Network Working Group   R. Bush
Internet-Draft   Arrcus & Internet Initiative Japan
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Expires: 29 November 2023   Vigil Security
                                                         R. Austein
                                                             Arrcus
                                                           S. Hares
                                             Hickory Hill Consulting
                                                           K. Patel
                                                             Arrcus
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                      Layer-3 Neighbor Discovery
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Abstract

   Data Centers where the topology is BGP-based need to discover
   neighbor IP addressing, IP Layer-3 BGP neighbors, etc. This Layer-3
   Neighbor Discovery protocol identifies BGP neighbor candidates.

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.

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1. Introduction

   The Massive Data Center (MDC) environment presents unusual problems
   of scale, e.g. O(10,000) forwarding devices, while its homogeneity
   presents opportunities for simple approaches. Layer-3 Discovery and
   Liveness (L3DL), [I-D.ietf-lsvr-l3dl], provides neighbor discovery at
   Layer-2. This document (set) provides a similar solution at Layer-3,
   attempting to be as similar as reasonable to L3DL.

   Some guiding principles when dealing with datacenters with tens of
   thousands of devices are

   * Predictable Reliability,

   * Security: Authorization and Integrity more than Confidentiality,
      and

   * Massive Scalability

   Layer-3 Neighbor Discovery (L3ND) provides brutally simple mechanisms
   for neighboring devices to

   * Discover each other's IP Addresses,

   * Discover mutually supported layer-3 encapsulations, e.g. IPv4/
      IPv6//MPLS,

   * Discover Layer-3 IP and/or MPLS addressing of interfaces of the
      encapsulations,

   * Provide authenticity, integrity, and verification of protocol
      messages, and

   * Accommodate scaling needed for EVPN etc.

L3ND is intended for use within single IP subnets (IP over Ethernet or other point-to-point or multi-point IP link) in order to exchange the data needed to bootstrap BGP-based peering, EVPN, etc.; especially in a datacenter Clos [Clos] environment. Once IP connectivity has been leveraged to discover layer-3 addressability and forwarding capabilities, normal IP forwarding and routing can take over.

L3ND might be more widely applicable to a range of routing and similar protocols which need Layer-3 neighbor discovery.

2. Terminology

Even though it concentrates on the inter-device layer, this document relies heavily on routing terminology. The following attempts to clarify the use of some possibly confusing terms:

Clos: A hierarchic subset of a crossbar switch topology commonly used in data centers [Clos].

Datagram: The L3ND content of a single Layer-3 UDP Datagram.

Encapsulation: Address Family Indicator and Subsequent Address Family Indicator (AFI/SAFI). I.e. classes of Layer-2.5 and Layer-3 addresses such as IPv4, IPv6, MPLS.

Link or Logical Link: A logical connection between two interfaces on two different devices. E.g. two VLANs between the same two ports are two links.

MDC: Massive Data Center, commonly composed of thousands of Top of Rack Switches (TORs).

MTU: Maximum Transmission Unit, the size in octets of the largest packet that can be sent on a medium, see [RFC1122] 1.3.3.

PDU: Protocol Data Unit, an L3ND application layer message.

Session: An established, via exchange of OPEN PDUs, session between two L3ND capable IP interfaces on a link.

TOR Switch: Top Of Rack switch, aggregates the servers in a rack and connects to aggregation layers of the Clos tree, AKA the Clos spine.

3. Background

   L3ND is primarily designed for a Clos type datacenter scale and
   topology, but can accommodate richer topologies which contain
   potential cycles.

   While L3ND is designed for the MDC, there are no inherent reasons it
   could not run on a WAN. The authentication and authorization needed
   to run safely on a WAN need to be considered, and the appropriate
   level of security options chosen.

   The number of addresses of one Encapsulation type on an interface
   link may be quite large given a TOR switch with tens of servers, each
   server having a few hundred micro-services, resulting in an
   inordinate number of addresses. And highly automated micro-service
   migration can cause serious address prefix disaggregation, resulting
   in interfaces with thousands of disaggregated prefixes.

   To meet such scaling needs, the L3ND protocol is session oriented and
   uses incremental announcement and withdrawal with session restart, a
   la BGP ([RFC4271]).

4. Inter-Link Protocol Overview

   A device broadcasts a Layer-3 Multicast UDP datagram (HELLO)
   containing the port number that is willing to serve a TLS or raw TCP
   connection to support the data exchange of the rest of the protocol
   in a reliable and preferably authenticated manner.

   Another device on the link then establishes a TLS or raw TCP session
   in which inter-device PDUs are used to exchange device and logical
   link identities and layer-2.5 (MPLS) and 3 identifiers (not
   payloads), e.g. more IP Addresses, loopback addresses, port
   identities, and Encapsulations.

   To assure discovery of new devices coming up on a multi-link
   topology, devices on such a topology, and only on a multi-link
   topology, send periodic HELLOs forever, see Section 12.1.

   Given the TLS/TCP session, OPEN PDUs (Section 8) are exchanged, the
   Encapsulations (Section 10) configured on an end point may be
   announced and modified. Note that these are only the encapsulation
   and addresses configured on the announcing interface; though a
   device's loopback and overlay interface(s) may also be announced.

4.1. L3ND Ladder Diagram

   The HELLO, Section 6, is a priming message sent on all logical links
   configured for L3ND. It is a small L3ND Multicast UDP PDU with the
   simple goal of advertising a TLS/TCP service available on an
   advertised port on the sending IP interface.

   The HELLO PDU is either IPv4 or IPv6, which selects the AFI to be
   used for the rest of the session(s) between end-points. Two
   endpoints MAY establish a link for each AFI.

   An interface on the link receiving the HELLO PDU attempts to
   establish a TLS or raw TCP, as specified by the HELLO, session to the
   source IP address of the HELLO on the port advertised in the HELLO.

   The OPEN, Section 8 PDUs, used to exchange details about the L3ND
   session, and the ACK/ERROR PDU, are mandatory; other PDUs are
   optional; though at least one encapsulation SHOULD be agreed at some
   point.

   Like Multi-Protocol BGP, [RFC4760], an L3ND session running over one
   AFI MAY carry encapsulations etc. of different AFIs,

   A L3DL extension, [I-D.ymbk-idr-l3nd-ulpc], describes the next upper
   layer L3DL protocol to exchange BGP parameter information.

   The following is a ladder-style diagram of the L3ND protocol
   exchanges:

```
|            HELLO             | Logical Link Peer discovery
|----------------------------->|
|           TCP OPEN           | Mandatory
|<-----------------------------|
|                              |
|                              |
|            OPEN              | IDs, security, etc.
|----------------------------->|
|            ACK               |
|<-----------------------------|
|                              |
|            OPEN              | Mandatory
|<-----------------------------|
|            ACK               |
|----------------------------->|
|                              |
|                              |
|    Interface IPv4 Addresses  | Interface IPv4 Addresses
|----------------------------->| Optional
```

```
         |                   ACK                   |
         |<----------------------------------------|
         |                                         |
         |        Interface IPv4 Addresses         |
         |<----------------------------------------|
         |                   ACK                   |
         |---------------------------------------->|
         |                                         |
         |                                         |
         |        Interface IPv6 Addresses         | Interface IPv6 Addresses
         |---------------------------------------->| Optional
         |                   ACK                   |
         |<----------------------------------------|
         |        Interface IPv6 Addresses         |
         |<----------------------------------------|
         |                   ACK                   |
         |---------------------------------------->|
         |                                         |
         |                                         |
         |        Interface MPLSv4 Labels          | Interface MPLSv4 Labels
         |---------------------------------------->| Optional
         |                   ACK                   |
         |<----------------------------------------|
         |        Interface MPLSv4 Labels          | Interface MPLSv4 Labels
         |<----------------------------------------| Optional
         |                   ACK                   |
         |---------------------------------------->|
         |                                         |
         |                                         |
         |        Interface MPLSv6 Labels          | Interface MPLSv6 Labels
         |---------------------------------------->| Optional
         |                   ACK                   |
         |<----------------------------------------|
         |                                         |
         |        Interface MPLSv6 Labels          | Interface MPLSv6 Labels
         |<----------------------------------------| Optional
         |                   ACK                   |
         |---------------------------------------->|
```

5. TLV PDUs

   The basic L3ND application layer PDU is a typical TLV (Type Length
   Value) PDU. As it is transported over TCP, integrity is assured.
   When it is transported over TLS, authenticity is also provided.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Version = 0  |    PDU Type   |          Payload Length     ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                               |                               ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                               ~
~                          Payload ...                          ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
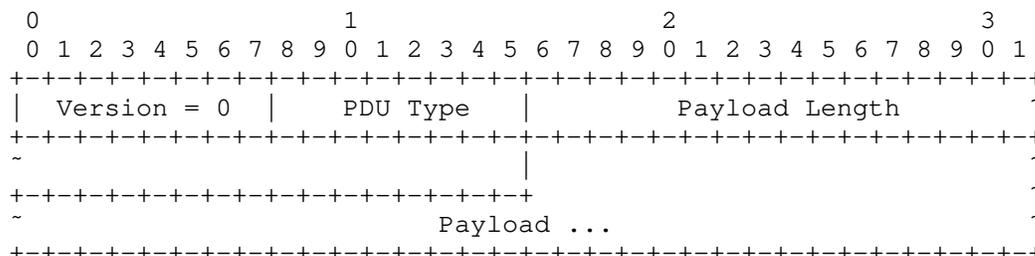
The fields of the basic L3ND header are as follows:

Version: An integer differentiating versions of the L3ND protocol.
   Currently only Version 0 MAY BE specified.

PDU Type: An integer differentiating PDU payload types. See
   Section 16.3.

Payload Length: Total number of octets in the Payload field.

Payload: The application layer content of the L3ND PDU.

6. HELLO

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Version = 0  |  PDU Type = 0 |       Payload Length = 4      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                               |    Transport  |     Flags     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             Port              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
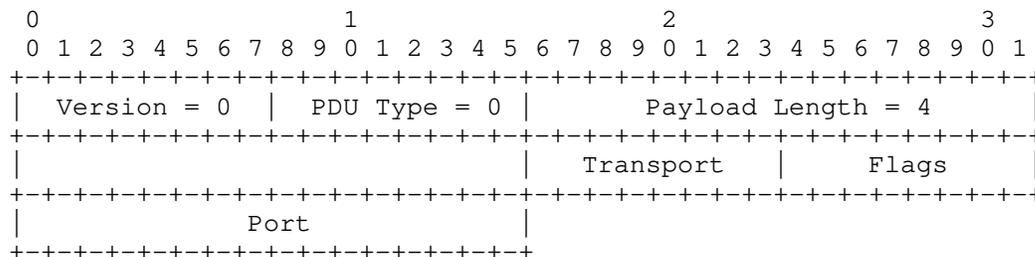
The Payload Length is 4 to cover the Transport, Flags, and Port
fields.

The IPv4 UDP packets are sent to the IPv4 link local multicast
address (TBD1) and the IPv6 UDP packets are sent to an IPv6 link
Local multicast address (TBD2). See Section 12.1 for why multicast
is used.

The HELLO PDU solicits a unicast TLS/TCP session open request of the
same AFI from other devices on the link.

When a HELLO is received from a source IP address with which there is
no established TLS/TCP L3ND session, if the receiver has the higher
of the two IP addresses, it SHOULD respond by sending a TLS/TCP
client open request, using the same AFI, to the source IP address of
the HELLO to establish an L3ND TLS/TCP session.

All L3ND PDUs other than HELLO are sent via TLS/TCP, as the server's
destination IP address is known after the HELLO.

When an interface is turned up on a device, it SHOULD issue a HELLO
if it is configured to participate in L3ND sessions and repeat HELLOs
at a configured interval, with a default of 60 seconds.

If the configured multicast destination address is one that is
propagated by switches, the HELLO SHOULD be repeated at a configured
interval, with a default of 60 seconds. This allows discovery by new
devices which come up on the mesh. In this multi-link scenario, the
operator should be aware of the trade-off between timer tuning and
network noise and adjust the inter-HELLO timer accordingly.

By default, GTSM, [RFC5082], SHOULD be enabled to test that a
received HELLO MUST be on the local link; thus leaving no middle on
which a monkey in the middle might stand. It MAY be disabled by
configuration. GTSM check failures SHOULD be logged, though with
rate limiting to keep from overwhelming logs.

If more than one device responds, one adjacency is formed for each
unique source IP address. L3ND treats each adjacency as a separate
logical link.

To ameliorate possible load spikes during bootstrap or event
recovery, there SHOULD be a jittered delay between receipt of a HELLO
and TLS/TCP open. The default delay range SHOULD be zero to five
seconds, and MUST be configurable.

If a HELLO is received from an IP Address with which there is an
established session for that AFI, the HELLO SHOULD be dropped.

A device with a TLS/TCP listener SHOULD log or otherwise report
repeated failed inbound attempts.

6.1. Transport

The Transport signals the type of transport security for the session.

The actual transport options are actually pre-configured in the
devices by provisioning, as most require certificates etc. It is
best to think of this field as in-band signaling to conform the

correctness of the pre-configurations. Any disagreements MUST BE considered to indicate an error condition and brought to the attention of the operator.

The Transport field is an enumeration with the following values:

0: Raw TCP: TLS is not used.

1: TLS TOFU: TLS using a self-signed server certificate.

2: TLS CA-NoIP: TLS using a CA-Based server certificate, with no IP address extension.

3: TLS CA WithIP: TLS using a CA-Based server certificate, with the server's IP address in the subject alternative name extension (see [RFC5280] Section 4.2.1.6).

4-255: Reserved.

If server certificates are to be used, they may be locally generated and then signed by a CA or generated by the CA and loaded. See [RFC8635].

6.2. Flags

Though the Working Group scope for this protocol is within a data center, an issue was raised that, on an internet echange with route server(s), it would attempt to form adjacencies with all members of the exchange. Hence a Flag field is provided to indicate that a device does not intend to field a TLS/TCP server on the announcing interface, but does seek one or more from peers.

Currently, only one Flags field is defined

Bit 0: Client Only This interface does not provide a TLS/TCP server.

Bits 1-7: Reserved.

6.3. Port

The Port is the two octet TCP Port Number (default is TBD3) on which the HELLO sender SHOULD have a waiting TLS/TCP (as specified in Flags) server listening unless the Client Only Flag is set. Though the IANA assigned well-known port SHOULD be used, this field allows configuration of alternate ports.

7. TCP Set-Up

   As it is assumed that the configured deployment of a data center
   would have compatible parameters on all devices, any disagreement
   over TLS/TCP or trust anchors MUST be logged; with rate limiting of
   the logging.

   By default, GTSM, [RFC5082], SHOULD be enabled to ensure that a SYN
   received in response to a HELLO is on the local link. It MAY be
   disabled by configuration. GTSM check failures SHOULD be logged;
   though with rate limiting to keep from overwhelming logs.

   If the receiver of a HELLO agrees with the sender's choice of TLS/TCP
   and authentication, both sides have agreed on an AFI for the
   transport and on each other's IP address in that AFI. This is
   sufficient to open a TCP session between them, which will allow for
   reliable transport of very large data PDUs while obviating the need
   to invent complex transports.

   The L3ND peer with the higher IP address MUST act as the TLS/TCP
   client and open the transport session (send SYN) toward the peer with
   the lower IP address.

   The server, the sender of the HELLO from the lower IP address,
   listens on the advertised port for the TLS/TCP session open. The
   receiver of the acceptable HELLO, the TLS/TCP client, initiates a TLS
   or raw TCP session toward the sender of the HELLO, the TLS/TCP
   server, preferably TLS, as advertised. If TLS, the server has chosen
   and signaled either a self-signed certificate or one configured from
   the operational CA trusted by both parties, as negotiated in the
   HELLO exchange.

   Once the TLS/TCP session is established, if its interface is
   configured as point to point, the client side SHOULD stop listening
   on any port for which it has sent a HELLO. The server, if configured
   as a point to point interface SHOULD stop sending HELLOs.

   If the TLS/TCP open fails, then this SHOULD be logged and the parties
   MUST go back to the initial state and try HELLO. Logging SHOULD be
   rate limited.

   Should an interface with an established TLS/TCP session be
   reconfigured changing the TLS/TCP parameters, the TLS/TCP session
   should be closed or torn down and both parties should return to the
   HELLO state.

   Should the TLS/TCP session terminate for any reason, the devices
   SHOULD restart/resume HELLOs. When the new TLS/TCP session is
   started, if possible the OPEN PDU SHOULD try to resume the lost
   logical session by using the same nonce and resuming from the last
   Serial Number.

   Once the TLS/TCP session has been established, the two devices
   exchange L3ND PDUs, starting with OPENs.

8. OPEN

   Each device has learned the other's IP Address from the HELLO
   exchange, see Section 6 and established a TLS/TCP session over a
   particular AFI.

   The first PDU each sends MUST be an OPEN, and the other side MUST
   respond with an ACK PDU.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |  Version = 0  |  PDU Type = 1 |          Payload Length      ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                               |          Session ID          ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                               |          Serial Number       ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                               | AttrCount     |              ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+              +
   ~                       Attribute List ...                     ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
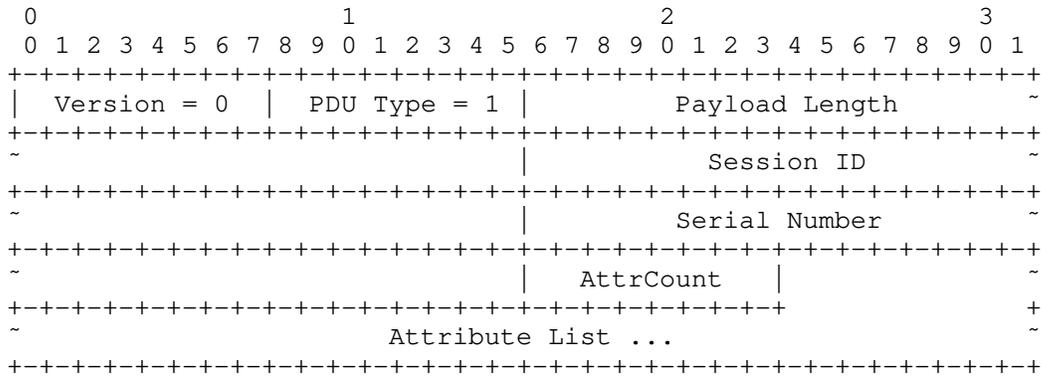
   The four octet Payload Length is the number of octets in all fields
   of the PDU from the Session ID through the Serial Number.

   The four octet Session ID is a nonce which uniquely identifies a
   session. It enables detection of a duplicate OPEN PDU. It SHOULD be
   either a random number or a high resolution timestamp. It is needed
   to prevent session closure due to a repeated OPEN caused by a race or
   a dropped or delayed ACK. It can be used to resume a dropped logical
   session.

   The one octet AttrCount is the number of attributes in the Attribute
   List. A node may send zero or more attributes.

   Attributes are single octets the semantics of which are operator-
   defined, e.g.: spine, leaf, backbone, route reflector, arabica, ...

Attribute syntax and semantics are local to an operator or
datacenter; hence there is no global registry. Nodes exchange their
attributes only in the OPEN PDU.

Unlike L3DL [I-D.ietf-lsvr-l3dl], there are no verifiable keys in the
PDUs. If the operator wants authentication, integrity,
confidentiality, then TLS MUST have been requested by the HELLO and
agreed by the TLS session open.

The Serial Number is a monotonically increasing four octet value
representing the sender's state at the time of sending the last PDU.
It may be a non-negative integer, a timestamp, etc. If incrementing
the Serial Number would cause it to be zero, it should be incremented
again.

On session restart (new OPEN, same Session ID), a receiver MAY send
the last received Serial Number to tell the sender to only send data
with a Serial Number greater (in the [RFC1982] sense), or send a
Serial Number of zero to request all data.

This allows a sender of an OPEN to tell the receiver that the sender
would like to resume a logical session and that the receiver of the
OPEN PDU only needs to send data starting with the PDU with the
lowest Serial Number greater (in the [RFC1982] sense) than the one
sent in the OPEN. If the sender is not trying to resume a dropped
session, the Serial Number MUST be zero.

If the receiver of an OPEN PDU with a non-zero Serial Number can not
resume from the requested point, it should return an ACK with an
Error Code of 5, Session May Not Be Continued, EType of 1. The
sender of the failing OPEN PDU SHOULD respond with an OPEN PDU with a
Serial Number of zero.

If a sender of OPEN does not receive an ACK of the OPEN PDU in a
configurable time (default 5 seconds), then they SHOULD close or
otherwise terminate the TLS/TCP session and restart from the HELLO
state.

If an OPEN arrives at L3ND speaker A from B with which A believes it
already has an L3ND session (i.e. OPENs have already been
exchanged), and the Serial Number in B's OPEN PDU is non-zero,
speaker A SHOULD establish a new sending session by sending an OPEN
with the Serial Number being the same as that of A's last sent and
ACKed PDU. A MUST resume sending encapsulations etc. subsequent to
the requested Sequence Number. And B MUST retain all previously
discovered encapsulation and other data received from A.

If an OPEN arrives at L3ND speaker A from B with which A believes it
already has an L3ND session (i.e. OPENs have already been
exchanged), and the Serial Number in B's OPEN is zero, then the A
MUST assume that B's internal state has been reset. All Previously
discovered encapsulation data MUST BE discarded; and A MUST respond
with a new OPEN PDU with a Serial Number of zero.

TCP KeepAlives should be configured and tuned to meet local
operational needs. Some defaults and recommendations are needed
here.

9. ACK

The ACK PDU acknowledges receipt of a PDU and reports any error
condition which might have been raised.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Version = 0  |  PDU Type = 3 |      Payload Length = 6       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                               |   ACKed PDU   |     EType     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|           Error Code          |           Error Hint          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
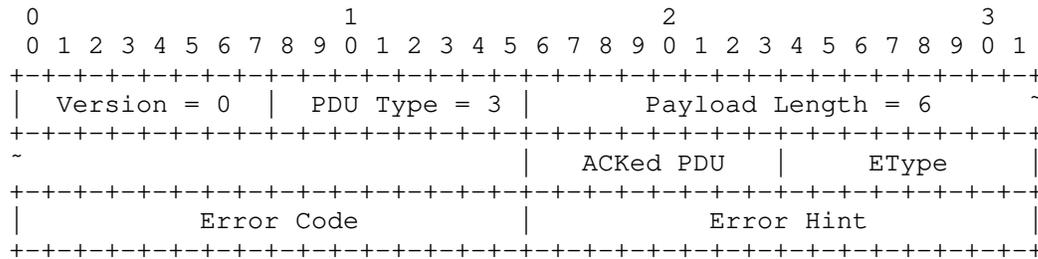
The ACK PDU acknowledges receipt of an OPEN, Encapsulation, Vendor
PDU, etc. and is used to return error codes if any.

The one octet ACKed PDU is the PDU Type of the PDU being
acknowledged, e.g., OPEN, one of the Encapsulations, etc.

If there was an error processing the received PDU, then the one octet
EType is non-zero. If the EType is zero, Error Code and Error Hint
MUST also be zero.

A non-zero EType is the receiver's way of telling the PDU's sender
that the receiver had problems processing the PDU. The Error Code
and Error Hint will tell the sender more detail about the error.

The decimal value of EType gives a strong hint how the receiver
sending the ACK believes things should proceed:

    0 - No Error, Error Code and Error Hint MUST be zero

    1 - Warning, something not too serious happened, continue

    2 - Session should not be continued, try to restart

        3 - Restart is hopeless, call the operator

        4-15 - Reserved

    The two octet Error Code, noting protocol failures, are listed in
    Section 16.5. Someone stuck in the 1990s might think the catenation
    of EType and Error Code as an echo of 0x1zzz, 0x2zzz, etc. They
    might be right; or not.

    The two octet Error Hint, is arbitrary additional data the sender of
    the error PDU thinks will help the recipient or the debugger with the
    particular error.

9.1. Retransmission

    If a PDU sender expects an ACK, e.g. for an OPEN, an Encapsulation, a
    Vendor PDU, etc., and does not receive the ACK for a configurable
    time (default five seconds) the TLS/TCP session should be closed or
    dropped, and both sides revert to HELLO state.

10. The Encapsulations

    Once the devices know each other's IP Addresses, and have established
    a TLS/TCP session and have successfully exchanged OPENs, the L3ND
    session is considered established, and the devices SHOULD exchange
    Layer-3 interface encapsulations, Layer-3 addresses, and Layer-2.5
    labels.

    Encapsulation data for any AFI/SAFI may be exchanged over a TLS/TCP
    session irrespective of the AFI/SAFI of the session transport.

    The Encapsulation types the peers exchange may be IPv4
    (Section 10.3), IPv6 (Section 10.4), MPLS IPv4 (Section 10.6), MPLS
    IPv6 (Section 10.7), and/or possibly others not defined here.

    The sender of an Encapsulation PDU MUST NOT assume that the receiver
    is capable of the same Encapsulation Type. An ACK (Section 9) with
    EType of 0 merely acknowledges receipt. Only if both peers have sent
    the same Encapsulation Type is it safe for Layer-3 protocols to
    assume that they are compatible for that Encapsulation Type.

    A receiver of an encapsulation might recognize an addressing
    conflict, such as both ends of the link trying to use the same
    address. In this case, the receiver MUST respond with an error
    (Error Code 2, Logical Link Addressing Conflict) ACK. As there may
    be other usable addresses or encapsulations, this error might log and
    continue, letting an upper layer topology builder deal with what
    works.

Further, to consider a logical link of a Encapsulation Type to
formally be established so that it may be used by other protocols,
the addressing for the type must be compatible, e.g. on the same IP
subnet.

10.1. The Encapsulation PDU Skeleton

The header for all encapsulation PDUs is as follows:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Version = 0 |    PDU Type   |         Payload Length      ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                        Count                ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                    Serial Number            ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                 Encapsulation List...       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
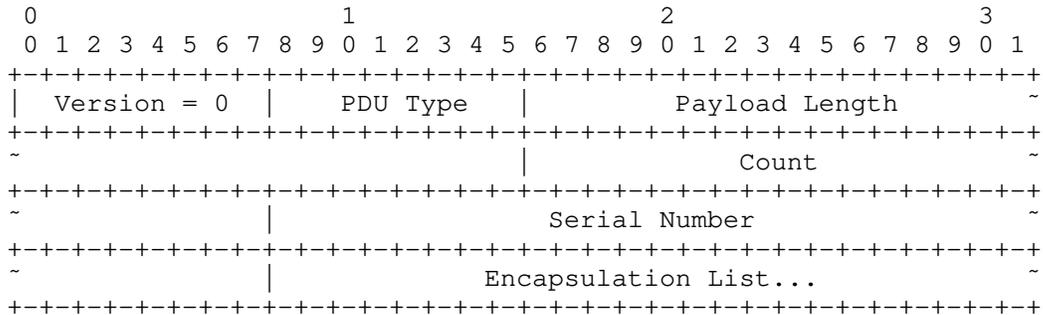
An Encapsulation PDU describes zero or more addresses of the
encapsulation type.

The three octet Count is the number of Encapsulations in the
Encapsulation List.

The Serial Number is a monotonically increasing four octet value
representing the sender's state in time. It may be an integer, a
timestamp, etc. On session restart (new OPEN), a receiver MAY send
the last received Serial Number to request the sender to only send
newer data.

If a sender has multiple links on the same interface, separate state:
data, ACKs, etc. must be kept for each peer session.

Over time, multiple Encapsulation PDUs may be sent for an interface
in a session as configuration changes.

The Receiver MUST acknowledge the Encapsulation PDU with an ACK PDU
(Section 9) with the Type field being that of the Type of the
Encapsulation PDU being announced, see Section 9.

   If the Sender does not receive an ACK in a configurable interval
   (default five seconds), they SHOULD retransmit. After a user
   configurable number of failures (default three), the L3ND session
   should be considered dead, TLS/TCP torn down, and the HELLO process
   SHOULD be restarted.

   If the link is broken below layer-3, retransmission MAY BE retried if
   data have not changed in the interim and the TLS/TCP session is still
   alive.

   Should an Encapsulation in the Encapsulation List be syntactically
   invalid, e.g. an out of bounds prefix length, the entire
   Encapsulation PDU MUST be dropped and the sending party notified by
   an ACK PDU with an EType of 1 and an Error Code of 3, Encapsulation
   Error.

10.2. Encapsulaion Flags

   The one octet Encapsulation Flags field is a sequence of one bit
   fields as follows:

```
    0            1            2            3            4 ...        7
   +------------+------------+------------+------------+------------+
   |  Ann/With  |  Primary   | Under/Over |  Loopback  | Reserved ..|
   +------------+------------+------------+------------+------------+
```
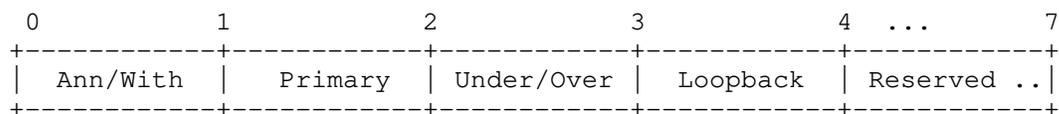
   Each encapsulation in an Encapsulation PDU of Type T may announce new
   and/or withdraw old encapsulations of Type T. It indicates this with
   the Ann/With Encapsulation Flag, Announce == 1, Withdraw == 0.

   Announcing an encapsulation which already exists SHOULD raise an
   Announce/Withdraw Error (see Section 16.5); the EType SHOULD be 2,
   suggesting a session restart (see Section 9) so all encapsulations
   will be resent.

   If an interface on a link has multiple addresses for an encapsulation
   type, one and only one address MAY be marked as primary (Primary Flag
   == 1) for that Encapsulation Type.

   An Encapsulation interface address in an Encapsulation PDU MAY be
   marked as a loopback, in which case the Loopback bit is set.
   Loopback addresses are generally not seen directly on an external
   interface. One or more loopback addresses MAY be exposed by
   configuration on one or more L3ND speaking external interfaces, e.g.
   for iBGP peering. They SHOULD be marked as such, Loopback Flag == 1.

Each Encapsulation interface address in an Encapsulation PDU is that
of the direct 'underlay interface (Under/Over == 1), or an 'overlay'
address (Under/Over == 0), likely that of a VM or container guest
bridged or configured on to the interface already having an underlay
address.

10.3. IPv4 Encapsulation

The IPv4 Encapsulation describes a device's ability to exchange IPv4
packets on one or more subnets. It does so by stating the
interface's addresses and the corresponding prefix lengths.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Version = 0  |  PDU Type = 4 |          Payload Length      ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                               |             Count            ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                 Serial Number                ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |  Encaps Flags |          IPv4 Address        ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                               |   PrefixLen   |   more ...    ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
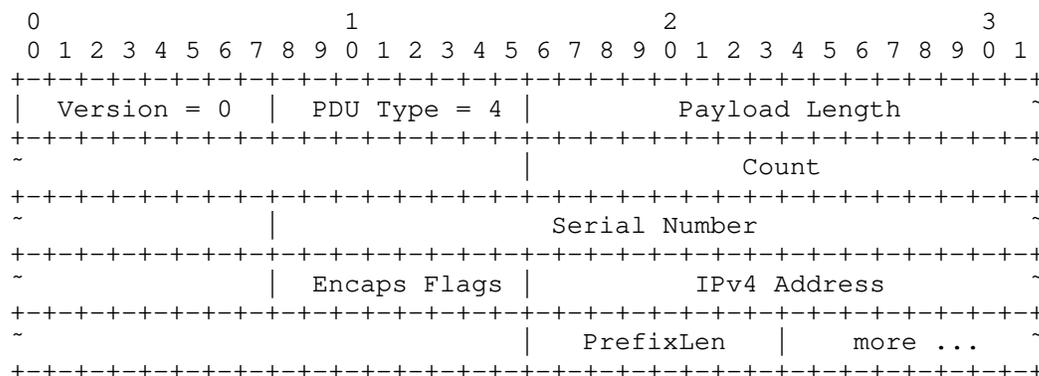
The three octet Count is the sum of the number of IPv4 Encapsulations
being announced and/or withdrawn.

10.4. IPv6 Encapsulation

The IPv6 Encapsulation describes a link's ability to exchange IPv6
packets on one or more subnets. It does so by stating the
interface's addresses and the corresponding prefix lengths.

```
   0                   1                   2                   3
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |  Version = 0  |  PDU Type = 5 |          Payload Length      ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  ~                               |             Count            ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  ~                               |         Serial Number        ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  ~                               | Encaps Flags |               ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+                               +
  |                                                              ~
  +                                                              +
  ~                                                              ~
  +                                                              +
  ~                           IPv6 Prefix                        ~
  +                               +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  ~                               |   PrefixLen   |   more ...    ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   The three octet Count is the sum of the number of IPv6 Encapsulations
   being announced and/or withdrawn.

10.5. MPLS Label List

   As an MPLS enabled interface may have a label stack, see [RFC3032], a
   variable length list of labels is needed. These are the labels the
   sender will accept for the prefix to which the list is attached.

```
   0                   1                   2                   3
   0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  | Label Count   |                Label                 | Exp |S|
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  ~                Label                 | Exp |S|   more ...     ~
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   A one octet Label Count of zero is an implicit withdraw of all labels
   for that prefix on that interface.

   The bottom of the stack flag, S, MUST be set on one and only one
   label. Should this not be the case, the receiver of the erroneous
   PDU MUST respond with an ACK PDU of EType 1 and Error Code 1, MPLS
   Error.

10.6. MPLS IPv4 Encapsulation

   The MPLS IPv4 Encapsulation describes a logical link's ability to
   exchange labeled IPv4 packets on one or more subnets. It does so by
   stating the interface's addresses the corresponding prefix lengths,
   and the corresponding labels which will be accepted for each address.

```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |  Version = 0  |  PDU Type = 6 |         Payload Length      ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                               |            Count            ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                       |         Serial Number               ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   ~                       |  Encaps Flags |    MPLS Label List ...   ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                          IPv4 Address                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |   PrefixLen   |                     more ...                 ~
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
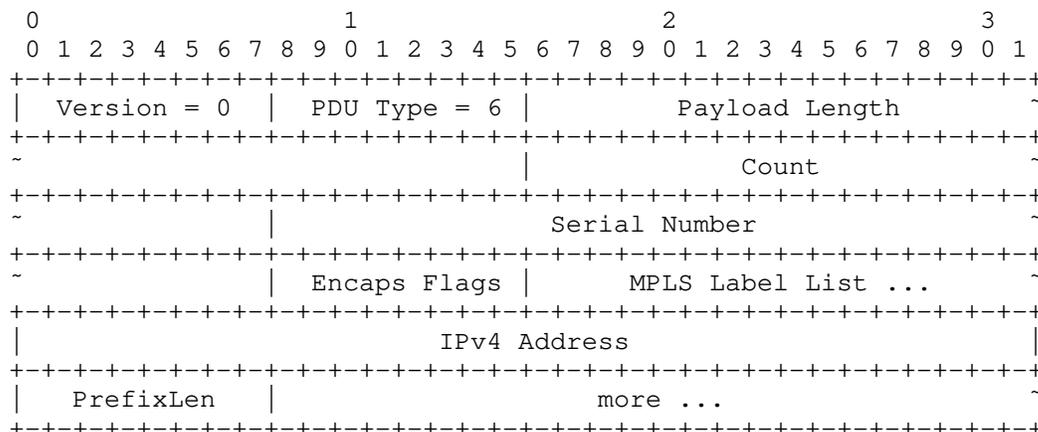
   The three octet Count is the sum of the number of MPLSv4
   Encapsulation being announced and/or withdrawn.

10.7. MPLS IPv6 Encapsulation

   The MPLS IPv6 Encapsulation describes a logical link's ability to
   exchange labeled IPv6 packets on one or more subnets. It does so by
   stating the interface's addresses, the corresponding prefix lengths,
   and the corresponding labels which will be accepted for each address.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Version = 0   | PDU Type = 7  |          Payload Length       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                      Count                    ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                  Serial Number                ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               | Encaps Flags  |     MPLS Label List ...       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               ~
+                                                               +
~                                                               ~
+                         IPv6 Address                          +
~                                                               ~
+                                                               +
~                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Prefix Len  |                    more ...                   ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
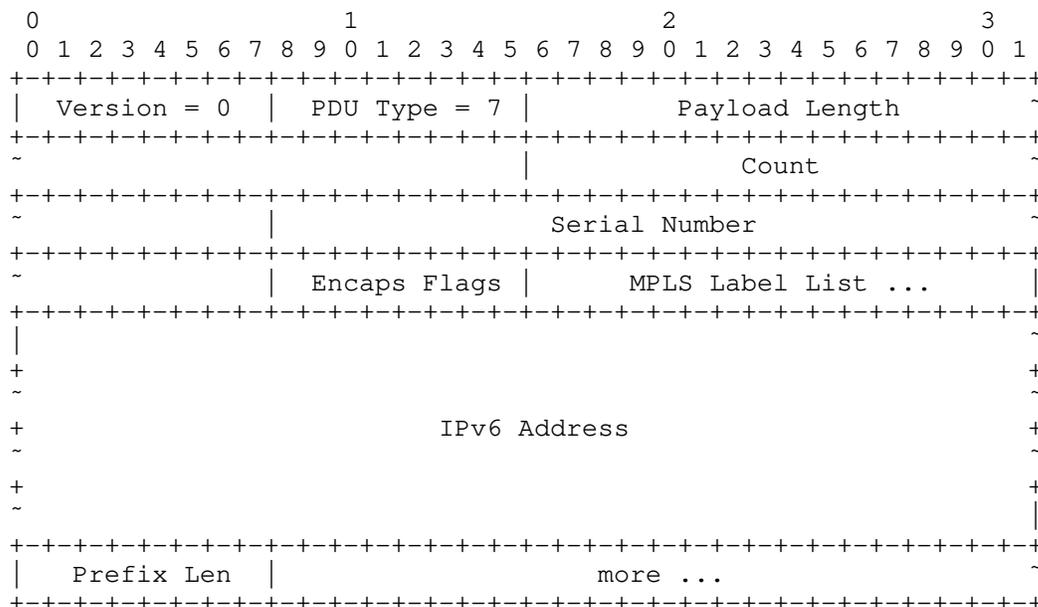
The three octet Count is the sum of the number of MPLSv6
Encapsulations being announced and/or withdrawn.

11. VENDOR - Vendor Extensions

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Version = 0   | PDU Type = 255|          Payload Length       ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                  Serial Number                ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |                Enterprise Number              ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~               |    Ent Type   |    Enterprise Data ...        ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
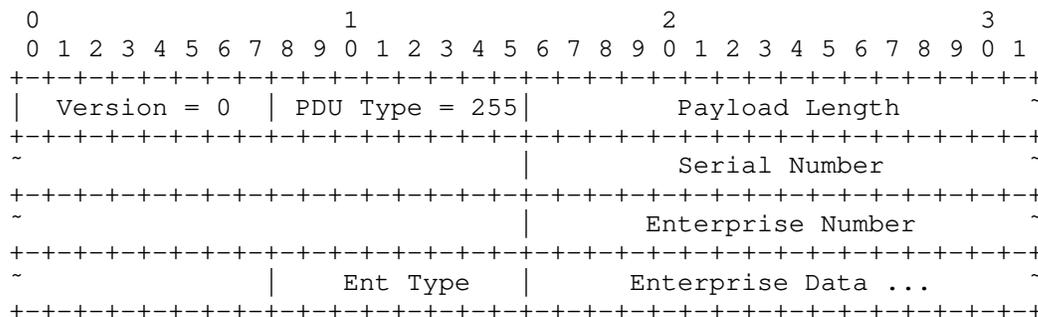
Vendors or enterprises may define TLVs beyond the scope of L3ND
standards. This is done using a Private Enterprise Number [IANA-PEN]
followed by Enterprise Data in a format defined for that three octet
Enterprise Number and one octet Ent Type.

Ent Type allows a Vendor PDU to be sub-typed in the event that the
vendor/enterprise needs multiple PDU types.

As with Encapsulation PDUs, a receiver of a Vendor PDU MUST respond
with an ACK PDU, possibly signalling an error. Similarly, a Vendor
PDU MUST only be sent over an open session.

12. Discussion

This section explores some trade-offs taken and some considerations.

12.1. HELLO Discussion

A device may send IP packets over a Layer-3 interface which transmits
data over a single Layer-2 interface or multiple Layer-2 interfaces.
Packets sourced by one Layer-3 IP interface over multiple Layer-2
should consider that a Layer-3 interface with multiple Layer-2
interfaces could have many devices which might come at various times,
therefore the configured HELLO PDU retransmit time SHOULD be set to a
non-zero value, and periodic HELLOs should continue. Packets
transmitted on a single Layer-2 interface on a point-to-point (p2p)
connection, MAY set the configuration value to zero, so when a TLS/
TCP session is up, HELLOs are no longer desirable.

A device with multiple Layer-2 interfaces, traditionally called a
switch, may be used to forward packets from multiple devices to one
Layer-3 interface, I, on an L3ND speaking device. Interface I could
discover a peer J across the switch. Later, a prospective peer K
could come up across the switch. If I was not still sending and
listening for HELLOs, the potential peering with K could not be
discovered. Therefore, on multi-link interfaces, L3ND MUST continue
to send HELLOs as long as they are turned up.

13. VLANs/SVIs/Sub-interfaces

One can think of the protocol as an instance (i.e. state machine)
which runs on each logical link of a device.

As the upper routing layer must view VLAN topologies as separate
graphs, L3ND treats VLAN ports as separate links.

As Sub-Interfaces each have their own layer-3 identities, they act as
separate interfaces, forming their own links.

14. Implementation Considerations

An implementation SHOULD provide the ability to configure each
logical interface as L3ND speaking or not.

An implementation SHOULD provide the ability to distribute one or
more loopback addresses or interfaces into L3ND on an external L3ND
speaking interface.

An implementation SHOULD provide the ability to distribute one or
more overlay and/or underlay addresses or interfaces into L3ND on an
external L3ND speaking interface.

An implementation SHOULD provide the ability to configure one of the
addresses of an encapsulation as primary on an L3ND speaking
interface. If there is only one address for a particular
encapsulation, the implementation MAY mark it as primary by default.

An implementation MAY allow optional configuration which updates the
local forwarding table with overlay and underlay data both learned
from L3ND peers and configured locally.

15. Security Considerations

For TLS, versions greater than 1.1 MUST be used.

The protocol as is MUST NOT be used outside a datacenter or similarly
closed environment without using TLS encapsulation which is based on
a configured CA trust anchor.

Many datacenter operators have a strange belief that physical walls
and firewalls provide sufficient security. This is not credible.
All DC protocols need to be examined for exposure and attack surface.
In the case of L3ND, authentication and integrity as provided by TLS
validated to a configured shared CA trust anchor is strongly
RECOMMENDED.

It is generally unwise to assume that on the wire Layer-3 is secure.
Strange/unauthorized devices may plug into a port. Mis-wiring is
very common in datacenter installations. A poisoned laptop might be
plugged into a device's port, form malicious sessions, etc. to
divert, intercept, or drop traffic.

Similarly, malicious nodes/devices could mis-announce addressing.

If OPEN PDUs are not over validated TLS, an attacker could forge an
OPEN for an existing session and cause the session to be reset.

16. IANA Considerations

16.1. Link Local Layer-3 Addresses

   IANA is requested to assignment one address (TBD1) for L3DL-L3-LL
   from the IPv4 Multicast Address Space Registry from the Local Network
   Control Block (224.0.0.0 - 224.0.0.255 (224.0.0/24)).

   IANA is requested to assign one address (TBD2) for L3DL-L3-LL from
   the IPv6 Multicast Address Space Registry in the the IPv6 Link-Local
   Scope Multicast address (TBD:2).

16.2. Ports for TLS/TCP

   This document requests the IANA to assign a well-known TCP Port
   Number (TBD3) to the Layer-3 Neighbor Discovery Protocol for the
   following, see Section 7:

            l3nd-server

16.3. PDU Types

   This document requests the IANA create a registry for L3ND PDU Type,
   which may range from 0 to 255. The name of the registry should be
   L3ND-PDU-Type. The policy for adding to the registry is RFC Required
   per [RFC5226], either standards track or experimental. The initial
   entries should be the following:

PDU Code	PDU Name
0	HELLO
1	reserved
2	OPEN
3	ACK
4	IPv4 Announcement
5	IPv6 Announcement
6	MPLS IPv4 Announcement
7	MPLS IPv6 Announcement
8-254	Reserved
255	Vendor

16.4. Flag Bits

   This document requests the IANA create a registry for L3ND PL Flag
   Bits, which may range from 0 to 7. The name of the registry should
   be L3ND-PL-Flag-Bits. The policy for adding to the registry is RFC
   Required per [RFC5226], either standards track or experimental. The
   initial entries should be the following:

```
              Bit     Bit Name
              ----    ------------------
               0      Announce/Withdraw (ann == 0)
               1      Primary
               2      Underlay/Overlay (under == 0)
               3      Loopback
               4-7    Reserved
```

16.5. Error Codes

   This document requests the IANA create a registry for L3ND Error
   Codes, a 16 bit integer. The name of the registry should be L3ND-
   Error-Codes. The policy for adding to the registry is RFC Required
   per [RFC5226], either standards track or experimental. The initial
   entries should be the following:

```
              Error
              Code    Error Name
              ----    ------------------
               0      No Error
               1      MPLS Error
               2      Logical Link Addressing Conflict
               3      Encapsulation Error
               4      Announce/Withdraw Error
               5      Session May Not Be Continued
```

17. Acknowledgments

   The authors thank Ben Maddison and Jeff Haas.

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Authors' Addresses

   Randy Bush
   Arrcus & Internet Initiative Japan
   5147 Crystal Springs
   Bainbridge Island, WA 98110
   United States of America
   Email: randy@psg.com

   Russ Housley
   Vigil Security, LLC
   516 Dranesville Road
   Herndon, VA 20170
   United States of America
   Email: housley@vigilsec.com

   Rob Austein
   Arrcus, Inc
   Email: sra@hactrn.net

   Susan Hares
   Hickory Hill Consulting
   7453 Hickory Hill
   Saline, MI 48176
   United States of America
   Phone: +1-734-604-0332
   Email: shares@ndzh.com

   Keyur Patel
   Arrcus
   2077 Gateway Place, Suite #400
   San Jose, CA 95119
   United States of America
   Email: keyur@arrcus.com