IPv4 routes with an IPv6 next hop in the Babel routing protocol

Abstract

This document defines an extension to the Babel routing protocol
that allows annoncing routes to an IPv4 prefix with an IPv6 next-
hop, which makes it possible for IPv4 traffic to flow through
interfaces that have not been assigned an IPv4 address. This
document updates RFC 8966.

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1. Introduction

The role of a routing protocol is to build a routing table, a data
structure that maps network prefixes in a given family (IPv4 or
IPv6) to next hops, pairs of an outgoing interface and a neighbour's
network address, for example:

```
      destination                     next hop
   2001:db8:0:1::/64            eth0, fe80::1234:5678
   203.0.113.0/24              eth0, 192.0.2.1
```

When a packet is routed according to a given routing table entry,
the forwarding plane typically uses a neighbour discovery protocol
(the Neighbour Discovery protocol (ND) [RFC4861] in the case of
IPv6, the Address Resolution Protocol (ARP) [RFC0826] in the case of
IPv4) to map the next-hop address to a link-layer address (a "MAC
address"), which is then used to construct the link-layer frames
that encapsulate forwarded packets.

It is apparent from the description above that there is no
fundamental reason why the destination prefix and the next-hop
address should be in the same address family: there is nothing
preventing an IPv6 packet from being routed through a next hop with
an IPv4 address (in which case the next hop's MAC address will be
obtained using ARP), or, conversely, an IPv4 packet from being
routed through a next hop with an IPv6 address. (In fact, it is even
possible to store link-layer addresses directly in the next-hop

entry of the routing table, which is commonly done in networks using the OSI protocol suite).

The case of routing IPv4 packets through an IPv6 next hop is particularly interesting, since it makes it possible to build networks that have no IPv4 addresses except at the edges and still provide IPv4 connectivity to edge hosts. In addition, since an IPv6 next hop can use a link-local address that is autonomously configured, the use of such routes enables a mode of operation where the network core has no statically assigned IP addresses of either family, which significantly reduces the amount of manual configuration required.

We call a route towards an IPv4 prefix that uses an IPv6 next hop a "v4-via-v6" route. This document describes an extension that allows the Babel routing protocol [RFC8966] to announce v4-via-v6 routes across interfaces that have no IPv4 addresses assigned. Section 3 describes procedures that ensure that all routers can originate ICMPv4 packets, even if they have not been assigned any IPv4 addresses.

The extension described in this document is inspired by a previously defined extension to the BGP protocol [RFC5549]. This document updates [RFC8966].

1.1. Specification of Requirements

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. Protocol operation

The Babel protocol fully supports dual-stack operation: all data that represent a neighbour address or a network prefix are tagged by an Address Encoding (AE), a small integer that identifies the address family (IPv4 or IPv6) of the address of prefix, and describes how it is encoded. This extension defines a new AE, called v4-via-v6, which has the same format as the existing AE for IPv4 addresses. This new AE is only allowed in TLVs that carry network prefixes: TLVs that carry a neighbour address use one of the normal encodings for IPv6 addresses.

2.1. Announcing v4-via-v6 routes

A Babel node can use a v4-via-v6 announcement to announce an IPv4 route over an interface that has no assigned IPv4 address. In order to do so, it first establishes an IPv6 next-hop address in the usual

manner (either by sending the Babel packet over IPv6, or by
including a Next Hop TLV containing an IPv6 address and using AE 2
or 3); it then sends an Update, with AE equal to 4 (v4-via-v6)
containing the IPv4 prefix being announced.

If the outgoing interface has been assigned an IPv4 address, then,
in the interest of maximising compatibility with existing routers,
the sender SHOULD prefer an ordinary IPv4 announcement; even in that
case, however, it MAY send a v4-via-v6 announcement. A node SHOULD
NOT send both ordinary IPv4 and v4-via-v6 announcements for the same
prefix over a single interface (if the update is sent to a multicast
address) or to a single neighbour (if sent to a unicast address),
since doing that provides no benefit while doubling the amount of
routing traffic.

Updates with infinite metric are retractions: they indicate that a
previously announced route is no longer available. Retractions do
not require a next hop, and there is therefore no difference between
v4-via-v6 retractions and ordinary retractions. A node MAY send IPv4
retractions only, or it MAY send v4-via-v6 retractions on interfaces
that have not been assigned an IPv4 address.

2.2. Receiving v4-via-v6 routes

Upon reception of an Update TLV with AE equal to 4 (v4-via-v6) and
finite metric, a Babel node computes the IPv6 next hop, as described
in Section 4.6.9 of [RFC8966]. If no IPv6 next hop exists, then the
Update MUST be silently ignored. If an IPv6 next hop exists, then
the node MAY acquire the route being announced, as described in
Section 3.5.3 of [RFC8966]; the parameters of the route are as
follows:

   *the prefix, plen, router-id, seqno, metric MUST be computed as
    for an IPv4 route, as described in Section 4.6.9 of [RFC8966];

   *the next hop MUST be computed as for an IPv6 route, as described
    in Section 4.6.9 of [RFC8966]: it is taken from the last
    preceding Next Hop TLV with an AE field equal to 2 or 3; if no
    such entry exists, and if the Update TLV has been sent in a Babel
    packet carried over IPv6, then the next hop is the network-layer
    source address of the packet.

An Update TLV with a v4-via-v6 AE and metric equal to infinity is a
retraction: it announces that a previously available route is being
retracted. In that case, no next hop is necessary, and the
retraction is treated as described in Section 4.6.9 of [RFC8966].

As usual, a node MAY ignore the update, e.g., due to filtering
(Appendix C of [RFC8966]). If a node cannot install v4-via-v6
routes, e.g., due to hardware or software limitations, then routes

to an IPv4 prefix with an IPv6 next hop MUST NOT be selected, as
described in Section 3.5.3 of [RFC8966].

2.3. Prefix and seqno requests

Prefix and seqno requests are used to request an update for a given
prefix. Since they are not related to a specific next hop, there is
no semantic difference between IPv4 and v4-via-v6 requests.
Therefore, a node SHOULD NOT send requests of either kind with the
AE field being set to 4 (v4-via-v6); instead, it SHOULD request IPv4
updates by sending requests with the AE field being set to 1 (IPv4).

When receiving requests, AEs 1 (IPv4) and 4 (v4-via-v6) MUST be
treated in the same manner: the receiver processes the request as
described in Section 3.8 of [RFC8966]. If an Update is sent, then it
MAY be sent with AE 1 or 4, as described in Section 2.1 above,
irrespective of which AE was used in the request.

When receiving a request with AE 0 (wildcard), the receiver SHOULD
send a full route dump, as described in Section 3.8.1.1 of
[RFC8966]. Any IPv4 routes contained in the route dump MAY use
either AE 1 (IPv4) or AE 4 (v4-via-v6), as described in Section 2.1
above.

2.4. Other TLVs

The only other TLVs defined by [RFC8966] that carry an AE field are
Next Hop and TLV. Next Hop and IHU TLVs MUST NOT carry the AE 4 (v4-
via-v6).

3. ICMPv4 and PMTU discovery

The Internet Control Message Protocol (ICMPv4, or simply ICMP)
[RFC0792] is a protocol related to IPv4 that is primarily used to
carry diagnostic and debugging information. ICMPv4 packets may be
originated by end hosts (e.g., the "destination unreachable, port
unreachable" ICMPv4 packet), but they may also be originated by
intermediate routers (e.g., most other kinds of "destination
unreachable" packets).

Some protocols deployed in the Internet rely on ICMPv4 packets sent
by intermediate routers. Most notably, path MTU Discovery (PMTUd)
[RFC1191] is an algorithm executed by end hosts to discover the
maximum packet size that a route is able to carry. While there exist
variants of PMTUd that are purely end-to-end [RFC4821], the variant
most commonly deployed in the Internet has a hard dependency on
ICMPv4 packets originated by intermediate routers: if intermediate
routers are unable to send ICMPv4 packets, PMTUd may lead to
persistent blackholing of IPv4 traffic.

Due to this kind of dependency, every Babel router that is able to
forward IPv4 traffic MUST be able originate ICMPv4 traffic. Since
the extension described in this document enables routers to forward
IPv4 traffic received over an interface that has not been assigned
an IPv4 address, a router implementing this extension MUST be able
to originate ICMPv4 packets even when the outgoing interface has not
been assigned an IPv4 address.

In such a situation, if a Babel router has an interface that has
been assigned an IPv4 address, or if an IPv4 address has been
assigned to the router itself (to the "loopback interface"), then
that IPv4 address may be used as the source of originated ICMPv4
packets. If no IPv4 address is available, a Babel router could use
the experimental mechanism described in Section 22 of [RFC7600],
which consists of using the dummy address 192.0.0.8 as the source
address of originated ICMPv4 packets. Note however that using the
same address on multiple routers may hamper debugging and fault
isolation, e.g., when using the "traceroute" utility.

4. Protocol encoding

This extension defines the v4-via-v6 AE, whose value is 4. This AE
is solely used to tag network prefixes, and MUST NOT be used to tag
neighbour addresses, e.g. in Next Hop or IHU TLVs.

This extension defines no new TLVs or sub-TLVs.

4.1. Prefix encoding

Network prefixes tagged with AE 4 (v4-via-v6) MUST be encoded and
decoded just like prefixes tagged with AE 1 (IPv4), as described in
Section 4.3.1 of [RFC8966].

A new compression state for AE 4 (v4-via-v6) distinct from that of
AE 1 (IPv4) is introduced, and MUST be used for address compression
of prefixes tagged with AE 4, as described in Section 4.6.9 of
[RFC8966]

4.2. Changes to existing TLVs

The following TLVs MAY be tagged with AE 4 (v4-via-v6):

  *Update (Type = 8)

  *Route Request (Type = 9)

  *Seqno Request (Type = 10)

As AE 4 (v4-via-v6) is suitable only for network prefixes, IHU
(Type = 5) and Next-Hop (Type = 7) TLVs MUST NOT be tagged with AE
4. Such (incorrect) TLVs MUST be ignored upon reception.

4.2.1. Update

An Update (Type = 8) TLV with AE 4 is constructed as described in
Section 4.6.9 of [RFC8966] for AE 1 (IPv4), with the following
specificities:

   *Prefix. The Prefix field is constructed according to Section 4.1
    above.

   *Next Hop. The next hop is determined as described in Section 2.2
    above.

4.2.2. Other TLVs

When tagged with the AE 4, Route Request and Seqno Request updates
MUST be constructed and decoded as described in Section 4.6 of
[RFC8966], and the network prefixes contained within them decoded as
described in Section 4.1 above.

5. Backwards compatibility

This protocol extension adds no new TLVs or sub-TLVs.

This protocol extension uses a new AE. As discussed in Appendix D of
[RFC8966] and specified in the same document, implementations that
do not understand the present extension will silently ignore the
various TLVs that use this new AE. As a result, incompatible
versions will ignore v4-via-v6 routes. They will also ignore
requests with AE 4, which, as stated in Section 2.3, are NOT
RECOMMENDED.

Using a new AE introduces a new compression state, used to parse the
network prefixes. As this compression state is separate from other
AEs' states, it will not interfere with the compression state of
unextended nodes.

This extension reuses the next-hop state from AEs 2 and 3 (IPv6),
but makes no changes to the way in which it is updated, and
therefore causes no compatibility issues.

As mentioned in Section 2.1, ordinary IPv4 announcements are
preferred to v4-via-v6 announcements when the outgoing interface has
an assigned IPv4 address; doing otherwise would prevent routers that
do not implement this extension from learning the route being
announced.

6. IANA Considerations

IANA has allocated value 4 in the "Babel Address Encodings" registry as follows:

AE	Name	Reference
4	v4-via-v6	(this document)

Table 1

7. Security Considerations

The extension defined in this document does not fundamentally change the security properties of the Babel protocol. However, by allowing IPv4 routes to be propagated across routers that have not been assigned IPv4 addresses, it might invalidate the assumptions made by network administrators, which could conceivably lead to security issues.

For example, if an island of IPv4-only hosts is separated from the IPv4 Internet by routers that have not been assigned IPv4 addresses, a network administrator might reasonably assume that the IPv4-only hosts are unreachable from the IPv4 Internet. This assumption is broken if the intermediary routers implement the extension described in this document, which might expose the IPv4-only hosts to traffic from the IPv4 Internet. If this is undesirable, the flow of IPv4 traffic must be restricted by the use of suitable filtering rules (Appendix C of [RFC8966]) together with matching packet filters in the data plane.

8. Acknowledgments

This protocol extension was originally designed, described and implemented in collaboration with Theophile Bastian. Margaret Cullen pointed out the issues with ICMP and helped coin the phrase "v4-via-v6". The author is also indebted to Donald Eastlake, Toke Hoiland-Jorgensen, David Schinazi, and Donald Sharp.

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