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Guidance Autonomous System (AS) Path Prepending in BGP

draft-ietf-grow-as-path-prepending-14

Abstract

Autonomous System (AS) ~~Path~~ path ~~Prepending~~ prepending ~~provides~~ is a tool to manipulate the BGP AS_PATH attribute through prepending ~~multiple entries of an~~one or more Autonomous System Number (ASN). AS p~~P~~ath ~~Prepending~~ prepending is used to deprioritize a route ~~or alternate path~~in the presence of a route with shorter AS PATH. By prepending ~~the~~ a local ASN multiple times, ~~ASs~~ASes can make advertised AS paths appear artificially longer. However, ~~Excessive~~ excessive AS p~~P~~ath ~~Prepending~~ prepending has caused routing issues in the Internet. This document provides guidance for the use of AS p~~P~~ath ~~Prepending~~prepending, including alternative solutions, in order to avoid negatively affecting the Internet.

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 4 September 2025.

Commenté [MB1]: Given https://www.rfc-editor.org/rfc/rfc7322.html#section-4.1.1, we need to discuss this.

Commenté [BMI2]: Or «Recommendations for »

Commenté [MB3]: No need to expand per https://www.rfc-editor.org/rpc/wiki/doku.php?id=abbrev_list

Commenté [BMI4]: I think we need better clarity

Commenté [BMI5]: I would delete as this is covered by the edited sentence right before

Table of Contents

1. Introduction

The Border Gateway Protocol (BGP) [RFC4271] specifies the AS_PATH attribute, which enumerates Autonomous Systems (ASes) ~~ASs~~ a route update has traversed. Per Section 5.1.2 of [RFC4271], ~~If~~ if ~~the~~a BGP UPDATE message is propagated ~~over~~ to an external ~~link~~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 ~~over~~ to an internal ~~link~~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 is frequently employed in an excessive

Commenté [BMI6]: Be consistent with the use in 4271

Commenté [BMI7]: To leverage terms in rfc4271#section-1.1

Commenté [BMI8]: It is too early at this stage to dig into subtle uses, but in some cases both a local and a global ASN may be prepended (e.g., VPN case). See «prepend-global-as » command in RFC 9182 - A YANG Network Data Model for Layer 3 VPNs

Please consider that and see if there is any required change/mention that is needed to record this.

Commenté [BMI9]: Add a reference to rfc4271#section-5.1.3

Commenté [BMI10]: Idem as above.

Commenté [BMI11]: Can we add a pointer?

manner such that it renders routes vulnerable to disruption or misdirection.

[RFC8195] discusses using BGP Large Communities for ~~traffic~~ Traffic ~~engineering~~ Engineering (TE) through selective AS_PATH prepending. ~~This~~The present document provides additional and specific guidance to operators for a safe use ~~on how to be good Internet citizens with less risky use of~~ AS ~~Path~~path ~~Prepending~~prepending.

1.1. Requirements Language

~~The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].~~
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~~ path p~~P~~repending is in use ~~today~~in networks, including:

* Prefer~~ring~~ one ISP over another ISP on the same ASBR or across different ASBRs for the multihoming case.

* Prefer~~ring~~ one ASBR over another ASBR in the same site or between sister sites.

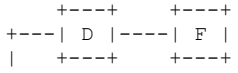
* Utilize one path exclusively and another path solely as a backup.

* 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 ~~at~~ within the same site or between sites for lowest latency path based on geographic location.

* An ISP doesn't accept ~~traffic engineering~~TE using BGP C~~c~~ommunities. Prepending is the only available option to influence path selection by a source AS.

~~The following~~The illustration shown in Figure 1, from ~~Geoff Huston's~~ [Path_Prepending_in_BGP], shows how AS p~~P~~repending is typically used:



Commenté [BMI12]: The transition is weird given that the previous sentence was about «excessive», while this one is about «selective».

Move to a new para would be a simple fix 😊

Commenté [BMI13]: To avoid confusion with 8195

Commenté [BMI14]: Refresh the boilerplate

Commenté [BMI15]: For consistence with the uses in other bullet items.

Commenté [BMI16]: I'm not used to this term. Can we please reword or use a more common term. If you maintain this wording, please supply a definition and/or authoritative source.

Commenté [BMI17]: Agree but this one is not exclusive to the other two uses. May be wroth saying so.

Commenté [BMI18]: This is a preference criteria.

Again this is not exclusive vs other bullets.

Commenté [BMI19]: The semantic can't be inferred from the prepended ASN. This smells more like a criteria to preference.

Commenté [BMI20]: Cited in the refs

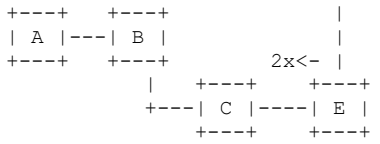


Figure X: Title

In ~~the diagram above~~Figure 1, 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 ~~were~~ to prepend ~~a further~~ two instances of its own ~~AS number~~ASN when advertising its routes to C,

then B will now see a different situation, where the AS ~~Path~~ 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 ~~neighbour~~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 ~~ASs~~ASes ~~can~~ may be influenced by selective AS p~~P~~ath prepending.

3. Potential Problems

~~Since it is so commonly used, what are the potential problems with the excessive use of AS Path Prepending?~~This section discusses some ~~Here are a~~ few examples to illustrate problems of AS path prepending~~:~~.

3.1. Cascading and R~~r~~ipple ~~effects~~ Effects of ~~prepending~~Prepending

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

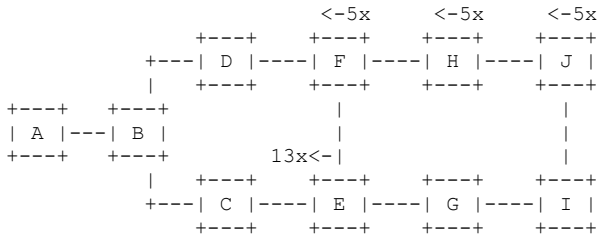


Figure X: Title

Commenté [BMI21]: Please add legends for all figures + call out these figure in the main text. Thanks.

Commenté [BMI22]: Please indicate what these entities represent (routers, AS).

I guess these are ASes

Commenté [BMI23]: Otherwise, I don't get what you meant by «have different AS»

Commenté [BMI24]: Should we say for a given prefix? I guess we need.

Commenté [BMI25]: Idem as above

In ~~the diagram above~~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, 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 ~~AS~~ ASN when advertising to H, and ISP H also prepends 5 additional instances of its own ~~AS~~ ASN 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. ~~We now have a situation where~~ B will send~~s~~ 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 ~~it's~~ its AS ~~Path~~ path prepending, then the preferred path changes again for B to use D to get to J.

Usage of BGP L~~l~~arge ~~communities~~Communities, along with care being taken when prepending is performed between providers, can help mitigate the potential adverse impacts of large prepending.

Some of these potential impacts are further illustrated below.

3.2. Excessive Prepending

The risk of excessive use of AS ~~P~~path ~~Prepending~~ prepending can be illustrated with real-world examples that have been anonymized using documentation prefixes [RFC5737] and ~~ASs~~ASes [RFC5398]~~.~~.

Consider the prefix 198.51.100.0/24 which is normally announced with an inordinate amount of prepending. A recent analysis revealed that 198.51.100.0/24 is announced to the ~~world~~ global Internet along the following AS path:

64496 64511

In this example, the origin AS with ASN 64511 appears 23 consecutive times

Commenté [BMI26]: So these are routers?

Commenté [BMI27]: For a given prefix

Commenté [BMI28]: And no check is enforced by peers on the as limit (as-prepend-limit, for example)

Commenté [BMI29]: Aah this an ISP!

Commenté [BMI30]: Not the trafic direction

Commenté [BMI31]: I don't parse this

Commenté [BMI32]: Where? Please add the exact section

Commenté [BMI33]: Let's use an IPv6 example. The practices for source AS prepending is balanced between v4/v6:

Pick a prefix from 3fff::/20 (RFC9637)

Commenté [BMI34]: Any pointer to cite?

before being passed on to a single upstream (AS with ASN ~~AS~~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 data center to allow announcements of the same prefix with a fabricated AS path such as 999999 64496 64511. Here the fictional AS with ASN ~~AS~~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.

3.3. Prepending Dduring a ~~routing~~ Routing ~~leak~~Leak

In April 2010, a service provider experienced a routing leak. While analyzing ~~the~~ that leak something peculiar was noticed. When ~~we~~ ranking~~ed~~
the approximately 50,000 prefixes involved in the leak based on how many ~~ASs~~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 (listed in the table below) were Country B routes.

Commenté [BMI35]: Add a pointer

Commenté [BMI36]: Which table?

During the routing leak, nearly all of the ~~ASs~~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 ~~ASs~~ASes to choose another origin
if one were to suddenly appear whether by mistake or otherwise.

3.4. 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. Prepended-to-all prefixes are those seen as prepended by all (or nearly all) of the ~~ASs~~ASes of the Internet. In this configuration, prepending is no longer shaping route propagation but is simply incentivizing ~~ASs~~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.

Commenté [BMI37]: Can we refresh this? Ex. refer to LACNIC Blog | Analysis of BGP Prepending in the LAC Region in 2024

3.5. Memory

Long AS p~~P~~aths cause an increase in memory usage by BGP speakers. A concern about an AS ~~Path~~ path longer than 255 is the 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.

Commenté [BMI38]: I would cite rfc4271#section-5.1.2 given that it covers the overflow case:

«If the act of prepending will cause an overflow in the AS_PATH segment (i.e., more than 255 ASes), it SHOULD prepend a new segment of type AS_SEQUENCE and prepend its own AS number to this new segment. »

3.6. Errant A~~a~~nnouncement

It is possible for an Internet-wide outage to occur because of a single errant routing announcement. For example, AS64496 could announce its one prefix with an extremely long AS path. Someone could enter their ASN instead of the prepend count. 64496 modulo 256 = 240 prepends, and when a ~~path lengths~~path length exceeded 255, routers could crash.

Commenté [BMI39]: Can we have a pointer for an example where this happend?

4. Alternatives to AS Path Prepending

Various options, to provide path preference without needing to use AS p~~P~~ath ~~Prepend~~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. When AS pPaths 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~~ non-transitive so it cannot influence an AS
more than ~~1~~ one AS hop away.

* Local-preference optional non-transitive attribute, above as-path in BGP path selection, can be used to influence route preference within ~~the~~ a local ~~operators~~ AS ~~administrative domain~~. Local-preference can shield the operator domain from traffic shifts off the preferred path to a de-preferred path caused by excess prepending done by service providers across the Internet. If all service providers across the Internet set ~~local-preference~~LOCAL_PREF inbound
conditionally with Large Community set on preferred paths, the impacts of suboptimal routing, as well as other routing issues resulting from excess prepending, can be mitigated.

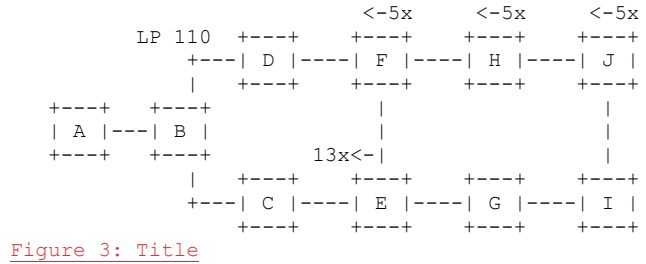


Figure 3: Title

In ~~the diagram above~~Figure 3, A, B, C, D, E, F G, H, I, J are all part of a
different AS. B will normally prefer the path via D to send traffic to J, as this represents the preferred path to B, due to E prepending 13 instances of its own AS number when advertising routes to C. ISP J decides to prepend 5 instances of its own ASN when advertising to H, and ISP H decides to do the same and prepends 5 instances of its own AS when advertising to F. ISP F decides to also prepend 5 instances of its own AS when advertising to D. B now sees 19 AS hops for prefixes coming from D to get to J which should be the preferred path

Commenté [BMI40]: Cited Section 4.3 of RFC4271

Commenté [BMI41]: Cite rfc4271#section-9.1.1

Commenté [BMI42]: Just use AS

compare to 18 AS hops coming from C which is now preferred. ~~We now~~There is now ~~have~~ suboptimal routing to I as B now sends all of its traffic through I to reach J. This suboptimal routing on B can be prevented locally within the operator domain by setting ~~local-preference~~LOCAL PREF inbound, which is above as-path length in the best path selection, to higher then default 100 to 110 inbound from D, thus shielding the operator B from being influenced by the excessive prepend cascading ripple ~~affect~~effect by F, H, and J.

Note that A still sees the cascading ripple ~~affect~~effect of excess prepending, however A, or any service provider AS downstream of B, ~~ingressing~~ entering B, will be shunted to D via local-preference and the suboptimal routing is now mitigated for all downstream AS to the left of B that prefer the path through B.

Commenté [BMI43]: Weird as these entities are ISPs. OK if this is about ASes.

5. Best Practices

~~Many of the best practices, or lack thereof, can be illustrated from the preceding examples. Here's a~~A summary of the best current practices when using AS ~~Path~~ path ~~Prepending~~prepending is provided below:

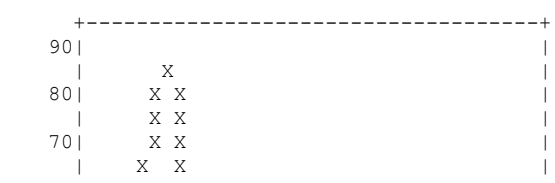
Commenté [BMI44]: Can we add a mention about monitoring the length of ASN and enforce limits to prevent excessive prepending?

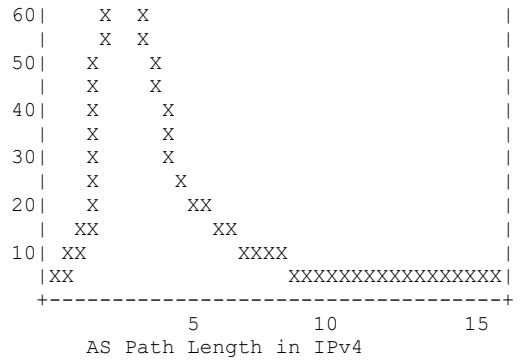
* Network operators should ensure prepending is absolutely necessary as many networks have excessive prepending. It is best to innumerate what the routing policies are intended to achieve before concluding that prepending is a solution.

* The neighbor ~~you~~ to which ~~are~~ prepending is used may have an unconditional preference for customer routes and prepending doesn't work. It i~~'~~s helpful to check with neighbors to see if they will honor the prepend to avoid wasting effort and potentially causing further vulnerabilities.

* Use of local-preference inbound on preferred paths between service providers to help mitigate the ~~adverse affects~~adverse effects of prepending

* As can be seen from the following diagram (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

* Don't prepend ASNs that you don't own.

* 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 ~~ASs~~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 to IANA.

7. Security Considerations

Long prepending may make a network more ~~vulnernable~~vulnerable to route hijacking which will exist whenever there is a ~~well connected~~well-connected peer that is willing to forge their AS_PATH or allows announcements with a ~~fabricated~~ fake AS path.

Accepting routes with extremely long AS_PATHs may cause increased memory usage and possible router crashes. Guards to prevent such routes with long AS path should be enabled. Also, ~~Using~~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

The authors would like to thank Greg Skinner, Randy Bush, David Farmer, Nick Hilliard, Martijn Schmidt, Michael Still, Geoff Huston, Jeffrey Haas, Alejandro Acosta and Martin Pels for contributing to this document.

9. References

9.1. Normative References

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