute:

High-Level Diagram of the BGPsec_Path Attribute



The following is the specification of the format for the BGPsec_Path attribute.

BGPsec_Path Attribute



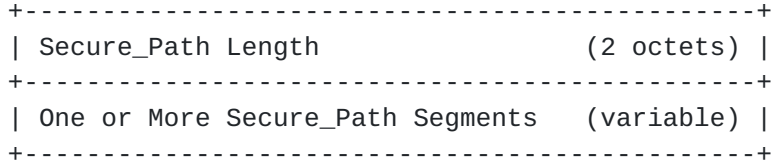
The Secure_Path contains AS path information for the BGPsec update message. This is logically equivalent to the information that is contained in a non-BGPsec AS_PATH attribute. The information in Secure_Path is used by BGPsec speakers in the same way that information from the AS_PATH is used by non-BGPsec speakers. The format of the Secure_Path is described below in Section 3.1.

The BGPsec_Path attribute will contain one or two Signature_Blocks, each of which corresponds to a different algorithm suite. Each of the Signature_Blocks will contain a signature segment for each AS number (i.e., Secure_Path segment) in the Secure_Path. In the most common case, the BGPsec_Path attribute will contain only a single Signature_Block. However, in order to enable a transition from an old algorithm suite to a new algorithm suite (without a flag day), it will be necessary to include two Signature_Blocks (one for the old algorithm suite and one for the new algorithm suite) during the transition period. (See Section 6.1 for more discussion of algorithm transitions.) The format of the Signature_Blocks is described below in Section 3.2.

3.1. Secure_Path

Here we provide a detailed description of the Secure_Path information in the BGPsec_Path attribute.

Secure_Path

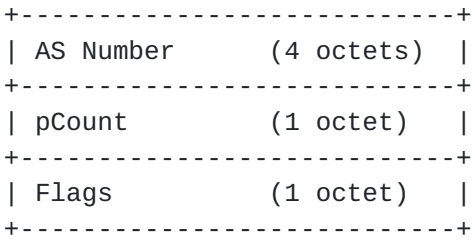


The Secure_Path Length contains the length (in octets) of the entire Secure_Path (including the two octets used to express this length

field). As explained below, each Secure_Path segment is six octets long. Note that this means the Secure_Path Length is two greater than six times the number Secure_Path Segments (i.e., the number of AS numbers in the path).

The Secure_Path contains one Secure_Path Segment for each (distinct) Autonomous System in the path to the originating AS of the NLRI specified in the update message.

Secure_Path Segment



The AS Number is the AS number of the BGP speaker that added this Secure_Path segment to the BGPsec_Path attribute. (See Section 4 for more information on populating this field.)

The pCount field contains the number of repetitions of the associated autonomous system number that the signature covers. This field enables a BGPsec speaker to mimic the semantics of prepending multiple copies of their AS to the AS_PATH without requiring the speaker to generate multiple signatures. The pCount field is also useful in managing route servers (see Section 4.2) and AS Number migrations, see [18] for details.

The first bit of the Flags field is the Confed_Segment flag. The Confed_Segment flag is set to one to indicate that the BGPsec speaker that constructed this Secure_Path segment is sending the update message to a peer AS within the same Autonomous System confederation [5]. (That is, the Confed_Segment flag is set in a BGPsec update message whenever, in a non-BGPsec update message, the BGP speaker's AS would appear in a AS_PATH segment of type AS_CONFED_SEQUENCE.) In all other cases the Confed_Segment flag is set to zero.

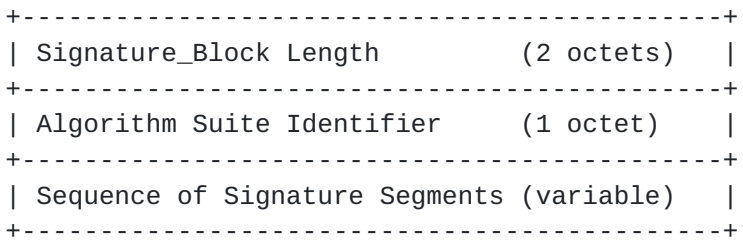
The remaining seven bits of the Flags MUST be set to zero by the sender, and ignored by the receiver. Note, however, that the signature is computed over all eight bits of the flags field.

3.2. Signature_Block

Here we provide a detailed description of the Signature_Blocks in the

BGPsec_Path attribute.

Signature_Block

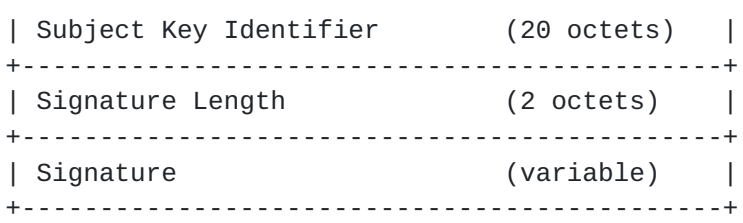


The Signature_Block Length is the total number of octets in the Signature_Block (including the two octets used to express this length field).

The Algorithm Suite Identifier is a one-octet identifier specifying the digest algorithm and digital signature algorithm used to produce the digital signature in each Signature Segment. An IANA registry of algorithm identifiers for use in BGPsec is specified in the BGPsec algorithms document [10].

A Signature_Block has exactly one Signature Segment for each Secure_Path Segment in the Secure_Path portion of the BGPsec_Path Attribute. (That is, one Signature Segment for each distinct AS on the path for the NLRI in the Update message.)

Signature Segments



The Subject Key Identifier contains the value in the Subject Key Identifier extension of the RPKI router certificate [9] that is used to verify the signature (see Section 5 for details on validity of BGPsec update messages).

The Signature Length field contains the size (in octets) of the value in the Signature field of the Signature Segment.

The Signature contains a digital signature that protects the NLRI and the BGPsec_Path attribute (see Sections 4 and 5 for details on

signature generation and validation, respectively).

4. BGPsec Update Messages

Section 4.1 provides general guidance on the creation of BGPsec Update Messages -- that is, update messages containing the BGPsec_Path attribute.

Section 4.2 specifies how a BGPsec speaker generates the BGPsec_Path attribute to include in a BGPsec Update message.

Section 4.3 contains special processing instructions for members of an autonomous system confederation [5]. A BGPsec speaker that is not a member of such a confederation MUST set the Flags field of the Secure_Path Segment to zero in all BGPsec update messages it sends.

Section 4.4 contains instructions for reconstructing the AS_Path attribute in cases where a BGPsec speaker receives an update message with a BGPsec_Path attribute and wishes to propagate the update message to a peer who does not support BGPsec.

4.1. General Guidance

The information protected by the signature on a BGPsec update message includes the AS number of the peer to whom the update message is being sent. Therefore, if a BGPsec speaker wishes to send a BGPsec update to multiple BGP peers, it MUST generate a separate BGPsec update message for each unique peer AS to whom the update message is sent.

A BGPsec update message MUST advertise a route to only a single NLRI. This is because a BGPsec speaker receiving an update message with multiple NLRI would be unable to construct a valid BGPsec update message (i.e., valid path signatures) containing a subset of the NLRI in the received update. If a BGPsec speaker wishes to advertise routes to multiple NLRI, then it MUST generate a separate BGPsec update message for each NLRI. Additionally, a BGPsec update message MUST use the MP_REACH_NLRI [3] attribute to encode the NLRI.

The BGPsec_Path attribute and the AS_Path attribute are mutually exclusive. That is, any update message containing the BGPsec_Path attribute MUST NOT contain the AS_Path attribute. The information that would be contained in the AS_Path attribute is instead conveyed in the Secure_Path portion of the BGPsec_Path attribute.

In order to create or add a new signature to a BGPsec update message with a given algorithm suite, the BGPsec speaker must possess a private key suitable for generating signatures for this algorithm

suite. Additionally, this private key must correspond to the public key in a valid Resource PKI end-entity certificate whose AS number resource extension includes the BGPsec speaker's AS number [9]. Note also that new signatures are only added to a BGPsec update message when a BGPsec speaker is generating an update message to send to an external peer (i.e., when the AS number of the peer is not equal to the BGPsec speaker's own AS number). Therefore, a BGPsec speaker who only sends BGPsec update messages to peers within its own AS, it does not need to possess any private signature keys.

The Resource PKI enables the legitimate holder of IP address prefix(es) to issue a signed object, called a Route Origination Authorization (ROA), that authorizes a given AS to originate routes to a given set of prefixes (see [7]). It is expected that most relying parties will utilize BGPsec in tandem with origin validation (see [19] and [20]). Therefore, it is RECOMMENDED that a BGPsec speaker only originate a BGPsec update advertising a route for a given prefix if there exists a valid ROA authorizing the BGPsec speaker's AS to originate routes to this prefix.

If a BGPsec router has received only a non-BGPsec update message (without the BGPsec_Path attribute), containing the AS_Path attribute, from a peer for a given prefix then it MUST NOT attach a BGPsec_Path attribute when it propagates the update message. (Note that a BGPsec router may also receive a non-BGPsec update message from an internal peer without the AS_Path attribute, i.e., with just the NLRI in it. In that case, the prefix is originating from that AS and hence the BGPsec speaker SHOULD sign and forward the update to its external BGPsec-speaking peers.)

Conversely, if a BGPsec router has received a BGPsec update message (with the BGPsec_Path attribute) from a peer for a given prefix and it chooses to propagate that peer's route for the prefix, then it SHOULD propagate the route as a BGPsec update message containing the BGPsec_Path attribute.

Note that removing BGPsec signatures (i.e., propagating a route advertisement without the BGPsec_Path attribute) has significant security ramifications. (See Section 7 for discussion of the security ramifications of removing BGPsec signatures.) Therefore, when a route advertisement is received via a BGPsec update message, propagating the route advertisement without the BGPsec_Path attribute is NOT RECOMMENDED, unless the message is sent to a peer that did not advertise the capability to receive BGPsec update messages (see Section 4.4).

Furthermore, note that when a BGPsec speaker propagates a route advertisement with the BGPsec_Path attribute it is not attesting to

the validation state of the update message it received. (See Section 7 for more discussion of the security semantics of BGPsec signatures.)

If the BGPsec speaker is producing an update message which would, in the absence of BGPsec, contain an AS_SET (e.g., the BGPsec speaker is performing proxy aggregation), then the BGPsec speaker MUST NOT include the BGPsec_Path attribute. In such a case, the BGPsec speaker must remove any existing BGPsec_Path in the received advertisement(s) for this prefix and produce a traditional (non-BGPsec) update message. It should be noted that BCP 172 [13] recommends against the use of AS_SET and AS_CONFED_SET in the AS_PATH of BGP updates.

The case where the BGPsec speaker sends a BGPsec update message to an internal (iBGP) peer is quite simple. When originating a new route advertisement and sending it to an internal peer, the BGPsec speaker omits the BGPsec_Path attribute. When propagating a received route advertisement to an internal peer, the BGPsec speaker typically populates the BGPsec_Path attribute by copying the BGPsec_Path attribute from the received update message. That is, the BGPsec_Path attribute is copied verbatim. However, in the case that the BGPsec speaker is performing an AS Migration, the BGPsec speaker may add an additional signature on ingress before copying the BGPsec_Path attribute (see [18] for more details). Note that when a BGPsec speaker chooses to forward a BGPsec update message to an iBGP peer, the BGPsec attribute SHOULD NOT be removed, unless the peer doesn't support BGPsec. In particular, the BGPsec attribute SHOULD NOT be removed even in the case where the BGPsec update message has not been that has not successfully validated. (See Section 5 for more information on validation, and Section 7 for the security ramifications of removing BGPsec signatures.)

4.2. Constructing the BGPsec_Path Attribute

When a BGPsec speaker receives a BGPsec update message containing a BGPsec_Path attribute (with one or more signatures) from an (internal or external) peer, it may choose to propagate the route advertisement by sending to its (internal or external) peers by creating a new BGPsec advertisement for the same prefix. Similarly, when sending a new route advertisement to an external, BGPsec-speaking peer, the BGPsec speaker may send a BGPsec Update message by generating a new BGPsec_Path attribute.

To generate the BGPsec_Path attribute on the outgoing update message, the BGPsec speaker first generates a new Secure_Path Segment. Note that if the BGPsec speaker is not the origin AS and there is an

existing BGPsec_Path attribute, then the BGPsec speaker prepends its new Secure_Path Segment (places in first position) onto the existing Secure_Path.

The AS number in this Secure_Path segment MUST match the AS number in the AS number resource extension field of the Resource PKI router certificate(s) that will be used to verify the digital signature(s) constructed by this BGPsec speaker [9].

The pCount field of the Secure_Path Segment is typically set to the value 1. However, a BGPsec speaker may set the pCount field to a value greater than 1. Setting the pCount field to a value greater than one has the same semantics as repeating an AS number multiple times in the AS_PATH of a non-BGPsec update message (e.g., for traffic engineering purposes). Setting the pCount field to a value greater than one permits this repetition without requiring a separate digital signature for each repetition.

A route server that participates in the BGP control path, but does not act as a transit AS in the data plane, may choose to set pCount to 0. This option enables the route server to participate in BGPsec and obtain the associated security guarantees without increasing the effective length of the AS path. (Note that BGPsec speakers compute the effective length of the AS path by summing the pCount values in the BGPsec_Path attribute, see Section 5.) However, when a route server sets the pCount value to 0, it still inserts its AS number into the Secure_Path segment, as this information is needed to validate the signature added by the route server. (See [18] for a discussion of setting pCount to 0 to facilitate AS Number Migration.) BGPsec speakers SHOULD drop incoming update messages with pCount set to zero in cases where the BGPsec speaker does not expect its peer to set pCount to zero. (That is, pCount is only to be set to zero in cases such as route servers or AS Number Migration where the BGPsec speaker's peer expects pCount to be set to zero.)

Next, the BGPsec speaker generates one or two Signature_Blocks. Typically, a BGPsec speaker will use only a single algorithm suite, and thus create only a single Signature_Block in the BGPsec_Path attribute. However, to ensure backwards compatibility during a period of transition from a 'current' algorithm suite to a 'new' algorithm suite, it will be necessary to originate update messages that contain a Signature_Block for both the 'current' and the 'new' algorithm suites (see Section 6.1).

If the received BGPsec update message contains two Signature_ Blocks and the BGPsec speaker supports both of the corresponding algorithms suites, then the new update message generated by the BGPsec speaker SHOULD include both of the Signature_Blocks. If the received BGPsec

update message contains two Signature_Blocks and the BGPsec speaker only supports one of the two corresponding algorithm suites, then the BGPsec speaker MUST remove the Signature_Block corresponding to the algorithm suite that it does not understand. If the BGPsec speaker does not support the algorithm suites in any of the Signature_Blocks contained in the received update message, then the BGPsec speaker MUST NOT propagate the route advertisement with the BGPsec_Path attribute. (That is, if it chooses to propagate this route advertisement at all, it must do so as an unsigned BGP update message).

Note that in the case where the BGPsec_Path has two Signature_Blocks (corresponding to different algorithm suites), the validation algorithm (see Section 5.2) deems a BGPsec update message to be 'Valid' if there is at least one supported algorithm suite (and corresponding Signature_Block) that is deemed 'Valid'. This means that a 'Valid' BGPsec update message may contain a Signature_Block which is not deemed 'Valid' (e.g., contains signatures that the BGPsec does not successfully verify). Nonetheless, such Signature_Blocks MUST NOT be removed. (See Section 7 for a discussion of the security ramifications of this design choice.)

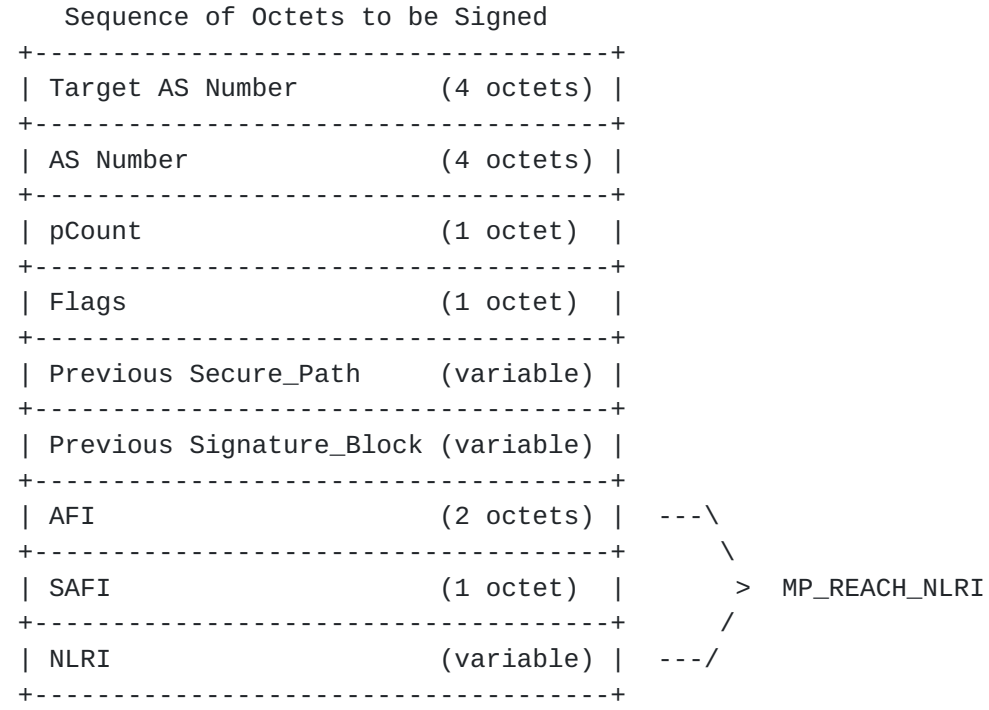
For each Signature_Block corresponding to an algorithm suite that the BGPsec speaker does support, the BGPsec speaker adds a new Signature Segment to the Signature_Block. This Signature Segment is prepended to the list of Signature Segments (placed in the first position) so that the list of Signature Segments appear in the same order as the corresponding Secure_Path segments. The BGPsec speaker populates the fields of this new signature segment as follows.

The Subject Key Identifier field in the new segment is populated with the identifier contained in the Subject Key Identifier extension of the RPKI router certificate corresponding to the BGPsec speaker [9]. This Subject Key Identifier will be used by recipients of the route advertisement to identify the proper certificate to use in verifying the signature.

The Signature field in the new segment contains a digital signature that binds the NLRI and BGPsec_Path attribute to the RPKI router certificate corresponding to the BGPsec speaker. The digital signature is computed as follows:

- Construct a sequence of octets by concatenating the Target AS Number, and the newly-created Secure_Path Segment (Origin AS, pCount, and Flags). Note that the Target AS Number is the AS Number of the BGPsec peer to whom the newly-created Update message is being sent. Then (if the BGPsec speaker is not the origin AS) append to this sequence previous Secure_Path and the previous

Signature_Block that were present on the received Update message. Finally, append the Address Family Identifier (AFI), Subsequent Address Family Identifier (SAFI), and Network Layer Reachability Information (NLRI) fields from the MP_REACH_NLRI attribute. Additionally, in the Prefix field of the NLRI (from MP_REACH_NLRI), all of the trailing bits MUST be set to zero when constructing this sequence. In this sequence, the Target AS Number is the AS to whom the BGPsec speaker intends to send the update message. (Note that the Target AS number is the AS number announced by the peer in the OPEN message of the BGP session within which the update is sent.)



- Apply to this octet sequence the digest algorithm (for the algorithm suite of this Signature_Block) to obtain a digest value.

- Apply to this digest value the signature algorithm, (for the algorithm suite of this Signature_Block) to obtain the digital signature. Then populate the Signature Field with this digital signature.

The Signature Length field is populated with the length (in octets) of the Signature field.

4.3. Processing Instructions for Confederation Members

Members of autonomous system confederations [5] MUST additionally follow the instructions in this section for processing BGPsec update

messages.

When a confederation member sends a BGPsec update message to a peer that is a member of the same confederation, the confederation member puts its (private) Member-AS Number (as opposed to the public AS Confederation Identifier) in the AS Number field of the Secure_Path Segment that it adds to the BGPsec update message. Furthermore, when a confederation member sends a BGPsec update message to a peer that is a member of the same confederation, the BGPsec speaker that generates the Secure_Path Segment sets the Confed_Segment flag to one. This means that in a BGPsec update message, an AS number appears in a Secure_Path Segment with the Confed_Segment flag set whenever, in a non-BGPsec update message, the AS number would appear in a segment of type AS_CONFED_SEQUENCE in a non-BGPsec update message.

Within a confederation, the verification of BGPsec signatures added by other members of the confederation is optional. If a confederation chooses not to have its members verify signatures added by other confederation members, then when sending a BGPsec update message to a peer that is a member of the same confederation, the confederation members MAY set the Signature field within the Signature Segment that it generates to be zero (in lieu of calculating the correct digital signature as described in Sections 4.1 and 4.2). Note that if a confederation chooses not to verify digital signatures within the confederation, then BGPsec is able to provide no assurances about the integrity of the (private) Member-AS Numbers placed in Secure_Path segments where the Confed_Segment flag is set to one.

When a confederation member receives a BGPsec update message from a peer within the confederation and propagates it to a peer outside the confederation, it needs to remove all of the Secure_Path Segments added by confederation members as well as the corresponding Signature Segments. To do this, the confederation member propagating the route outside the confederation does the following:

- First, starting with the most recently added Secure_Path segment, remove all of the consecutive Secure_Path segments that have the Confed_Segment flag set to one. Stop this process once a Secure_Path segment is reached which has its Confed_Segment flag set to zero. Keep a count of the number of segments removed in this fashion.

- Second, starting with the most recently added Signature Segment, remove a number of Signature Segments equal to the number of Secure_Path Segments removed in the previous step. (That is,

remove the K most recently added signature segments, where K is the number of Secure_Path Segments removed in the previous step.)

- Finally, add a Secure_Path Segment containing, in the AS field, the AS Confederation Identifier (the public AS number of the confederation) as well as a corresponding Signature Segment. Note that all fields other that the AS field are populated as per Sections 4.1 and 4.2.

When validating a received BGPsec update message, confederation members need to make the following adjustment to the algorithm presented in Section 5.2. When a confederation member processes (validates) a Signature Segment and its corresponding Secure_Path Segment, the confederation member must note the following. For a signature produced by a peer BGPsec speaker outside of a confederation, the Target AS will always be the AS Confederation Identifier (the public AS number of the confederation) as opposed to the Member-AS Number.

To handle this case, when a BGPsec speaker (that is a confederation member) processes a current Secure_Path Segment that has the Confed_Segment flag set to zero, if the next most recently added Secure_Path segment has the Confed_Segment flag set to one then, when computing the digest for the current Secure_Path segment, the BGPsec speaker takes the Target AS Number to be the AS Confederation Identifier of the validating BGPsec speaker's own confederation. (Note that the algorithm in Section 5.2 processes Secure_Path Segments in order from most recently added to least recently added, therefore this special case will apply to the first Secure_Path segment that the algorithm encounters that has the Confed_Segment flag set to zero.)

Finally, as discussed above, an AS confederation may optionally decide that its members will not verify digital signatures added by members. In such a federation, when a confederation member runs the algorithm in Section 5.2, the confederation member, during processing of a Signature Segment, first checks whether the Confed_Sequence flag in the corresponding Secure_Path segment is set to one. If the Confed_Sequence flag is set to one in the corresponding Secure_Path segment, the confederation member does not perform any further checks on the Signature Segment and immediately moves on to the next Signature Segment (and checks its corresponding Secure_Path segment). Note that as specified in Section 5.2, it is an error when a BGPsec speaker receives from a peer, who is not in the same AS confederation, a BGPsec update containing a Confed_Sequence flag set to one. (As discussed in Section 5.2, any error in the BGPsec_Path attribute MUST be handled using the "treat-as-withdraw", approach as defined in RFC WXYZ [11].)

4.4. Reconstructing the AS_PATH Attribute

BGPsec update messages do not contain the AS_PATH attribute. However, the AS_PATH attribute can be reconstructed from the BGPsec_Path attribute. This is necessary in the case where a route advertisement is received via a BGPsec update message and then propagated to a peer via a non-BGPsec update message (e.g., because the latter peer does not support BGPsec). Note that there may be additional cases where an implementation finds it useful to perform this reconstruction.

The AS_PATH attribute can be constructed from the BGPsec_Path attribute as follows. Starting with an empty AS_PATH attribute, process the Secure_Path segments in order from least-recently added (corresponding to the origin) to most-recently added. For each Secure_Path segment perform the following steps:

1. If the Confed_Segment flag in the Secure_Path segment is set to one, then look at the most-recently added segment in the AS_PATH.

   * In the case where the AS_PATH is empty or in the case where the most-recently added segment is of type AS_SEQUENCE then add (prepend to the AS_PATH) a new AS_PATH segment of type AS_CONFED_SEQUENCE. This segment of type AS_CONFED_SEQUENCE shall contain a number of elements equal to the pCount field in the current Secure_Path segment. Each of these elements shall be the AS number contained in the current Secure_Path segment. (That is, if the pCount field is X, then the segment of type AS_CONFED_SEQUENCE contains X copies of the Secure_Path segment's AS Number field.)

   * In the case where the most-recently added segment in the AS_PATH is of type AS_CONFED_SEQUENCE then add (prepend to the segment) a number of elements equal to the pCount field in the current Secure_Path segment. The value of each of these elements shall be the AS number contained in the current Secure_Path segment. (That is, if the pCount field is X, then add X copies of the Secure_Path segment's AS Number field to the existing AS_CONFED_SEQUENCE.)

2. If the Confed_Segment flag in the Secure_Path segment is set to zero, then look at the most-recently added segment in the AS_PATH.

   * In the case where the AS_PATH is empty, and the pCount field in the Secure_Path segment is greater than zero, add (prepend to the AS_PATH) a new AS_PATH segment of type AS_SEQUENCE. This segment of type AS_SEQUENCE shall contain a number of elements equal to the pCount field in the current Secure_Path

segment. Each of these elements shall be the AS number contained in the current Secure_Path segment. (That is, if the pCount field is X, then the segment of type AS_SEQUENCE contains X copies of the Secure_Path segment's AS Number field.)

* In the case where the most recently added segment in the AS_PATH is of type AS_SEQUENCE then add (prepend to the segment) a number of elements equal to the pCount field in the current Secure_Path segment. The value of each of these elements shall be the AS number contained in the current Secure_Path segment. (That is, if the pCount field is X, then add X copies of the Secure_Path segment's AS Number field to the existing AS_SEQUENCE.)

5. Processing a Received BGPsec Update

Upon receiving a BGPsec update message from an external (eBGP) peer, a BGPsec speaker SHOULD validate the message to determine the authenticity of the path information contained in the BGPsec_Path attribute. Typically, a BGPsec speaker will also wish to perform origin validation (see [19] and [20]) on an incoming BGPsec update message, but such validation is independent of the validation described in this section.

Section 5.1 provides an overview of BGPsec validation and Section 5.2 provides a specific algorithm for performing such validation. (Note that an implementation need not follow the specific algorithm in Section 5.2 as long as the input/output behavior of the validation is identical to that of the algorithm in Section 5.2.) During exceptional conditions (e.g., the BGPsec speaker receives an incredibly large number of update messages at once) a BGPsec speaker MAY temporarily defer validation of incoming BGPsec update messages. The treatment of such BGPsec update messages, whose validation has been deferred, is a matter of local policy. However, an implementation SHOULD ensure that deferment of validation and status of deferred messages is visible to the operator.

The validity of BGPsec update messages is a function of the current RPKI state. When a BGPsec speaker learns that RPKI state has changed (e.g., from an RPKI validating cache via the RTR protocol), the BGPsec speaker MUST re-run validation on all affected update messages stored in its ADJ-RIB-IN. That is, when a given RPKI certificate ceases to be valid (e.g., it expires or is revoked), all update messages containing a signature whose SKI matches the SKI in the given certificate must be re-assessed to determine if they are still valid. If this reassessment determines that the validity state of an

update has changed then, depending on local policy, it may be necessary to re-run best path selection.

BGPsec update messages do not contain an AS_PATH attribute. Therefore, a BGPsec speaker MUST utilize the AS path information in the BGPsec_Path attribute in all cases where it would otherwise use the AS path information in the AS_PATH attribute. The only exception to this rule is when AS path information must be updated in order to propagate a route to a peer (in which case the BGPsec speaker follows the instructions in Section 4). Section 4.4 provides an algorithm for constructing an AS_PATH attribute from a BGPsec_Path attribute. Whenever the use of AS path information is called for (e.g., loop detection, or use of AS path length in best path selection) the externally visible behavior of the implementation shall be the same as if the implementation had run the algorithm in Section 4.4 and used the resulting AS_PATH attribute as it would for a non-BGPsec update message.

Many signature algorithms are non-deterministic. That is, many signature algorithms will produce different signatures each time they are run (even when they are signing the same data with the same key). Therefore, if an implementation receives a BGPsec update from a peer and later receives a second BGPsec update message from the same peer, the implementation SHOULD treat the second message as a duplicate update message if it differs from the first update message only in the Signature fields (within the BGPsec_Path attribute). That is, if all the fields in the second update are identical to the fields in the first update message, except for the Signature fields, then the second update message should be treated as a duplicate of the first update message. Note that if other fields (e.g., the Subject Key Identifier field) within a Signature segment differ between two update messages then the two updates are not duplicates.

With regards to the processing of duplicate update messages, if the first update message is valid, then an implementation SHOULD NOT run the validation procedure on the second, duplicate update message (even if the bits of the signature field are different). If the first update message is not valid, then an implementation SHOULD run the validation procedure on the second duplicate update message (as the signatures in the second update may be valid even though the first contained a signature that was invalid).

5.1. Overview of BGPsec Validation

Validation of a BGPsec update messages makes use of data from RPKI certificates and signed Route Origination Authorizations (ROA). In particular, to validate update messages containing the BGPsec_Path attribute, it is necessary that the recipient have access to the

following data obtained from valid RPKI certificates and ROAs:

- For each valid RPKI router certificate, the AS Number, Public Key and Subject Key Identifier are required,

- For each valid ROA, the AS Number and the list of IP address prefixes.

Note that the BGPsec speaker could perform the validation of RPKI certificates and ROAs on its own and extract the required data, or it could receive the same data from a trusted cache that performs RPKI validation on behalf of (some set of) BGPsec speakers. (For example, the trusted cache could deliver the necessary validity information to the BGPsec speaker using the router key PDU [16] for the RTR protocol [15].)

To validate a BGPsec update message containing the BGPsec_Path attribute, the recipient performs the validation steps specified in Section 5.2. The validation procedure results in one of two states: 'Valid' and 'Not Valid'.

It is expected that the output of the validation procedure will be used as an input to BGP route selection. That said, BGP route selection, and thus the handling of the validation states is a matter of local policy, and is handled using local policy mechanisms. Implementations SHOULD enable operators to set such local policy on a per-session basis. (That is, we expect some operators will choose to treat BGPSEC validation status differently for update messages received over different BGP sessions.)

It is expected that BGP peers will generally prefer routes received via 'Valid' BGPsec update messages over both routes received via 'Not Valid' BGPsec update messages and routes received via update messages that do not contain the BGPsec_Path attribute. However, BGPsec specifies no changes to the BGP decision process. (See [17] for related operational considerations.)

BGPsec validation needs only be performed at the eBGP edge. The validation status of a BGP signed/unsigned update MAY be conveyed via iBGP from an ingress edge router to an egress edge router via some mechanism, according to local policy within an AS. As discussed in Section 4, when a BGPsec speaker chooses to forward a (syntactically correct) BGPsec update message, it SHOULD be forwarded with its BGPsec_Path attribute intact (regardless of the validation state of the update message). Based entirely on local policy, an egress router receiving a BGPsec update message from within its own AS MAY choose to perform its own validation.

5.2. Validation Algorithm

This section specifies an algorithm for validation of BGPsec update messages. A conformant implementation MUST include a BGPsec update validation algorithm that is functionally equivalent to the externally visible behavior of this algorithm.

First, the recipient of a BGPsec update message performs a check to ensure that the message is properly formed. Specifically, the recipient performs the following checks:

1. Check to ensure that the entire BGPsec_Path attribute is syntactically correct (conforms to the specification in this document).

2. Check that each Signature_Block contains one Signature segment for each Secure_Path segment in the Secure_Path portion of the BGPsec_Path attribute. (Note that the entirety of each Signature_Block must be checked to ensure that it is well formed, even though the validation process may terminate before all signatures are cryptographically verified.)

3. Check that the update message does not contain an AS_PATH attribute.

4. If the update message was received from a peer that is not a member of the BGPsec speaker's AS confederation, check to ensure that none of the Secure_Path segments contain a Flags field with the Confed_Sequence flag set to one.

5. If the update message was received from a peer that is not expected to set pCount equal to zero (see Section 4.2) then check to ensure that the pCount field in the most-recently added Secure_Path segment is not equal to zero.

If any of these checks fail, it is an error in the BGPsec_Path attribute. Any of these errors in the BGPsec_Path attribute are handled as per RFC WXYZ [11]. BGPsec speakers MUST handle these errors using the "treat-as-withdraw" approach as defined in RFC WXYZ [11].

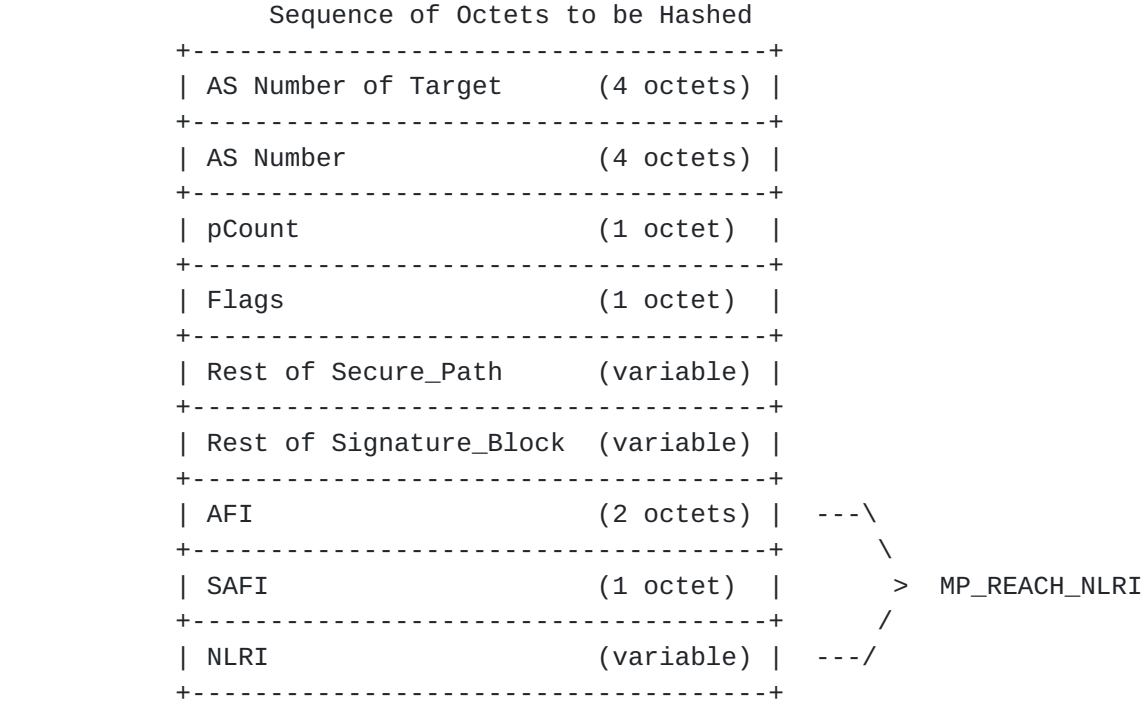
Next, the BGPsec speaker examines the Signature_Blocks in the BGPsec_Path attribute. A Signature_Block corresponding to an algorithm suite that the BGPsec speaker does not support is not considered in validation. If there is no Signature_Block corresponding to an algorithm suite that the BGPsec speaker supports, then the BGPsec speaker MUST treat the update message in the same manner that the BGPsec speaker would treat an (unsigned) update

message that arrived without a BGPsec_Path attribute.

For each remaining Signature_Block (corresponding to an algorithm suite supported by the BGPsec speaker), the BGPsec speaker iterates through the Signature segments in the Signature_Block, starting with the most recently added segment (and concluding with the least recently added segment). Note that there is a one-to-one correspondence between Signature segments and Secure_Path segments within the BGPsec_Path attribute. The following steps make use of this correspondence.

- (Step I): Locate the public key needed to verify the signature (in the current Signature segment). To do this, consult the valid RPKI router certificate data and look up all valid (AS, SKI, Public Key) triples in which the AS matches the AS number in the corresponding Secure_Path segment. Of these triples that match the AS number, check whether there is an SKI that matches the value in the Subject Key Identifier field of the Signature segment. If this check finds no such matching SKI value, then mark the entire Signature_Block as 'Not Valid' and proceed to the next Signature_Block.

- (Step II): Compute the digest function (for the given algorithm suite) on the appropriate data.



For the first segment to be processed (the most recently added

segment), the 'AS Number of Target AS' is the AS number of the BGPsec speaker validating the update message. Note that if a BGPsec speaker uses multiple AS Numbers (e.g., the BGPsec speaker is a member of a confederation), the AS number used here MUST be the AS number announced in the OPEN message for the BGP session over which the BGPsec update was received.

For each other Signature Segment, the 'AS Number of Target AS' is the AS number in the Secure_Path segment that corresponds to the Signature Segment added immediately after the one being processed. (That is, in the Secure_Path segment that corresponds to the Signature segment that the validator just finished processing.)

The AS Number, pCount and Flags fields are taken from the Secure_Path segment that corresponds to the Signature segment currently being processed. The 'Rest of Secure_Path' is obtained by removing from the Secure_Path the segment that is currently being processes. That is, 'Rest of Secure_Path' is what the Secure_Path would have contained before the currently processed segment was added. Similarly, the 'Rest of Signature_Block' is obtained by removing from the Signature_Block the Signature Segment corresponding to the current Secure_Path Segment. That is, 'Rest of Signature_Block' is what the Signature_Block would have contained before the currently processed segment was added.

The Address Family Identifier (AFI), Subsequent Address Family Identifier (SAFI), and Network Layer Reachability Information (NLRI) are obtained directly from the MP_REACH_NLRI attribute of the update message. However, in the Prefix field of the NLRI (from MP_REACH_NLRI), all of the trailing bits MUST be set to zero for the purpose of signature verification.

- (Step III): Use the signature validation algorithm (for the given algorithm suite) to verify the signature in the current segment. That is, invoke the signature validation algorithm on the following three inputs: the value of the Signature field in the current segment; the digest value computed in Step II above; and the public key obtained from the valid RPKI data in Step I above. If the signature validation algorithm determines that the signature is invalid, then mark the entire Signature_Block as 'Not Valid' and proceed to the next Signature_Block. If the signature validation algorithm determines that the signature is valid, then continue processing Signature Segments (within the current Signature_Block).

If all Signature Segments within a Signature_Block pass validation (i.e., all segments are processed and the Signature_Block has not yet been marked 'Not Valid'), then the Signature_Block is marked as

'Valid'.

If at least one Signature_Block is marked as 'Valid', then the validation algorithm terminates and the BGPsec update message is deemed to be 'Valid'. (That is, if a BGPsec update message contains two Signature_Blocks then the update message is deemed 'Valid' if the first Signature_Block is marked 'Valid' OR the second Signature_Block is marked 'Valid'.)

6. Algorithms and Extensibility

6.1. Algorithm Suite Considerations

Note that there is currently no support for bilateral negotiation (using BGP capabilities) between BGPsec peers to use of a particular (digest and signature) algorithm suite. This is because the algorithm suite used by the sender of a BGPsec update message must be understood not only by the peer to whom he is directly sending the message, but also by all BGPsec speakers to whom the route advertisement is eventually propagated. Therefore, selection of an algorithm suite cannot be a local matter negotiated by BGP peers, but instead must be coordinated throughout the Internet.

To this end, a mandatory algorithm suites document will be created which specifies a mandatory-to-use 'current' algorithm suite for use by all BGPsec speakers [10].

We anticipate that, in the future, the mandatory algorithm suites document will be updated to specify a transition from the 'current' algorithm suite to a 'new' algorithm suite. During the period of transition (likely a small number of years), all BGPsec update messages SHOULD simultaneously use both the 'current' algorithm suite and the 'new' algorithm suite. (Note that Sections 3 and 4 specify how the BGPsec_Path attribute can contain signatures, in parallel, for two algorithm suites.) Once the transition is complete, use of the old 'current' algorithm will be deprecated, use of the 'new' algorithm will be mandatory, and a subsequent 'even newer' algorithm suite may be specified as recommend to implement. Once the transition has successfully been completed in this manner, BGPsec speakers SHOULD include only a single Signature_Block (corresponding to the 'new' algorithm).

6.2. Extensibility Considerations

This section discusses potential changes to BGPsec that would require substantial changes to the processing of the BGPsec_Path and thus

necessitate a new version of BGPsec. Examples of such changes include:

- A new type of signature algorithm that produces signatures of variable length
- A new type of signature algorithm for which the number of signatures in the Signature_Block is not equal to the number of ASes in the Secure_Path (e.g., aggregate signatures)
- Changes to the data that is protected by the BGPsec signatures (e.g., attributes other than the AS path)

In the case that such a change to BGPsec were deemed desirable, it is expected that a subsequent version of BGPsec would be created and that this version of BGPsec would specify a new BGP path attribute, let's call it BGPsec_PATH_TWO, which is designed to accommodate the desired changes to BGPsec. In such a case, the mandatory algorithm suites document would be updated to specify algorithm suites appropriate for the new version of BGPsec.

At this point a transition would begin which is analogous to the algorithm transition discussed in Section 6.1. During the transition period all BGPsec speakers SHOULD simultaneously include both the BGPsec_Path attribute and the new BGPsec_PATH_TWO attribute. Once the transition is complete, the use of BGPsec_Path could then be deprecated, at which point BGPsec speakers SHOULD include only the new BGPsec_PATH_TWO attribute. Such a process could facilitate a transition to a new BGPsec semantics in a backwards compatible fashion.

7. Security Considerations

For a discussion of the BGPsec threat model and related security considerations, please see [14].

7.1 Security Guarantees

When used in conjunction with Origin Validation (see [19] and [20]), a BGPsec speaker who receives a valid BGPsec update message, containing a route advertisement for a given prefix, is provided with the following security guarantees:

- The origin AS number corresponds to an autonomous system that has been authorized, in the RPKI, by the IP address space holder to originate route advertisements for the given prefix.

- For each AS in the path, a BGPsec speaker authorized by the holder of the AS number intentionally chose (in accordance with local policy) to propagate the route advertisement to the subsequent AS in the path.

That is, the recipient of a valid BGPsec Update message is assured that the Secure_Path portion of the BGPsec_Path attribute corresponds to a sequence of autonomous systems who have all agreed in principle to forward packets to the given prefix along the indicated path. (It should be noted that BGPsec does not offer any guarantee that the data packets would flow along the indicated path; it only guarantees that the BGP update conveying the path indeed propagated along the indicated path.) Furthermore, the recipient is assured that this path terminates in an autonomous system that has been authorized by the IP address space holder as a legitimate destination for traffic to the given prefix.

Note that although BGPsec provides a mechanism for an AS to validate that a received update message has certain security properties, the use of such a mechanism to influence route selection is completely a matter of local policy. Therefore, a BGPsec speaker can make no assumptions about the validity of a route received from an external BGPsec peer. That is, a compliant BGPsec peer may (depending on the local policy of the peer) send update messages that fail the validity test in Section 5. Thus, a BGPsec speaker MUST completely validate all BGPsec update messages received from external peers. (Validation of update messages received from internal peers is a matter of local policy, see Section 5).

7.2 On the Removal of BGPsec Signatures

There may be cases where a BGPsec speaker deems 'Valid' (as per the validation algorithm in Section 5.2) a BGPsec update message that contains both a 'Valid' and a 'Not Valid' Signature_Block. That is, the update message contains two sets of signatures corresponding to two algorithm suites, and one set of signatures verifies correctly and the other set of signatures fails to verify. In this case, the protocol specifies that a BGPsec speaker choosing to propagate the route advertisement in such an update message SHOULD add its signature to each of the Signature_Blocks. Thus the BGPsec speaker creates a signature using both algorithm suites and creates a new update message that contains both the 'Valid' and the 'Not Valid' set of signatures (from its own vantage point).

To understand the reason for such a design decision consider the case where the BGPsec speaker receives an update message with both a set of algorithm A signatures which are 'Valid' and a set of algorithm B signatures which are 'Not Valid'. In such a case it is possible

(perhaps even likely, depending on the state of the algorithm transition) that some of the BGPsec speaker's peers (or other entities further 'downstream' in the BGP topology) do not support algorithm A. Therefore, if the BGPsec speaker were to remove the 'Not Valid' set of signatures corresponding to algorithm B, such entities would treat the message as though it were unsigned. By including the 'Not Valid' set of signatures when propagating a route advertisement, the BGPsec speaker ensures that 'downstream' entities have as much information as possible to make an informed opinion about the validation status of a BGPsec update.

Note also that during a period of partial BGPsec deployment, a 'downstream' entity might reasonably treat unsigned messages differently from BGPsec updates that contain a single set of 'Not Valid' signatures. That is, by removing the set of 'Not Valid' signatures the BGPsec speaker might actually cause a downstream entity to 'upgrade' the status of a route advertisement from 'Not Valid' to unsigned. Finally, note that in the above scenario, the BGPsec speaker might have deemed algorithm A signatures 'Valid' only because of some issue with RPKI state local to his AS (for example, his AS might not yet have obtained a CRL indicating that a key used to verify an algorithm A signature belongs to a newly revoked certificate). In such a case, it is highly desirable for a downstream entity to treat the update as 'Not Valid' (due to the revocation) and not as 'unsigned' (which would happen if the 'Not Valid' Signature_Blocks were removed).

A similar argument applies to the case where a BGPsec speaker (for some reason such as lack of viable alternatives) selects as his best path (to a given prefix) a route obtained via a 'Not Valid' BGPsec update message. In such a case, the BGPsec speaker should propagate a signed BGPsec update message, adding his signature to the 'Not Valid' signatures that already exist. Again, this is to ensure that 'downstream' entities are able to make an informed decision and not erroneously treat the route as unsigned. It should also be noted that due to possible differences in RPKI data observed at different vantage points in the network, a BGPsec update deemed 'Not Valid' at an upstream BGPsec speaker may be deemed 'Valid' by another BGP speaker downstream.

Indeed, when a BGPsec speaker signs an outgoing update message, it is not attesting to a belief that all signatures prior to its are valid. Instead it is merely asserting that:

- The BGPsec speaker received the given route advertisement with the indicated NLRI and Secure_Path; and

- The BGPsec speaker chose to propagate an advertisement for this

route to the peer (implicitly) indicated by the 'Target AS'

7.3 Mitigation of Denial of Service Attacks

The BGPsec update validation procedure is a potential target for denial of service attacks against a BGPsec speaker. Here we consider the mitigation only of denial of service attacks that are specific to BGPsec.

To mitigate the effectiveness of such denial of service attacks, BGPsec speakers should implement an update validation algorithm that performs expensive checks (e.g., signature verification) after performing less expensive checks (e.g., syntax checks). The validation algorithm specified in Section 5.2 was chosen so as to perform checks which are likely to be expensive after checks that are likely to be inexpensive. However, the relative cost of performing required validation steps may vary between implementations, and thus the algorithm specified in Section 5.2 may not provide the best denial of service protection for all implementations.

Additionally, sending update messages with very long AS paths (and hence a large number of signatures) is a potential mechanism to conduct denial of service attacks. For this reason, it is important that an implementation of the validation algorithm stops attempting to verify signatures as soon as an invalid signature is found. (This ensures that long sequences of invalid signatures cannot be used for denial of service attacks.) Furthermore, implementations can mitigate such attacks by only performing validation on update messages that, if valid, would be selected as the best path. That is, if an update message contains a route that would lose out in best path selection for other reasons (e.g., a very long AS path) then it is not necessary to determine the BGPsec-validity status of the route.

7.4 Additional Security Considerations

The mechanism of setting the pCount field to zero is included in this specification to enable route servers in the control path to participate in BGPsec without increasing the effective length of the AS-PATH. However, entities other than route servers could conceivably use this mechanism (set the pCount to zero) to attract traffic (by reducing the effective length of the AS-PATH) illegitimately. This risk is largely mitigated if every BGPsec speaker drops incoming update messages that set pCount to zero but come from a peer that is not a route server. However, note that a recipient of a BGPsec update message within which an upstream entity two or more hops away has set pCount to zero is unable to verify for themselves whether pCount was set to zero legitimately.

BGPsec does not provide protection against attacks at the transport layer. As with any BGP session, an adversary on the path between a BGPsec speaker and its peer is able to perform attacks such as modifying valid BGPsec updates to cause them to fail validation, injecting (unsigned) BGP update messages without BGPsec_Path_Signature attributes, injecting BGPsec update messages with BGPsec_Path_Signature attributes that fail validation, or causing the peer to tear-down the BGP session. The use of BGPsec does nothing to increase the power of an on-path adversary -- in particular, even an on-path adversary cannot cause a BGPsec speaker to believe a BGPsec-invalid route is valid. However, as with any BGP session, BGPsec sessions SHOULD be protected by appropriate transport security mechanisms.

One might be concerned about a potential attack in which an adversary replays a valid signature on an origin Secure_Path segment as though it were a signature on later Secure_Path segment (in a different update message). The only way such an attack could succeed would be if a structure of bits to be signed in Section 4.1 (origin segment) could also be parsed as a valid sequence of bits to be signed in Section 4.2 (later segment). This, in particular, would require that the length of the two structures match exactly, which cannot happen given the current choice of algorithms in [10]. We do not expect this to be a problem with future signature algorithms, as it is likely that signatures will get longer (instead of shorter) over time. However, authors of future revisions of the algorithms document [10] should take care to ensure that this attack remains infeasible.

8. IANA Considerations

This document registers a new capability in the registry of BGP Capabilities. The description for the new capability is "BGPsec Capability". The reference for the new capability is this document (i.e., the RFC that replaces draft-ietf-sidr-bgpsec-protocol).

This document registers a new path attribute in the registry of BGP Path Attributes. The code for this new attribute is "BGPsec_PATH". The reference for the new capability is this document (i.e., the RFC that replaces draft-ietf-sidr-bgpsec-protocol).

This document does not create any new IANA registries.

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