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## Deprecation of AS\_SET and AS\_CONFED\_SET in BGP

### Abstract

BCP 172 (i.e., RFC 6472) recommends not using AS\_SET and AS\_CONFED\_SET AS\_PATH segment types in the Border Gateway Protocol (BGP). This document advances that recommendation to a standards requirement in BGP; it prohibits the use of the AS\_SET and AS\_CONFED\_SET path segment types in the AS\_PATH. This is done to simplify the design and implementation of BGP and to make the semantics of the originator of a BGP route clearer. This will also simplify the design, implementation, and deployment of various BGP security mechanisms. This document updates RFC 4271 by deprecating the origination of BGP routes with AS\_SET (Type 1 AS\_PATH segment) and updates RFC 5065 by deprecating the origination of BGP routes with AS\_CONFED\_SET (Type 4 AS\_PATH segment). Finally, it obsoletes RFC 6472.

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## 1. Introduction

[BCP172] recommends not using AS\_SET [RFC4271] and AS\_CONFED\_SET [RFC5065] AS\_PATH path segment types in the Border Gateway Protocol (BGP). This document advances the BCP recommendation to a standards requirement in BGP; it prohibits the use of the AS\_SET and AS\_CONFED\_SET types of path segments in the AS\_PATH. The purpose is to simplify the design and implementation of BGP and to make the semantics of the originator of a BGP route clearer. This will also simplify the design, implementation, and deployment of various BGP security mechanisms. In particular, the prohibition of AS\_SETs and AS\_CONFED\_SETs removes any ambiguity about the origin AS in RPKI-based Route Origin Validation (RPKI-ROV) [RFC6811] [RFC6907] [RFC9319].

The AS\_SET path segment in the AS\_PATH attribute (Sections 4.3 and 5.1.2 of [RFC4271]) is created by a router that is performing route aggregation and contains an unordered set of Autonomous Systems (ASes) that contributing prefixes in the aggregate have traversed.

The AS\_CONFED\_SET path segment [RFC5065] in the AS\_PATH attribute is created by a router that is performing route aggregation and contains an unordered set of Member AS Numbers in the local confederation that contributing prefixes in the aggregate have traversed. It is very similar to an AS\_SET but is used within a confederation.

By performing aggregation, a router is combining multiple BGP routes for more specific destinations into a new route for a less specific destination (see [RFC4271], Section 9.1.2.2). Aggregation may blur the semantics of the origin AS for the prefix being announced by producing an AS\_SET or AS\_CONFED\_SET. Such sets can cause operational issues, such as not being able to authenticate a route origin for the aggregate prefix in new BGP security technologies such as those that take advantage of X.509 extensions for IP addresses and AS identifiers (see [RFC6480], [RFC6811], [RFC6907], [RFC8205], and [RFC9319]). This could result in reachability problems for the destinations covered by the aggregated prefix.

From analysis of historical Internet routing data, it is apparent that aggregation that involves AS\_SETs is very seldom used in practice on the public Internet (see [Analysis]). When it is used, it is often used incorrectly; only a single AS in the AS\_SET is the most common case [Analysis]. Also, very often the same AS appears in the AS\_SEQUENCE and the AS\_SET in the BGP update. The occurrence of reserved AS numbers [IANA-SP-ASN] is also somewhat frequent.

## 2. 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.

## 3. Updates to the Requirements of RFCs 4271 and 5065

Unless explicitly configured by a network operator to do otherwise (e.g., during a transition phase), BGP speakers:

- \* MUST NOT advertise BGP UPDATE messages containing AS\_SETs or AS\_CONFED\_SETs and
- \* MUST use the "treat-as-withdraw" error handling behavior per [RFC7606] upon reception of BGP UPDATE messages containing AS\_SETs or AS\_CONFED\_SETs in the AS\_PATH or AS4\_PATH [RFC6793].

Per the above specifications, this document updates [RFC4271] and [RFC5065] by deprecating AS\_SET (see [RFC4271], Section 4.3) and AS\_CONFED\_SET (see [RFC5065], Section 3), respectively.

## 4. Treatment of Routes with AS\_SET in RPKI-Based BGP Security

Resource Public Key Infrastructure (RPKI) [RFC6480] uses X.509 extensions for IP addresses and AS identifiers [RFC3779]. RPKI-ROV [RFC6811] [RFC6907] is a BGP security technology that never allows a route with AS\_SET to be considered Valid. BGPsec [RFC8205] and Autonomous System Provider Authorization (ASPA) [ASPA-VERIFICATION] are also BGP security technologies based on RPKI. BGPsec does not support AS\_SETs. In ASPA-based AS\_PATH verification, a route with AS\_SET is always considered Invalid and hence ineligible for route selection.

## 5. BGP AS\_PATH "Brief" Aggregation

Sections 9.1.4 and 9.2.2.2 of [RFC4271] describe BGP aggregation procedures. Appendix F.6 of [RFC4271] describes a generally less utilized "Complex AS\_PATH Aggregation" procedure.

[RFC4271], Section 5.1.6 describes the ATOMIC\_AGGREGATE Path Attribute and notes that:

When a BGP speaker aggregates several routes for the purpose of advertisement to a particular peer, the AS\_PATH of the aggregated route normally includes an AS\_SET formed from the set of ASes from which the aggregate was formed. In many cases, the network administrator can determine if the aggregate can safely be advertised without the AS\_SET, and without forming route loops.

If an aggregate excludes at least some of the AS numbers present in the AS\_PATH of the routes that are aggregated as a result of dropping the AS\_SET, the aggregated route, when advertised to the peer, SHOULD include the ATOMIC\_AGGREGATE attribute.

When BGP AS\_PATH aggregation is done according to the procedures in [RFC4271], Section 9.2.2.2, and any resulting AS\_SETs are discarded, it is typically referred to as "brief" aggregation in implementations. That terminology is adopted here: In this document, brief aggregation refers to what is described in this section, in contrast to consistent brief aggregation as described in Section 5.2. Brief aggregation results in an AS\_PATH that has the following property (from [RFC4271], Section 9.2.2.2):

```
| [D]etermine the longest leading sequence of tuples (as defined
| above) common to all the AS_PATH attributes of the routes to be
| aggregated. Make this sequence the leading sequence of the
| aggregated AS_PATH attribute.
```

The ATOMIC\_AGGREGATE Path Attribute is subsequently attached to the BGP route, if AS\_SETs are dropped.

#### 5.1. Issues with "Brief" AS\_PATH Aggregation and RPKI-ROV

While brief AS\_PATH aggregation has the desirable property of not containing AS\_SETs, the resulting aggregated AS\_PATH may contain an unpredictable origin AS. This is because the aggregating AS may be different from the purported origin AS (for the aggregate), which may vary as explained below. Such unpredictable origin ASes may result in RPKI-ROV validation issues:

- \* Depending on the contributing routes to the aggregate route, the resulting origin AS may vary.
- \* The presence of expected contributing routes may be unpredictable due to route availability from BGP neighbors.
- \* In the presence of such varying origin ASes, it would be necessary for the resource holder to register ROAs [RFC9582] for each potential origin AS that may result from the expected aggregated AS\_PATHs.

#### 5.2. Recommendations to Mitigate Unpredictable AS\_PATH Origins for RPKI-ROV Purposes

To ensure a consistent BGP origin AS is announced for aggregate BGP routes for implementations of "brief" BGP aggregation, the implementation MUST be configured to truncate the AS\_PATH after the right-most instance of the desired origin AS for the aggregate. The desired origin AS could be the aggregating AS itself. A ROA would be necessary for the aggregate prefix with the desired origin AS.

This form of brief aggregation is referred to as "consistent brief" BGP aggregation.

If the resulting AS\_PATH would be truncated from the otherwise expected result of BGP AS\_PATH aggregation (an AS\_SET would not be generated and possibly some ASes are removed from the "longest leading sequence" of ASes), the ATOMIC\_AGGREGATE Path Attribute SHOULD be attached. This is consistent with the intent of [RFC4271], Section 5.1.6.

### 6. Operational Considerations

This section provides advice to operators regarding deployment and configuration.

#### 6.1. Implementing Consistent Brief Aggregation

When aggregating prefixes, network operators MUST use consistent brief aggregation as described in Section 5.2. In consistent brief

aggregation, the AGGREGATOR and ATOMIC\_AGGREGATE Path Attributes are included, but the AS\_PATH does not have AS\_SET or AS\_CONFED\_SET path segment types. See Appendix B for examples of brief aggregation while keeping the origin AS unambiguous and generating appropriate ROAs.

## 6.2. Not Advertising Aggregate Routes to Contributing ASes

An aggregate prefix SHOULD NOT be announced to the contributing ASes. Instead, more specific prefixes (from the aggregate) SHOULD be announced to each contributing AS, excluding any that were learned from the contributing AS in consideration. See Appendix A for an example of this filtering policy.

## 6.3. Mitigating Forwarding Loops

When both less specific and more specific destinations are present, it's possible to create forwarding loops between networks, as discussed in Section 5.1 of [RFC4632].

As a reminder, Rule #2 in Section 5.1 of [RFC4632] requires that BGP implementations performing aggregation discard packets that match the aggregate route but do not match any of the more specific routes.

Further discussion of forwarding loops and their relationship to AS\_SETs can be found in Appendix C.

## 7. Security Considerations

This document deprecates the use of aggregation techniques that create AS\_SETs or AS\_CONFED\_SETs. Obsoleting these path segment types from BGP and the removal of the related code from implementations would potentially decrease the attack surface for BGP. Deployments of new BGP security technologies (e.g., [RFC6480], [RFC6811], and [RFC8205]) benefit greatly if AS\_SETs and AS\_CONFED\_SETs are not used in BGP.

## 8. IANA Considerations

This document has no IANA actions.

## 9. References

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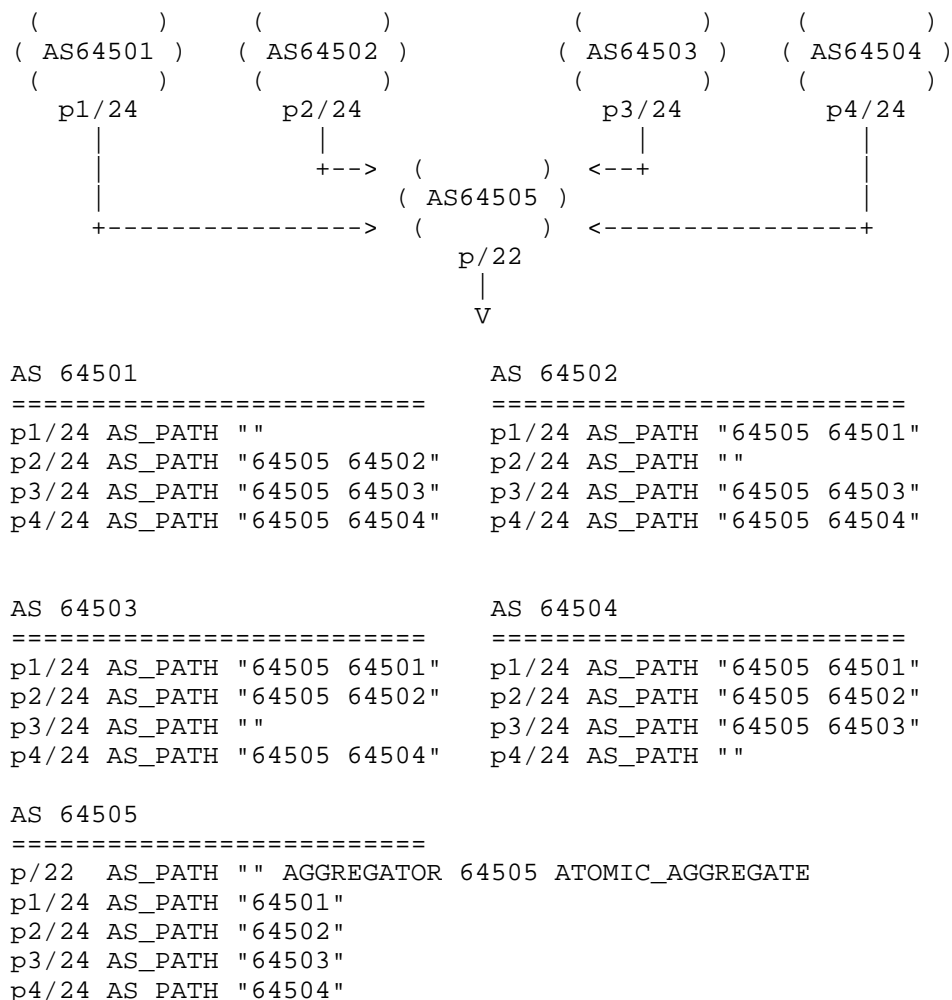
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#### Appendix A. Example of Route Filtering for Aggregate Routes and Their Contributors

The illustration presented below shows how an AS\_SET is not used when aggregating and how data plane route loops are avoided. Consider that p1/24 (from AS 64501), p2/24 (from AS 64502), p3/24 (from AS 64503), and p4/24 (from AS 64504) are aggregated by AS 64505 to p/22. AS\_SET is not used with the aggregate p/22 but AGGREGATOR and ATOMIC AGGREGATE are used. Data plane route loops are avoided by not announcing the aggregate p/22 to the contributing ASes, i.e., AS 64501, AS 64502, AS 64503, and AS 64504. Instead, as further illustrated, p1/24, p2/24, and p4/24 are announced to AS 64503. The routing tables (post aggregation) of each of the ASes are depicted in the diagram below.



#### Appendix B. Examples of Consistent and Inconsistent BGP Origin AS Generated by Brief Aggregation

The examples below illustrate how brief aggregation may result in an

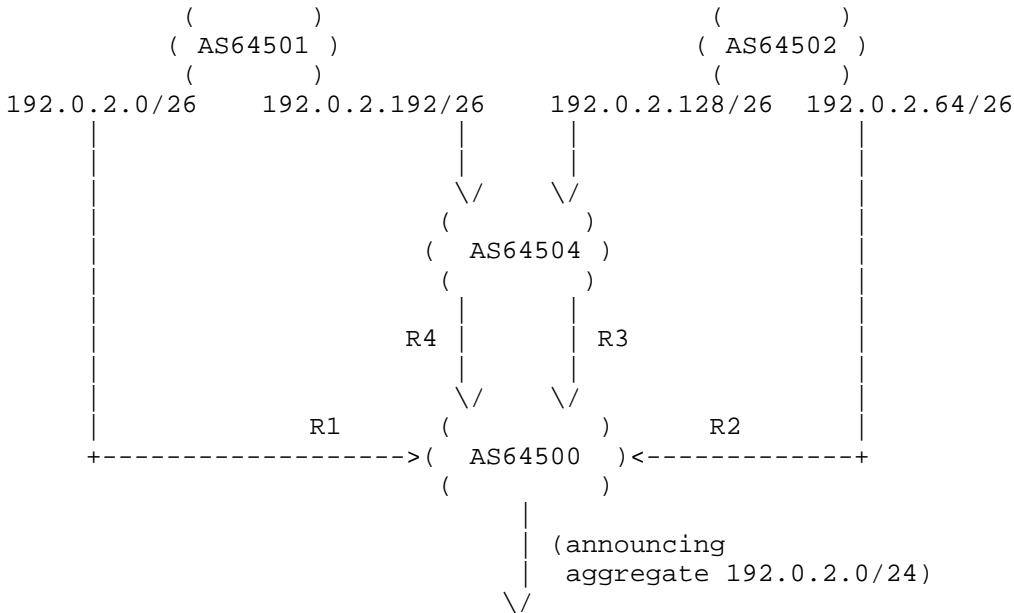
inconsistent origin AS.

AS 64500 aggregates more specific routes into 192.0.2.0/24.

Consider the following scenarios where brief aggregation is done by AS 64500 and what the resultant origin ASes would be.

Routes:

```
R1 - 192.0.2.0/26   AS_PATH "64501"
R2 - 192.0.2.64/26  AS_PATH "64502"
R3 - 192.0.2.128/26 AS_PATH "64504 64502"
R4 - 192.0.2.192/26 AS_PATH "64504 64501"
```



B.1. Scenario 1: First one route, then another, each with a fully disjoint AS\_PATH

Receive R1. Aggregate 192.0.2.0/24 AS\_PATH "64501"

Alternate "bug?": Aggregate 192.0.2.0/24 AS\_PATH "[ 64501 ]"

(Note: AS numbers within square brackets represent an AS\_SET.)

Receive R2. Aggregate 192.0.2.0/24 AS\_PATH "[ 64501 64502 ]"

If brief aggregation is in use, the AS\_PATH would be truncated to the empty AS\_PATH, "".

The resulting AS\_PATH is thus not stable and depends on the presence of specific routes.

B.2. Scenario 2: First one route, then another, and the AS\_PATHs overlap at the origin AS

Receive R1. Aggregate 192.0.2.0/24 AS\_PATH "64501"

Receive R4. Aggregate 192.0.2.0/24 AS\_PATH "[ 64504 64501 ]"

If brief aggregation is in use, the AS\_PATH is truncated to "".

The resulting AS\_PATH is thus not stable and depends on the presence of specific routes.

B.3. Scenario 3: First one route, then another, and the AS\_PATHs overlap at the neighbor AS



Receive R3. Aggregate 192.0.2.0/24 AS\_PATH "64504 64501"

Receive R4. Aggregate 192.0.2.0/24 AS\_PATH "64504 [ 64501 64502 ]"

If brief aggregation is in use, the AS\_PATH is truncated to "64504".

The resulting AS\_PATH is thus not stable and depends on the presence of specific routes.

#### B.4. Achieving Consistent Origin AS During Aggregation

In the three scenarios above, the aggregating AS 64500 is using brief aggregation. This results in inconsistent origin ASes as the contributing routes are learned. This motivates the "consistent brief" BGP aggregation mentioned in Section 5.2 and discussed further with examples below.

The trivial solution to addressing the issue is to simply discard all of the ASes for the contributing routes. In simple BGP aggregation topologies, this is likely the correct thing to do. The AS originating the aggregate, 192.0.2.0/24 in this example, is likely the resource holder for the route in question. In such a case, simply originating the route to its BGP upstream neighbors in the Internet with its own AS, 64500, means that a consistent ROA could be registered in the RPKI for this prefix. This satisfies the need for a consistent (unambiguous) origin AS.

If the contributing ASes are themselves multihomed to the Internet outside of their connections to AS 64500, then additional ROAs would need to be created for each of the more specific prefixes.

In more complex proxy aggregation scenarios, there may be a desire to permit some stable (i.e., common) portion of the contributing AS\_PATHs to be kept in the aggregate route. Consider the case for Scenario 3, where the neighbor AS is the same for both R3 and R4 -- AS 64504. In such a case, an implementation may permit the aggregate's brief AS\_PATH to be "64504", and a ROA would be created for the aggregate prefix with 64504 as the origin AS.

#### Appendix C. Discussion on Forwarding Loops and AS\_SETs

Although BGP-4 was designed to carry Classless Inter-Domain Routing (CIDR) routes, [RFC4271] does not discuss the installation of "discard" or "null" routes when implementing its aggregation procedures. Implementations could originate an aggregate prefix without a covering route for a more specific prefix (subsumed by the aggregate prefix) present in the local routing table.

When aggregating more specific routes according to the aggregation procedures of [RFC4271], the aggregating BGP speaker will place contributing routes into the generated AS\_PATH, perhaps using AS\_SETs. As a result, a contributing AS will not install the aggregated route into its RIB since the route is an AS\_PATH loop. This provides a form of protection against forwarding loops created by BGP aggregation.

When brief aggregation methods are used, a BGP speaker may receive a route containing a less specific destination covering a local more specific destination and install it in its routing table since it is not prevented from doing so by BGP AS\_PATH loop detection. This gives rise to the possibility of forwarding loops. To help prevent forwarding loops, it is critical to adhere to the following:

1. Rule #2 in Section 5.1 of [RFC4632]:

| A router that generates an aggregate route for multiple, more-  
| specific routes must discard packets that match the aggregate  
| route, but not any of the more-specific routes. In other words,  
| the "next hop" for the aggregate route should be the null  
| destination.

2. Not advertising aggregate routes to contributing ASes as specified in Section 6.2 of this document (also see Appendix A).

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