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IPv4 NLRI with IPv6 Next Hop Use Cases
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Abstract

As Enterprises and Service Providers upgrade their brown field or green field MPLS/SR core to an IPv6 transport such as MPLS LDPv6, SR-MPLSv6 or SRv6, Multiprotocol BGP (MP-BGP) now plays an important role in the transition of the core from IPv4 to IPv6 being able to continue to support legacy IPv4, VPN-IPv4, and Multicast VPN IPv4 customers.

This document describes the critical use case and OPEX savings of being able to leverage the MP-BGP capability exchange usage as a pure transport allowing both IPv4 and IPv6 to be carried over the same BGP TCP session. By doing so, allows for the elimination of Dual Stacking on the PE-CE connections making the peering IPv6-ONLY to now carry both IPv4 and IPv6 Network Layer Reachability Information (NLRI). This document now provides a solution for IXPs (Internet Exchange points) that are facing IPv4 address depletion at these peering points to use BGP-MP capability exchange defined in [RFC5549] to carry IPv4 (Network Layer Reachability Information) NLRI in an IPv6 next hop using the [RFC5565] software mesh framework.

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1. Introduction

As Enterprises and Service Providers upgrade their brown field or green field MPLS/SR core to an IPv6 transport such as MPLS LDPv6, SR-MPLSv6 or SRv6, Multiprotocol BGP (MP-BGP) now plays an important role in the transition of the core from IPv4 to IPv6, and being able to continue to support legacy IPv4, VPN-IPv4, and Multicast VPN IPv4 customers.

IXPs (Internet Exchange points) are also facing IPv4 address depletion at their peering points, which are large Layer 2 transit backbones that service providers peer and exchange IPv4 and IPv6 (Network Layer Reachability Information) NLRI. Today these transit exchange points are dual stacked. One proposal to solve this issue is to use [[RFC5549](#)] to carry IPv4 (Network Layer Reachability Information) NLRI in an IPv6 next hop and eliminate the IPv4 peering completely using the concept of [[RFC5565](#)] software mesh framework. So now with the MP-BGP reach capability exchanged over IPv4 AFI over IPv6 next hop peer we can now advertise IPv4 (Network Layer Reachability Information) NLRI over IPv6 peering using the [[RFC5565](#)] software mesh framework.

Multiprotocol BGP (MP-BGP) specifies that the set of usable next-hop address families is determined by the Address Family Identifier (AFI) and the Subsequent Address Family Identifier (SAFI). Historically the AFI/SAFI definitions for the IPv4 address family only have provisions for advertising a Next Hop address that belongs to the IPv4 protocol when advertising IPv4 or VPN-IPv4 Network Layer Reachability Information (NLRI). [[RFC5549](#)] specifies the extensions necessary to allow advertising IPv4 NLRI or VPN-IPv4 NLRI with a Next Hop address that belongs to the IPv6 protocol. This comprises an extension of the AFI/SAFI definitions to allow the address of the Next Hop for IPv4 NLRI or VPN-IPv4 NLRI to also belong to the IPv6 Protocol. [[RFC5549](#)] defines the encoding of the Next Hop to determine which of the protocols the address actually belongs to, and a new BGP Capability allowing MP-BGP Peers to dynamically discover

whether they can exchange IPv4 NLRI and VPN-IPv4 NLRI with an IPv6 Next Hop.

With this new MP-BGP capability exchange allows the BGP peering session to act as a pure transport to allow the session to carry Address Family Identifier (AFI) and the Subsequent Address Family Identifier (SAFI) for both IPv4 and IPv6.

Furthermore, a number of these existing AFI/SAFIs allow the Next Hop to belong to either the IPv4 Network Layer Protocol or the IPv6 Network Layer Protocol, and specify the encoding of the Next Hop information to determine which of the protocols the address actually

belongs to. For example, [[RFC4684](#)] allows the Next Hop address to be either IPv4 or IPv6 and states that the Next Hop field address shall be interpreted as an IPv4 address whenever the length of Next Hop address is 4 octets, and as an IPv6 address whenever the length of the Next Hop address is 16 octets.

For example, the AFI/SAFI <25/65> used (as per [[RFC6074](#)]) to perform L2VPN auto-discovery, allows advertising NLRI that contains the identifier of a Virtual Private LAN Service (VPLS) instance or that identifies a particular pool of attachment circuits at a given Provider Edge (PE), while the Next Hop field contains the loopback address of a PE. Similarly, the AFI/SAFI <1/132> (defined in [[RFC4684](#)]) to advertise Route Target (RT) membership information, allows advertising NLRI that contains such RT membership information, while the Next Hop field contains the address of the advertising router.

There are situations such as those described in [[RFC4925](#)] and in [[RFC5565](#)] where carriers (or large enterprise networks acting as carrier for their internal resources) may be required to establish connectivity between 'islands' of networks of one address family type across a transit core of a differing address family type. This includes both the case of IPv6 islands across an IPv4 core and the case of IPv4 islands across an IPv6 core. Where Multiprotocol BGP (MP-BGP) is used to advertise the corresponding reachability information, this translates into the requirement for a BGP speaker to advertise Network Layer Reachability Information (NLRI) of a given address family via a Next Hop of a different address family (i.e., IPv6 NLRI with IPv4 Next Hop and IPv4 NLRI with IPv6 Next Hop).

The current AFI/SAFI definitions for the IPv6 address family assume that the Next Hop address belongs to the IPv6 address family type. Specifically, as per [\[RFC2545\]](#) and [\[RFC8277\]](#), when the <AFI/SAFI> is <2/1>, <2/2>, or <2/4>, the Next Hop address is assumed to be of IPv6 type. As per [\[RFC4659\]](#), when the <AFI/SAFI> is <2/128>, the Next Hop address is assumed to be of IPv6-VPN type.

However, [\[RFC4798\]](#) and [\[RFC4659\]](#) specify how an IPv4 address can be encoded inside the Next Hop IPv6 address field when IPv6 NLRI needs to be advertised with an IPv4 Next Hop. [\[RFC4798\]](#) defines how the IPv4-mapped IPv6 address format specified in the IPv6 addressing architecture ([\[RFC4291\]](#)) can be used for that purpose when the <AFI/SAFI> is <2/1>, <2/2>, or <2/4>. [\[RFC4659\]](#) defines how the IPv4-mapped IPv6 address format as well as a null Route Distinguisher can be used for that purpose when the <AFI/SAFI> is <2/128>. Thus, there are existing solutions for the advertisement of IPv6 NLRI with an IPv4 Next Hop.

Similarly, the current AFI/SAFI definitions for advertisement of IPv4 NLRI or VPN-IPv4 NLRI assume that the Next Hop address belongs to the IPv4 address family type. Specifically, as per [\[RFC4760\]](#) and [\[RFC8277\]](#), when the <AFI/SAFI> is <1/1>, <1/2>, or <1/4>, the Next Hop address is assumed to be of IPv4 type. As per [\[RFC4364\]](#), when the <AFI/SAFI> is <1/128>, the Next Hop address is assumed to be of VPN-IPv4 type. As per [\[RFC6513\]](#) and [\[RFC6514\]](#), when the <AFI/SAFI> is <1/129>, the Next Hop address is assumed to be of VPN-IPv4 type. There is clearly no generally applicable method for encoding an IPv6 address inside the IPv4 address field of the Next Hop. Hence, there is currently no specified solution for advertising IPv4 or VPN-IPv4 NLRI with an IPv6 Next Hop.

A new specification for carrying IPv4 Network Layer Reachability Information (NLRI) of a given address family via a Next Hop of a different address family is now defined in [\[RFC5549\]](#), and specifies the extensions necessary to do so. This comprises an extension of the AFI/SAFI definitions to allow the address of the Next Hop for IPv4 NLRI or VPN-IPv4 NLRI to belong to either the IPv4 or the IPv6 protocol, the encoding of the Next Hop information to determine which of the protocols the address actually belongs to, and a new BGP Capability allowing MP-BGP peers to dynamically discover whether they

can exchange IPv4 NLRI and VPN- IPv4 NLRI with an IPv6 Next Hop.

With the new extensions defined in [[RFC5549](#)] supporting Network Layer Reachability Information (NLRI) and next hop address family mismatch, the BGP peer session can now be treated as a pure transport and carry both IPv4 and IPv6 NLRI at the PE-CE edge over a single IPv6 TCP session. This allows for the elimination of dual stack from the PE-CE peering point, and now allow the peering to be IPv6-ONLY. The elimination of IPv4 on the PE-CE peering points translates into OPEX expenditure savings of point-to-point infrastructure links as well as /31 address space savings and administration and network management of both IPv4 and IPv6 BGP peers. This reduction decreases the number of PE-CE BGP peers by fifty percent, which is a tremendous cost savings for all Enterprises and Service Providers.

While the savings exists at the PE-CE edge, on the core side PE to Route Reflector peering carrying <AFI/SAFI> IPv4 <1/1>, VPN-IPv4 <1/128>, and Multicasat VPN <1/129>, the cost savings nets to a break even to be the same as with an IPV4 Core carrying IPv6 NLRI IPV6 <2/1>, VPN-IPV6 <2/128>, and Multicasat VPN <2/129>. This document also provides a possible solution for IXPs (Internet Exchange points) that are facing IPv4 address depletion at these peering points to use BGP-MP capability exchange defined in [[RFC5549](#)] to carry IPv4 (Network Layer Reachability Information) NLRI in an IPv6 next hop using the [[RFC5565](#)] software mesh framework.

[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.](#) Extension of AFI/SAFI Definitions for the IPv4 Address Family

As mentioned earlier, MP-BGP specifies that the set of usable next-hop address families is determined by the Address Family Identifier (AFI) and the Subsequent Address Family Identifier (SAFI). The following current AFI/SAFI definitions for the IPv4 NLRI or VPN-IPv4 NLRI (<1/1>, <1/2>, <1/4>, <1/128> and <1/129>) only have provisions

for advertising a Next Hop address that belongs to the IPv4 protocol. This document extends the definition of the AFI/SAFI for advertisement of IPv4 NLRI and VPN-IPv4 NLRI to extend the set of usable next-hop address families to include IPv6 in addition to IPv4.

Specifically, this document allows advertising with [[RFC4760](#)] of an MP_REACH_NLRI with:

- o AFI = 1
- o SAFI = 1, 2, or 4
- o Length of Next Hop Address = 16 or 32
- o Next Hop Address = IPv6 address of next hop (potentially followed by the link-local IPv6 address of the next hop). This field is to be constructed as per [Section 3 of \[RFC2545\]](#).
- o NLRI= NLRI as per current AFI/SAFI definition

It also allows advertising with [[RFC4760](#)] of an MP_REACH_NLRI with:

- o AFI = 1
- o SAFI = 128 or 129
- o Length of Next Hop Address = 24 or 48
- o Next Hop Address = VPN-IPv6 address of next hop with an 8-octet RD set to zero (potentially followed by the link-local VPN-IPv6 address of the next hop with an 8-octet RD is set to zero).
- o NLRI= NLRI as per current AFI/SAFI definition

This is in addition to the current mode of operation allowing advertisement of NLRI for <AFI/SAFI> of <1/1>, <1/2> and <1/4> with a next hop address of IPv4 type and advertisement of NLRI for <AFI/SAFI> of <1/128> and <1/129> with a next hop address of VPN-IPv4 type.

The BGP speaker receiving the advertisement MUST use the Length of Next Hop Address field to determine which network-layer protocol the

next hop address belongs to.

- o When the AFI/SAFI is <1/1>, <1/2> or <1/4> and when the Length of Next Hop Address field is equal to 16 or 32, the next hop address is of type IPv6.
- o When the AFI/SAFI is <1/128>, or <1/129> and when the Length of Next Hop Address field is equal to 24 or 48, the next hop address is of type VPN-IPv6.

Note that this method of using the Length of the Next Hop Address field to determine which network-layer protocol the next hop address belongs to (out of the set of protocols allowed by the AFI/SAFI definition) is the same as used in [[RFC4684](#)] and [[RFC6074](#)].

4. Use of BGP Capability Advertisement

[RFC5492] defines a mechanism to allow two BGP speakers to discover if a particular capability is supported by their BGP peer and thus whether it can be used with that peer. This document defines a new capability that can be advertised using [[RFC5492](#)] and that is referred to as the Extended Next Hop Encoding capability. This capability allows BGP speakers to discover whether, for a given NLRI <AFI/SAFI>, a peer supports advertisement with a next hop whose network protocol is determined by the value of the Length of Next Hop Address field, as specified in [Section 3](#).

A BGP speaker that wishes to advertise to a BGP peer an IPv6 Next Hop for IPv4 NLRI or for VPN-IPv4 NLRI as per this specification MUST use the Capability Advertisement procedures defined in [[RFC5492](#)] with the Extended Next Hop Encoding Capability to determine whether its peer supports this for the NLRI AFI/SAFI pair(s) of interest. The fields in the Capabilities Optional Parameter MUST be set as follows:

- o The Capability Code field MUST be set to 5 (which indicates the Extended Next Hop Encoding capability).
- o The Capability Length field is set to a variable value that is the length of the Capability Value field (which follows).

- o The Capability Value field has the following format:

NLRI AFI - 1 (2 octets)	
NLRI SAFI - 1 (2 octets)	
Nexthop AFI - 1 (2 octets)	
.....	
NLRI AFI - N (2 octets)	
NLRI SAFI - N (2 octets)	
Nexthop AFI - N (2 octets)	

where:

- * each triple <NLRI AFI, NLRI SAFI, Nexthop AFI> indicates that NLRI of <NLRI AFI / NLRI SAFI> may be advertised with a Next Hop address belonging to the network-layer protocol of Nexthop AFI.
- * the AFI and SAFI values are defined in the Address Family Identifier and Subsequent Address Family Identifier registries maintained by IANA.

Since this document only concerns itself with the advertisement of IPv4 NLRI and VPN-IPv4 NLRI with an IPv6 Next Hop, this specification only allows the following values in the Capability Value field of the Extended Next Hop Encoding capability:

- o NLRI AFI = 1 (IPv4)
- o NLRI SAFI = 1, 2, 4, 128 or 129
- o Nexthop AFI = 2 (IPv6)

This document does not specify the use of the Extended Next Hop Encoding capability with any other combinations of <NLRI AFI, NLRI SAFI, Nexthop AFI>. For example, the Next Hop Encoding capability specified in this document is not intended to be used for NLRI AFI/SAFIs whose definition already allows use of both IPv4 and IPv6 next hops (e.g., AFI/SAFI = <1/132> as defined in [[RFC4684](#)]). Similarly,

it is not intended that the Extended Next Hop Encoding capability be used for NLRI AFI/SAFIs for which there is already solution for advertising a next hop of a different address family (e.g., AFI/SAFI = <2/1>, <2/2>, or <2/4> with IPv4 Next Hop as per [[RFC4798](#)] and AFI/SAFI = <2/128> with IPv4 Next Hop as per [[RFC4659](#)]).

It is expected that if new AFI/SAFIs are defined in the future, their definition will have provisions (where appropriate) for both IPv4 and IPv6 Next Hops from the onset, with determination based on Length of Next Hop Address field. Thus, new AFI/SAFIs are not expected to make use of the Extended Next Hop Encoding capability.

A BGP speaker MUST only advertise to a BGP peer the IPv4 or VPN-IPv4 NLRI with an IPv6 Next Hop if the BGP speaker has first ascertained via BGP Capability Advertisement that the BGP peer supports the Extended Next Hop Encoding capability for the relevant AFI/SAFI pair.

The Extended Next Hop Encoding capability provides information about next hop encoding for a given AFI/SAFI, assuming that AFI/SAFI is allowed. It does not influence whether that AFI/SAFI is indeed allowed. Whether a AFI/SAFI can be used between the BGP peers is purely determined through the Multiprotocol Extensions capability defined in [[RFC4760](#)].

The Extended Next Hop Encoding capability MAY be dynamically updated through the use of the Dynamic Capability capability and associated mechanisms defined in [[I-D.ietf-idr-dynamic-cap](#)].

5. Operational Improvements with Single IPv6 transport peer

As Enterprises and Service Providers migrate their IPv4 core to an MPLS LDPv6 or SRv6 transport, they must continue to be able to support legacy IPv4 customers. With the new extensions defined in [[RFC4760](#)], supporting Network Layer Reachability Information (NLRI) and next hop address family mismatch, the BGP peer session can now be treated as a pure transport and carry both IPv4 and IPv6 NLRI at the PE-CE edge. This paves the way to now eliminate dual stacking on all PE-CE peering points to customers making the peering IPv6 only. With this change all IPv4 and IPv6 Network Layer Reachability Information (NLRI) will now be carried over a single BGP session. This also solves the dual stack issue with IXP (Internet Exchange Points) having to maintain separate peering for both IPv4 and IPv6. From an operations perspective the PE-CE edge peering will be drastically simplified with the elimination of IPv4 peers yielding a reduction of peers by 50 percent. From an operations perspective prior to elimination of IPv4 peers an audit is recommended to identify and

prior to elimination of the IPv4 peers. No operational impacts or issues are expected with this change.

[6.](#) Operational Considerations

With a single IPv6 Peer carrying both IPv4 and IPv6 NLRI there are some operational considerations in terms of what changes and what does not change.

What does not change with a single IPv6 transport peer carrying IPv4 NLRI and IPv6 NLRI below:

Routing Policy configuration is still separate for IPv4 and IPv6 configured by capability as previously

Layer 1, Layer 2 issues such as 1 way fiber or fiber cut will impact both IPv4 and IPv6 as previously.

If the interface is admin down the IPv6 peer would go down and IPv4 NLRI and IPv6 NLRI would be withdrawn as previously.

What does change with a single IPv6 transport peer carrying IPv4 NLRI and IPv6 NLRI below:

Physical interface is no longer dual stacked. Any change in IPv6 address or DAD state will impact both IPv4 and IPv6 NLRI exchange

Single BFD session for both IPv4 and IPv6 NLRI fate sharing as the session is now tied to the transport which now is only IPv6 address family

Both IPv4 and IPv6 peer now exists under the IPv4 address family configuration

Fate sharing of IPv4 and IPv6 address family from a logical perspective now carried over a single IPv6 peer

[7.](#) Software Framework Use Cases of IPv4 NLRI with IPv6 Next Hop

[7.1.](#) VPN-IPv4 over MPLS LDPv6 or SRv6 Core

The new MP-BGP extensions defined in [\[RFC5549\]](#) is used to support IPV4 VPNs over an IPv6 MPLS LDPv6 or SRv6 backbone. In this scenario the PE routers would advertise and receive VPN-IPv4 NLRI in the MP_REACH_NLRI along with an IPv6 Next Hop from the Route Reflector (RR).

MP-BGP Reach Pseudo code:

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```
If ((Update AFI == VPN-IPv4)
and (Length of next hop == 24 Bytes || 48 Bytes))
{
This is an VPN-IPv4 route, but
with an IPv6 next hop;
}
```

The MP_REACH_NLRI is encoded with:

- o AFI = 1
- o SAFI = 128
- o Length of Next Hop Network Address = 24 (or 48)
- o Network Address of Next Hop = VPN-IPv6 address of Next Hop whose RD is set to zero
- o NLRI = IPv4-VPN routes

During BGP Capability Advertisement, the PE routers would include the following fields in the Capabilities Optional Parameter:

- o Capability Code set to "Extended Next Hop Encoding"
- o Capability Value containing <NLRI AFI=1, NLRI SAFI=128, Nexthop AFI=2>

[7.2.](#) IPv4 VPN multicast over MPLS LDPv6 or SRv6 Core

The new MP-BGP extensions defined in [\[RFC8126\]](#) is used to support IPV4 Multicast VPNs over an MPLS LDPv6 or SRv6 backbone. In this scenario, the PE routers would advertise and receive VPN-IPv4 NLRI in the MP_REACH_NLRI along with an IPv6 Next Hop from the Route Reflector (RR).

MP-BGP Reach Pseudo code:

```
If ((Update AFI == MVPN-IPv4)
and (Length of next hop == 24 Bytes || 48 Bytes))
{
```

```
This is an MVPN-IPv4 route, but
with an IPv6 next hop;
}
```

The MP_REACH_NLRI is encoded with:

- o AFI = 1
- o SAFI = 129
- o Length of Next Hop Network Address = 24 (or 48)
- o Network Address of Next Hop = VPN-IPv6 address of Next Hop whose RD is set to zero
- o NLRI = IPv4-VPN routes

During BGP Capability Advertisement, the PE routers would include the following fields in the Capabilities Optional Parameter:

- o Capability Code set to "Extended Next Hop Encoding"
- o Capability Value containing <NLRI AFI=1, NLRI SAFI=129, Nexthop

AFI=2>

[7.3.](#) IPv4 Islands over MPLS LDPv6 or SRv6 Core

The new MP-BGP extensions defined in [[RFC5549](#)] is used to support IPv4 islands over an IPv6 MPLS LDPv6 or SRv6 backbone. In this scenario the PE routers would use BGP labeled unicast address family (BGP-LU) to advertise BGP with label binding and receive labeled IPv4 NLRI in the MP_REACH_NLRI along with an IPv6 Next Hop from the Route Reflector (RR).

MP-BGP Reach Pseudo code:

```
If ((Update AFI == IPv4)
and (Length of next hop == 16 Bytes || 32 Bytes))
{
This is an IPv4 route, but
with an IPv6 next hop;
```

```
}
```

The MP_REACH_NLRI is encoded with:

- o AFI = 1
- o SAFI = 1
- o Length of Next Hop Network Address = 16 (or 32)
- o Network Address of Next Hop = IPv6 address of Next Hop whose RD is set to zero
- o NLRI = IPv4-VPN routes

During BGP Capability Advertisement, the PE routers would include the following fields in the Capabilities Optional Parameter:

- o Capability Code set to "Extended Next Hop Encoding"
- o Capability Value containing <NLRI AFI=1, NLRI SAFI=1, Nexthop AFI=2>

8. IANA Considerations

There are not any IANA considerations.

9. Security Considerations

The extensions defined in this document allow BGP to propagate reachability information about IPv6 routes over an MPLS IPv4 core network. As such, no new security issues are raised beyond those that already exist in BGP-4 and use of MP-BGP for IPv6. The security features of BGP and corresponding security policy defined in the ISP domain are applicable. For the inter-AS distribution of IPv6 routes according to case (a) of [Section 4](#) of this document, no new security issues are raised beyond those that already exist in the use of eBGP for IPv6 [[RFC2545](#)].

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Appendix A. IPv4 NLRI IPv6 Next Hop Vendor Testing

IPv4 NLRI with IPv6 Next Hop encoding is supported for all BGP peers both iBGP and eBGP.

This section details the vendor support of [RFC5549](#) "PE-RR iBGP", "PE-CE eBGP" using GUA (Global Unicast Address), Link Local (LL) peering and Quality Assurance lab testing. This drafts goal is to ensure that all features and functionality works with "eBGP PE-CE" use case single peer carrying both IPv4 NLRI and IPv6 NLRI and that the routing policy features are all still fully functionality do not change.

A.1. Router and Switch Vendors Support and Quality Assurance Engineering Lab Results.

Vendor	PE-RR iBGP	PE-CE eBGP GUI	PE-CE eBGP LL	QA Tested
Cisco	***	***		
Juniper	***	***		
Nokia/ALU	***	***		
Arista				
Huawei				

Table 1: Vendor Support

A.2. Router and Switch Vendors Interoperability Lab Results.

This section details the vendor interoperability testing and support of [RFC5549](#) that all features and functionality works with "eBGP PE-CE" use case with having a single peer carrying both IPv4 NLRI and IPv6 NLRI and that the routing policy features are fully tested for quality assurance.

Vendor	Cisco	Juniper	Nokia/ALU	Arista	Huawei
Cisco					
Juniper					
Nokia/ALU					
Arista					
Huawei					

Table 2: Vendor Interop

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