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AS Path Prepending  
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Abstract

Autonomous System (AS) path prepending is a tool to manipulate the BGP AS\_PATH attribute through prepending one or more Autonomous System Numbers (ASNs). AS path prepending is used to deprioritize a route in the presence of a route with a shorter AS\_PATH. By prepending a local ASN multiple times, ASes can make advertised AS paths appear artificially longer. However, excessive AS path prepending has caused routing issues in the Internet. This document provides guidance for the use of AS path prepending, including alternative solutions, in order to avoid negatively affecting the Internet.

Status of This Memo

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## 1. Introduction

The Border Gateway Protocol (BGP) [RFC4271] specifies the AS\_PATH attribute, which enumerates Autonomous Systems (ASes) a route update has traversed. Per Section 5.1.2 of [RFC4271], If a BGP UPDATE message is propagated to an external peer, then the local AS number is prepended to the AS\_PATH attribute, and the NEXT\_HOP attribute is updated with an IP address of the router that should be used as a next hop to the network. If the UPDATE message is propagated to an internal peer, then the AS\_PATH attribute and the NEXT\_HOP attribute are passed unmodified.

A common practice among operators is to prepend multiple entries of an AS (known as AS Path Prepending) in order to deprioritize a route or a path. So far, this has not caused many problems. However, the practice is increasing, with both IPv4 and IPv6, and there are now inherent risks to the global Internet, especially with excessive AS Path Prepending. Prepending may be employed in an excessive manner such that it renders routes vulnerable to disruption or misdirection.

[RFC8195] discusses using BGP Large Communities for Traffic Engineering (TE) through selective AS\_PATH prepending. The present document provides additional and specific guidance to operators for a safe use of AS path prepending.

### 1.1. 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.

## 2. Sample Use Cases

There are various reasons that AS path prepending is in use in networks, including:

- \* Prefer one ISP over another ISP on the same ASBR or across different ASBRs for the multihoming case.
- \* Prefer one ASBR over another ASBR in the same site or between sites.
- \* Utilize one path exclusively and another path solely as a backup.
- \* Signal to indicate that one path may have a different amount of capacity than another where the lower capacity link still takes traffic.
- \* Conditionally prefer one ASBR over another ASBR within the same site or between sites for lowest latency path based on geographic location.
- \* An ISP doesn't accept TE using BGP Communities. Prepending is the only available option to influence path selection by a source AS.

The illustration shown in Figure 1, from [Path\_Prepending\_in\_BGP], shows how AS Prepending is typically used:

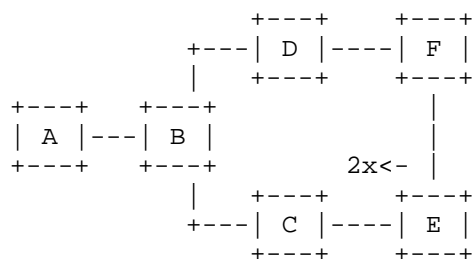


Figure 1: Path Prepending in BGP

In Figure 1, ASes A, B, C, D, E, and F all have a different ASN. B will normally prefer the path via C to send traffic to E, as this represents the shorter AS path for B. If E is instructed to prepend two instances of its own ASN when advertising its routes to C, then B will now see a different situation, where the AS path via D represents the shorter path. Through the use of selective prepending, E is able to alter the routing decision of B, even though B is not an adjacent neighbor of E. The result is that traffic from A and B will be passed via D and F to reach E, rather than via C. In this way prepending implements action at a distance where the routing decisions made by non-adjacent ASes may be influenced by selective AS Path prepending.

### 3. Potential Problems

This section discusses examples which illustrate problems of AS path prepending.

#### 3.1. Cascading and Ripple Effects of Prepending

Care should be taken in prepending, as prepending can cause ripple effects with multiple ASes performing the same set of prepends in the same path direction. This may result in unintended forwarding where the valid preferred path becomes now de-preferred.

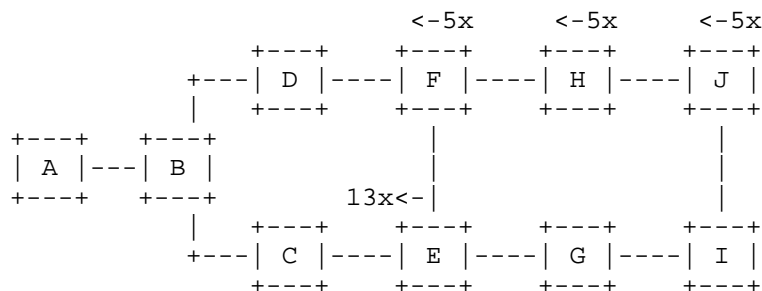


Figure 2: Prepending ripple effect

In Figure 2, A, B, C, D, E, F, G, H, I and J are all part of different ASes and can help illustrate the ripple effect of prepending. With no prepending, B will normally prefer the path via D to send traffic to a source attached to J, as this represents the preferred path. If E, unnecessarily, prepends 13 additional instances of its own AS number, when advertising routes to C, and no AS limit check is enforced by peers, there is no change to the preferred path from B to J and only causes an increase in the AS Path. If ISP J then decides to prepend 5 additional instances (making it 5+1) of its own ASN when advertising to H, and ISP H also prepends 5 additional instances of its own AS when advertising to F, and ISP F also prepends 5 additional instances of its own ASN when advertising to D, B now sees 19 AS hops for prefixes coming from D to get to J. The path with 18 AS hops coming from C is now preferred. B will send all of its traffic through I to reach J. This is a scenario where providers decide to de-prefer a path. However, the same de-preference of a path gets cascaded in the same announcement direction and, as a result, the path that should not be preferred, through C, ends up being the preferred path. If E then decides to further increase its AS path prepending, then the preferred path changes again for B to use D to get to J. Usage of BGP Large Communities, along with care being taken when prepending is performed between providers, can help mitigate the potential adverse impacts of large prepending.

### 3.2. Excessive Prepending

The risk of excessive use of AS path prepending can be illustrated with real-world examples that have been anonymized using documentation prefixes [RFC5737] and ASes [RFC5398]. Consider the prefix 198.51.100.0/24 which is normally announced with an inordinate amount of prepending. 198.51.100.0/24 is announced to the world along the following AS path:

```

64496 64511 64511 64511 64511 64511 64511 64511 64511 64511 64511
64511 64511 64511 64511 64511 64511 64511 64511 64511 64511 64511
64511 64511

```

In this example, the origin AS with ASN 64511 appears 23 consecutive times before being passed on to a single upstream (AS with ASN 64496), which passes it on to the global Internet, prepended-to-all. An attacker, wanting to intercept or manipulate traffic to this prefix, could enlist a datacenter to allow announcements of the same prefix with a fabricated AS path such as 999999 64496 64511. Here the fictional AS with ASN 999999 represents the shady datacenter. This malicious route would be preferred due to the shortened AS path length and might go unnoticed by the true origin, even if route-monitoring had been implemented. Standard BGP route monitoring checks a route's origin and upstream and both would be intact in this scenario. The length of the prepending gives the attacker room to craft an AS path that would appear plausible to the casual observer, comply with origin validation mechanisms, and not be detected by off-the-shelf route monitoring. While the root cause of the attacker problem is prefix hijacking, the blast radius of an existing hijacking incident will most likely be increased by excessive as-path prepending.

### 3.2.1. Prepending during a routing leak

In April 2010, a service provider experienced a routing leak. While analyzing that leak, something peculiar was noticed. When ranking the approximately 50,000 prefixes involved in the leak based on how many ASes accepted the leaked routes, most of the impact was constrained to Country A routes. However, two of the top five most-propagated leaked routes were Country B routes.

During the routing leak, nearly all of the ASes of the Internet preferred the Country A leaked routes for 192.0.2.0/21 and 198.51.100.0/22 because, at the time, these two Country B prefixes were being announced to the entire Internet along the following excessively prepended AS path: 64496 64500 64511 64511 64511 64511 64511 64511. Virtually any illegitimate route would be preferred over the legitimate route. In this case, the victim is all but ensuring their victimhood.

There was only a single upstream seen in the prepending example from above, so the prepending was achieving nothing except incurring risk. You would think such mistakes would be relatively rare, especially now, 10 years later. As it turns out, there is quite a lot of prepending-to-all going on right now and during leaks, it doesn't go well for those who make this mistake. While one can debate the merits of prepending to a subset of multiple transit providers, it is

difficult to see the utility in prepending to every provider. In this configuration, the prepending is no longer shaping route propagation. It is simply incentivizing ASes to choose another origin if one were to suddenly appear whether by mistake or otherwise.

### 3.2.2. Prepending to All

Based on analysis done in 2019 [Excessive\_AS\_Path\_Prepending], out of approximately 750,000 routes in the IPv4 global routing table, nearly 60,000 BGP routes are prepended to 95% or more of hundreds of BGP sources. About 8% of the global routing table, or 1 out of every 12 BGP routes, is configured with prepends to virtually the entire Internet. The 60,000 routes include entities of every stripe: governments, financial institutions, even important parts of Internet infrastructure.

Much of the worst propagation of leaked routes during big leak events have been due to routes being prepended-to-all. The AS64505 leak of April 2014 (>320,000 prefixes) was prepended-to-all. And the AS64506 leak of June 2015 (>260,000 prefixes) was also prepended-to-all. Prepend-to-all prefixes are those seen as prepended by all (or nearly all) of the ASes of the Internet. In this configuration, prepending is no longer shaping route propagation but is simply incentivizing ASes to choose another origin if one were to suddenly appear whether by mistake or otherwise. The percentage of the IPv4 table that is prepended-to-all is growing at 0.5% per year. The IPv6 table is growing slower at 0.2% per year. The reasons for using prepend-to-all appears to be due to 1) the AS forgetting to remove the prepending for one of its transit providers when it is no longer needed and 2) the AS attempting to de-prioritize traffic from transit providers over settlement-free peers and 3) there are simply a lot of errors in BGP routing. Consider the prepended AS path below:

```
64496 64501 64501 64510 64510 64501 64510 64501 64501 64510 64510
64501 64501 64510
```

The prepending here involves a mix of two distinct ASNs (64501 and 64510) with the last two digits transposed.

### 3.3. Memory

Long AS Paths cause an increase in memory usage by BGP speakers. A concern about an AS path longer than 255 is the potential extra complexity required to process it, because it needs to be encoded in more than one AS\_SEQUENCE in the AS\_PATH BGP path attribute.

#### 4. Alternatives to AS Path Prepending

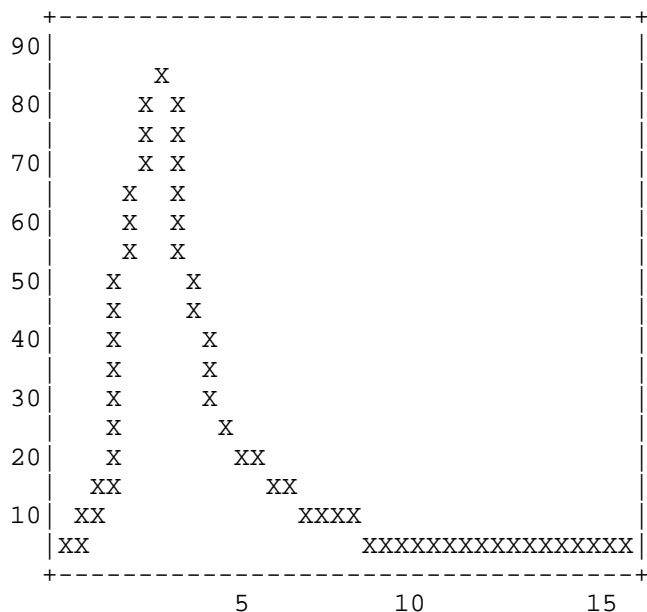
Various options, to provide path preference without needing to use AS path prepending, include:

- \* Use predefined communities that are mapped to a particular behavior when propagated.
- \* Announce more specific routes on the preferred path.
- \* The BGP Origin Code is an attribute that is used for path selection and can be used as a high order tie-breaker. The three origin codes are IGP, EGP and INCOMPLETE [RFC4271]. When AS Paths are of equivalent length, users could advertise paths, with IGP or EGP origin, over the preferred path while the other ASBRs (which would otherwise need to prepend N times) advertises with an INCOMPLETE origin code.
- \* The Multi Exit Discriminator (MED) is an optional non-transitive attribute that can be used to influence path preference instead of using as-path. MED is non-transitive so it cannot influence an AS more than one AS hop away.

#### 5. Best Practices

A summary of the best current practices when using AS path prepending is provided below:

- \* Network operators should ensure prepending is absolutely necessary as many networks have excessive prepending. It is best to innumerate what the routing policies are intended to achieve before concluding that prepending is a solution.
- \* The neighbor, to which prepending is used, may have an unconditional preference for customer routes and prepending doesn't work. It is helpful to check with neighbors to see if they will honor the prepend to avoid wasting effort and potentially causing further vulnerabilities.
- \* As shown in Figure 3 (reproduced from [Excessive\_AS\_Path\_Prepending]), prepending more than 5 times rarely provides any benefit. Note that routing patterns may change over time and may be different in various parts of the internet. A looking glass, as provided by many Internet Service Providers, can be used to get a better understanding of as-path length of an IP address prefix of interest.



X Axis = unique AS Paths in millions

Figure 3: AS Path Length in IPv4

- \* Don't prepend ASNs that you don't own. Using non-local ASNs can lead to route rejection, misconfigurations, or unintended AS path validation failures.
- \* Don't prepend if your AS is single homed.
- \* Prepending-to-all is a self-inflicted and needless risk that serves little purpose. Those excessively prepending their routes should consider this risk and adjust their routing configuration.
- \* The Internet is typically around 5 ASes deep with the largest AS\_PATH being 16-20 ASNs. Some have added 100 or more AS Path Prepends and operators should therefore consider limiting the maximum AS-path length being accepted through aggressive filter policies.

## 6. IANA Considerations

This document does not make any request of IANA.

## 7. Security Considerations

Long prepending may make a network more vulnerable to route hijacking which will exist whenever there is a well connected peer that is willing to forge their AS\_PATH or allows announcements with a fake AS path. Guards to prevent such routes with long AS paths should be enabled. Also, using Autonomous System Provider Authorization (ASPA) objects in the Resource Public Key Infrastructure (RPKI), to verify the BGP AS\_PATH attribute of advertised routes, would provide detection and mitigation of route leaks and improbable AS paths.

For a more comprehensive discussion of BGP Operations and Security, see [RFC7454].

## 8. Acknowledgement

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