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YANG Data Model for Bidirectional Forwarding Detection (BFD)
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Abstract

This document defines a YANG data model that can be used to configure and manage Bidirectional Forwarding Detection (BFD).

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].

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 January 1, 2018.

Table of Contents

1. Introduction

This document defines a YANG data model that can be used to configure and manage Bidirectional Forwarding Detection (BFD) [RFC5880]. BFD is a network protocol which is used for liveness detection of arbitrary paths between systems. Some examples of different types of paths over which we have BFD:

1) Two systems directly connected via IP. This is known as BFD over single-hop IP, a.k.a. BFD for IPv4 and IPv6 [RFC5881]

2) Two systems connected via multiple hops as described in BFD for Multiple Hops. [RFC5883]

3) Two systems connected via MPLS Label Switched Paths (LSPs) as described in BFD for MPLS LSP [RFC5884]

4) Two systems connected via a Link Aggregation Group (LAG) interface as described in BFD on LAG Interfaces [RFC7130]

5) Two systems connected via pseudowires (PWs), this is known as Virtual Circuit Connectivity Verification (VCCV) as described in BFD for PW VCCV [RFC5885]. This is not addressed in this document.

BFD typically does not operate on its own. Various control protocols, also known as BFD clients, use the services provided by BFD for their own operation as described in Generic Application of BFD [RFC5882]. The obvious candidates which use BFD are those which do not have "hellos" to detect failures, e.g. static routes, and routing protocols whose "hellos" do not support sub-second failure detection, e.g. OSPF and IS-IS.

2. Design of the Data Model

Since BFD is used for liveliness detection of various forwarding paths, there is no uniform key to identify a BFD session. So the BFD data model is split in multiple YANG modules where each module corresponds to one type of forwarding path. For example, BFD for IP single-hop is in one YANG module and BFD for MPLS-TE is in another YANG module. The main difference between these modules is how a BFD session is uniquely identified, i.e the key for the list containing the BFD sessions for that forwarding path. To avoid duplication of BFD definitions, we have common types and groupings which are used by all the modules.

A new control-plane protocol "bfdv1" is defined and a "bfd" container is created under control-plane-protocol as specified in A YANG Data Model for Routing Management [RFC8022]. This new "bfd" node is augmented by all the YANG modules for their respective specific information.

BFD can operate in the following contexts:

1. Network devices as described in Network Device YANG Organizational Models [I-D.ietf-rtgwg-device-model]

2. Logical Network Elements as described in YANG Logical Network Element [I-D.ietf-rtgwg-lne-model]

3. Network instances as described in YANG Logical Network Element [I-D.ietf-rtgwg-ni-model]

The approach taken is to do a schema-mount (see Schema Mount [I-D.ietf-netmod-schema-mount]) of the BFD model in the appropriate locations. For example, if an implementation supports BFD IP multi-hop in network instances, the implementation would do schema-mount of the BFD IP multi-hop model in a mount-point which resides in a network instance.

The data models in this document strive to follow the "Network Management Datastore Architecture" (NMDA) guidelines described in [I-D.dsdt-nmda-guidelines]. This means that the data models do NOT have separate top-level or sibling containers for configuration and operational data. One exception at the moment is the model for MPLS-TE in Section 2.1.4

2.1. Design of Configuration Model

The configuration model consists mainly of the parameters specified in BFD [RFC5880]. Some examples are desired minimum transmit interval, required minimum receive interval, detection multiplier, etc

BFD clients are applications that use BFD for fast detection of failures. Some implementations have BFD session configuration under the BFD clients. For example, BFD session configuration under routing applications such as OSPF, IS-IS, BGP etc. Other implementations have BFD session configuration centralized under BFD, i.e. outside the multiple BFD clients.

The BFD parameters of interest to a BFD client are mainly the multiplier and interval(s) since those parameters impact the convergence time of the BFD clients when a failure occurs. Other parameters such as BFD authentication are not specific to the requirements of the BFD client. To avoid splitting the BFD configuration between BFD clients and this centralized model of BFD, all the configuration is kept under this centralized model of BFD. The only BFD configuration under BFD clients should be an "enable" knob which makes those clients react to BFD liveliness detection events.

2.1.1. Common BFD configuration parameters

The basic BFD configuration parameters are:

local-multiplier
: This is the detection time multiplier as defined in BFD [RFC5880].

desired-min-tx-interval
: This is the Desired Min TX Interval as defined in BFD [RFC5880].

required-min-rx-interval
: This is the Required Min RX Interval as defined in BFD [RFC5880].

Although BFD [RFC5880] allows for different values for transmit and receive intervals, some implementations allow users to specify just one interval which is used for both transmit and receive intervals or separate values for transmit and receive intervals. The BFD YANG model supports this: there is a choice between "min-interval", used for both transmit and receive intervals, and "desired-min-tx-interval" and "required-min-rx-interval". This is supported via a

grouping which is used by the YANG modules for the various forwarding paths. For BFD authentication we have:

key-chain
: This is a reference to key-chain defined in YANG Data Model for Key Chains [RFC8177]. The keys, cryptographic algotihms, key lifetime etc are all defined in the key-chain model.

replay-protection
: This specifies meticulous v/s non-meticulous mode as per BFD [RFC5880].

2.1.2. Single-hop IP

For single-hop IP, there is an augment of the "bfd" data node in Section 2. The "ip-sh" node contains a list of IP single-hop sessions where each session is uniquely identified by the interface and destination address pair. For the configuration parameters we use what is defined in Section 2.1.1

[RFC5880] and [RFC5881] do not specify whether echo function is continuous or on demand. Therefore the mechanism used to start and stop echo function is implementation specific and should be done by augmentation:

1) Configuration. This is suitable for continuous echo function. An example is provided in Appendix A.

2) RPC. This is suitable for on-demand echo function.

2.1.3. Multi-hop IP

For multi-hop IP, there is an augment of the "bfd" data node in Section 2.

Because of multiple paths, there could be multiple multi-hop IP sessions between a source and a destination address. We identify this as a "session-group". The key for each "session-group" consists of:

source address
: Address belonging to the local system as per BFD for Multiple Hops [RFC5883]

destination address
: Address belonging to the remote system as per BFD for Multiple Hops [RFC5883]

For the configuration parameters we use what is defined in Section 2.1.1

Here are some extra parameters:

tx-ttl
: TTL of outgoing BFD control packets.

rx-ttl
: Minimum TTL of incoming BFD control packets.

2.1.4. MPLS Traffic Engineering Tunnels

For MPLS-TE tunnels, BFD is configured under the MPLS-TE tunnel since the desired failure detection parameters is a property of the MPLS-TE tunnel. This is achieved by augmenting the MPLS-TE data model in YANG Data Model for TE Topologies [I-D.ietf-teas-yang-te]. For BFD parameters which are specific to the TE application, e.g. whether to tear down the tunnel in the event of a BFD session failure, these parameters will be defined in the YANG model of the MPLS-TE application.

On top of the usual BFD parameters, we have the following per MPLS-TE tunnel:

encap
: Encapsulation for the BFD packets: choice between IP, G-ACh and IP with G-ACh as per MPLS Generic Associated Channel [RFC5586]

For general MPLS-TE data, "mpls-te" data node is added under the "bfd" node in Section 2. Since some MPLS-TE tunnels are uni-directional there is no MPLS-TE configuration for these tunnels on the egress node (note that this does not apply to bi-directional MPLS-TP tunnels). The BFD parameters for the egress node are added under "mpls-te".

2.1.5. MPLS Label Switched Paths

Here we address MPLS LSPs whose FEC is an IP address. The "bfd" node in Section 2 is augmented with "mpls" which contains a list of sessions uniquely identified by an IP prefix. Because of multiple paths, there could be multiple MPLS sessions to an MPLS FEC. We identify this as a "session-group".

Since these LSPs are uni-directional there is no LSP configuration on the egress node.

The BFD parameters for the egress node are added under "mpls".

2.1.6. Link Aggregation Groups

Per BFD on LAG Interfaces [RFC7130], configuring BFD on LAG consists of having micro-BFD sessions on each LAG member link. Since the BFD parameters are an attribute of the LAG, they should be under the LAG. However there is no LAG YANG model which we can augment. So a "lag" data node is added to the "bfd" node in Section 2, the configuration is per-LAG: we have a list of LAGs. The destination IP address of the micro-BFD sessions is configured per-LAG and per address-family (IPv4 and IPv6)

2.2. Design of Operational Model

The operational model contains both the overall statistics of BFD sessions running on the device and the per session operational information.

The overall statistics of BFD sessions consist of number of BFD sessions, number of BFD sessions up etc. This information is available globally (i.e. for all BFD sessions) under the "bfd" node in Section 2 and also per type of forwarding path.

For each BFD session, mainly three categories of operational items are shown. The fundamental information of a BFD session such as the local discriminator, remote discriminator and the capability of supporting demand detect mode are shown in the first category. The second category includes a BFD session running information, e.g. the remote BFD state and the diagnostic code received. Another example is the actual transmit interval between the control packets, which may be different from the desired minimum transmit interval configured, is shown in this category. Similar examples are actual received interval between the control packets and the actual transmit interval between the echo packets. The third category contains the detailed statistics of the session, e.g. when the session transitioned up/down and how long it has been in that state.

For some session types, there may be more than 1 session on the virtual path to the destination. For example, with IP multi-hop and MPLS LSPs, there could be multiple BFD sessions from the source to the same destination to test the various paths (ECMP) to the destination. This is represented by having multiple "sessions" under each "session-group".

2.3. Notifications

This YANG model defines notifications to inform clients of BFD of important events detected during the protocol operation. Pair of local and remote discriminator identifies a BFD session on local system. Notifications also give more important details about BFD sessions; e.g. new state, time in previous state, network-instance and the reason that the BFD session state changed. The notifications are defined for each type of forwarding path but use groupings for common information.

2.4. RPC Operations

None.

2.5. BFD top level hierarchy

At the "bfd" node under control-plane-protocol, there is no configuration data, only operational data. The operational data consist of overall BFD session statistics, i.e. for BFD on all types of forwarding paths. The "bfd" node under control-plane-protocol can be used in a network device (top-level), or mounted in an LNE or in a network instance.

```
module: ietf-bfd
augment /rt:routing/rt:control-plane-protocols
        /rt:control-plane-protocol:
   +--rw bfd
      +--ro bfd-session-statistics
         +--ro session-count?              uint32
         +--ro session-up-count?           uint32
         +--ro session-down-count?         uint32
         +--ro session-admin-down-count?   uint32
```

2.6. BFD IP single-hop hierarchy

An "ip-sh" node is added under "bfd" node in control-plane-protocol. The configuration and operational data for each BFD IP single-hop session is under this "ip-sh" node. The "ip-sh" node can be used in a network device (top-level), or mounted in an LNE or in a network instance.

```
module: ietf-bfd-ip-sh
augment /rt:routing/rt:control-plane-protocols/rt:control-plane-protoco
l/bfd:bfd:
   +--rw ip-sh
      +--ro bfd-session-statistics
      |  +--ro session-count?              uint32
```

```
      |  +--ro session-up-count?           uint32
      |  +--ro session-down-count?         uint32
      |  +--ro session-admin-down-count?   uint32
      +--rw sessions* [interface dest-addr]
         +--rw interface                         if:interface-ref
         +--rw dest-addr                         inet:ip-address
         +--rw source-addr?                      inet:ip-address
         +--rw local-multiplier?                 bfd-multiplier
         +--rw (interval-config-type)?
         |  +--:(tx-rx-intervals)
         |  |  +--rw desired-min-tx-interval          uint32
         |  |  +--rw required-min-rx-interval         uint32
         |  +--:(single-interval)
         |     +--rw min-interval                     uint32
         +--rw demand-enabled?                   boolean
                                                 {bfd-demand-mode}?
         +--rw admin-down?                       boolean
         +--rw authentication-parms! {bfd-authentication}?
         |  +--rw key-chain?           kc:key-chain-ref
         |  +--rw replay-protection?   identityref
         +--rw desired-min-echo-tx-interval?    uint32
         +--rw required-min-echo-rx-interval?   uint32
         +--ro path-type?                        identityref
         +--ro ip-encapsulation?                 boolean
         +--ro local-discriminator?              bfd-discriminator
         +--ro remote-discriminator?             bfd-discriminator
         +--ro remote-multiplier?                bfd-multiplier
         +--ro demand-capability?                boolean
                                                 {bfd-demand-mode}?
         +--ro source-port?                      inet:port-number
         +--ro dest-port?                        inet:port-number
         +--ro session-running
         |  +--ro session-index?                 uint32
         |  +--ro local-state?                   bfd-state
         |  +--ro remote-state?                  bfd-state
         |  +--ro local-diagnostic?              iana-bfd-types:
                                                 bfd-diagnostic
         |  +--ro remote-diagnostic?             iana-bfd-types:
                                                 bfd-diagnostic
         |  +--ro remote-authenticated?          boolean
         |  +--ro remote-authentication-type?    iana-bfd-types:
                                                 bfd-auth-type
         |  +--ro detection-mode?                enumeration
         |  +--ro negotiated-tx-interval?        uint32
         |  +--ro negotiated-rx-interval?        uint32
         |  +--ro detection-time?                uint32
         |  +--ro echo-tx-interval-in-use?       uint32 {bfd-echo-mode}?
         +--ro sesssion-statistics
```

```
            +--ro create-time?            yang:date-and-time
            +--ro last-down-time?         yang:date-and-time
            +--ro last-up-time?           yang:date-and-time
            +--ro down-count?             uint32
            +--ro admin-down-count?       uint32
            +--ro receive-packet-count?   uint64
            +--ro send-packet-count?      uint64
            +--ro receive-bad-packet?     uint64
            +--ro send-failed-packet?     uint64
notifications:
   +---n bfd-singlehop-notification
      +--ro local-discr?                 bfd-discriminator
      +--ro remote-discr?                bfd-discriminator
      +--ro new-state?                   bfd-state
      +--ro state-change-reason?         iana-bfd-types:bfd-diagnostic
      +--ro time-of-last-state-change?   yang:date-and-time
      +--ro dest-addr?                   inet:ip-address
      +--ro source-addr?                 inet:ip-address
      +--ro session-index?               uint32
      +--ro path-type?                   identityref
      +--ro interface?                   if:interface-ref
      +--ro echo-enabled?                boolean
```

2.7. BFD IP multi-hop hierarchy

An "ip-mh" node is added under the "bfd" node in cntrol-plane-protocol. The configuration and operational data for each BFD IP multi-hop session is under this "ip-mh" node. In the operational model we support multiple BFD multi-hop sessions per remote address (ECMP), the local discriminator is used as key. The "ip-mh" node can be used in a network device (top-level), or mounted in an LNE or in a network instance.

```
module: ietf-bfd-ip-mh
augment /rt:routing/rt:control-plane-protocols
        /rt:control-plane-protocol/bfd:bfd:
   +--rw ip-mh
      +--ro bfd-session-statistics
      |  +--ro session-count?              uint32
      |  +--ro session-up-count?           uint32
      |  +--ro session-down-count?         uint32
      |  +--ro session-admin-down-count?   uint32
      +--rw session-group* [source-addr dest-addr]
         +--rw source-addr                 inet:ip-address
         +--rw dest-addr                   inet:ip-address
         +--rw local-multiplier?           bfd-multiplier
         +--rw (interval-config-type)?
```

```
|  +--:(tx-rx-intervals)
|  |  +--rw desired-min-tx-interval     uint32
|  |  +--rw required-min-rx-interval    uint32
|  +--:(single-interval)
|     +--rw min-interval                uint32
+--rw demand-enabled?             boolean {bfd-demand-mode}?
+--rw admin-down?                 boolean
+--rw authentication-parms! {bfd-authentication}?
|  +--rw key-chain?           kc:key-chain-ref
|  +--rw replay-protection?   identityref
+--rw tx-ttl?                     bfd:hops
+--rw rx-ttl                      bfd:hops
+--ro sessions*
   +--ro path-type?              identityref
   +--ro ip-encapsulation?       boolean
   +--ro local-discriminator?    bfd-discriminator
   +--ro remote-discriminator?   bfd-discriminator
   +--ro remote-multiplier?      bfd-multiplier
   +--ro demand-capability?      boolean {bfd-demand-mode}?
   +--ro source-port?            inet:port-number
   +--ro dest-port?              inet:port-number
   +--ro session-running
   |  +--ro session-index?               uint32
   |  +--ro local-state?                 bfd-state
   |  +--ro remote-state?                bfd-state
   |  +--ro local-diagnostic?            iana-bfd-types:
   |                                     bfd-diagnostic
   |  +--ro remote-diagnostic?           iana-bfd-types:
   |                                     bfd-diagnostic
   |  +--ro remote-authenticated?        boolean
   |  +--ro remote-authentication-type?  iana-bfd-types:
   |                                     bfd-auth-type
   |  +--ro detection-mode?              enumeration
   |  +--ro negotiated-tx-interval?      uint32
   |  +--ro negotiated-rx-interval?      uint32
   |  +--ro detection-time?              uint32
   |  +--ro echo-tx-interval-in-use?     uint32
   |                                     {bfd-echo-mode}?
   +--ro session-statistics
      +--ro create-time?           yang:date-and-time
      +--ro last-down-time?        yang:date-and-time
      +--ro last-up-time?          yang:date-and-time
      +--ro down-count?            uint32
      +--ro admin-down-count?      uint32
      +--ro receive-packet-count?  uint64
      +--ro send-packet-count?     uint64
      +--ro receive-bad-packet?    uint64
      +--ro send-failed-packet?    uint64
```

```
notifications:
   +---n bfd-multihop-notification
      +--ro local-discr?                bfd-discriminator
      +--ro remote-discr?               bfd-discriminator
      +--ro new-state?                  bfd-state
      +--ro state-change-reason?        iana-bfd-types:bfd-diagnostic
      +--ro time-of-last-state-change?  yang:date-and-time
      +--ro dest-addr?                  inet:ip-address
      +--ro source-addr?                inet:ip-address
      +--ro session-index?              uint32
      +--ro path-type?                  identityref
```

2.8. BFD over LAG hierarchy

A "lag" node is added under the "bfd" node in control-plane-protocol. The configuration and operational data for each BFD LAG session is under this "lag" node. The "lag" node can be used in a network device (top-level), or mounted in an LNE or in a network instance.

```
module: ietf-bfd-lag
augment /rt:routing/rt:control-plane-protocols
        /rt:control-plane-protocol/bfd:bfd:
   +--rw lag
      +--rw micro-bfd-ipv4-session-statistics
      |  +--ro bfd-session-statistics
      |     +--ro session-count?             uint32
      |     +--ro session-up-count?          uint32
      |     +--ro session-down-count?        uint32
      |     +--ro session-admin-down-count?  uint32
      +--rw micro-bfd-ipv6-session-statistics
      |  +--ro bfd-session-statistics
      |     +--ro session-count?             uint32
      |     +--ro session-up-count?          uint32
      |     +--ro session-down-count?        uint32
      |     +--ro session-admin-down-count?  uint32
      +--rw sessions* [lag-name]
         +--rw lag-name                   if:interface-ref
         +--rw ipv4-dest-addr?            inet:ipv4-address
         +--rw ipv6-dest-addr?            inet:ipv6-address
         +--rw local-multiplier?          bfd-multiplier
         +--rw (interval-config-type)?
         |  +--:(tx-rx-intervals)
         |  |  +--rw desired-min-tx-interval     uint32
         |  |  +--rw required-min-rx-interval    uint32
         |  +--:(single-interval)
         |     +--rw min-interval                uint32
         +--rw demand-enabled?            boolean {bfd-demand-mode}?
         +--rw admin-down?                boolean
```

```
        +--rw authentication-parms! {bfd-authentication}?
        |  +--rw key-chain?           kc:key-chain-ref
        |  +--rw replay-protection?   identityref
        +--rw use-ipv4?                   boolean
        +--rw use-ipv6?                   boolean
        +--ro member-links* [member-link]
           +--ro member-link       if:interface-ref
           +--ro micro-bfd-ipv4
           |  +--ro path-type?              identityref
           |  +--ro ip-encapsulation?       boolean
           |  +--ro local-discriminator?    bfd-discriminator
           |  +--ro remote-discriminator?   bfd-discriminator
           |  +--ro remote-multiplier?      bfd-multiplier
           |  +--ro demand-capability?      boolean {bfd-demand-mode}?
           |  +--ro source-port?            inet:port-number
           |  +--ro dest-port?              inet:port-number
           |  +--ro session-running
           |  |  +--ro session-index?               uint32
           |  |  +--ro local-state?                 bfd-state
           |  |  +--ro remote-state?                bfd-state
           |  |  +--ro local-diagnostic?            iana-bfd-types:
           |                                        bfd-diagnostic
           |  |  +--ro remote-diagnostic?           iana-bfd-types:
           |                                        bfd-diagnostic
           |  |  +--ro remote-authenticated?        boolean
           |  |  +--ro remote-authentication-type?  iana-bfd-types:
           |                                        bfd-auth-type
           |  |  +--ro detection-mode?              enumeration
           |  |  +--ro negotiated-tx-interval?      uint32
           |  |  +--ro negotiated-rx-interval?      uint32
           |  |  +--ro detection-time?              uint32
           |  |  +--ro echo-tx-interval-in-use?     uint32
           |                                        {bfd-echo-mode}?
           |  +--ro sesssion-statistics
           |     +--ro create-time?            yang:date-and-time
           |     +--ro last-down-time?         yang:date-and-time
           |     +--ro last-up-time?           yang:date-and-time
           |     +--ro down-count?             uint32
           |     +--ro admin-down-count?       uint32
           |     +--ro receive-packet-count?   uint64
           |     +--ro send-packet-count?      uint64
           |     +--ro receive-bad-packet?     uint64
           |     +--ro send-failed-packet?     uint64
           +--ro micro-bfd-ipv6
              +--ro path-type?              identityref
              +--ro ip-encapsulation?       boolean
              +--ro local-discriminator?    bfd-discriminator
              +--ro remote-discriminator?   bfd-discriminator
```

```
               +--ro remote-multiplier?      bfd-multiplier
               +--ro demand-capability?      boolean {bfd-demand-mode}?
               +--ro source-port?            inet:port-number
               +--ro dest-port?              inet:port-number
               +--ro session-running
               |  +--ro session-index?               uint32
               |  +--ro local-state?                 bfd-state
               |  +--ro remote-state?                bfd-state
               |  +--ro local-diagnostic?            iana-bfd-types:
               |                                     bfd-diagnostic
               |  +--ro remote-diagnostic?           iana-bfd-types:
               |                                     bfd-diagnostic
               |  +--ro remote-authenticated?        boolean
               |  +--ro remote-authentication-type?  iana-bfd-types:
               |                                     bfd-auth-type
               |  +--ro detection-mode?              enumeration
               |  +--ro negotiated-tx-interval?      uint32
               |  +--ro negotiated-rx-interval?      uint32
               |  +--ro detection-time?              uint32
               |  +--ro echo-tx-interval-in-use?     uint32
               |                                     {bfd-echo-mode}?
               +--ro sesssion-statistics
                  +--ro create-time?           yang:date-and-time
                  +--ro last-down-time?        yang:date-and-time
                  +--ro last-up-time?          yang:date-and-time
                  +--ro down-count?            uint32
                  +--ro admin-down-count?      uint32
                  +--ro receive-packet-count?  uint64
                  +--ro send-packet-count?     uint64
                  +--ro receive-bad-packet?    uint64
                  +--ro send-failed-packet?    uint64
notifications:
   +---n bfd-lag-notification
      +--ro local-discr?                bfd-discriminator
      +--ro remote-discr?               bfd-discriminator
      +--ro new-state?                  bfd-state
      +--ro state-change-reason?        iana-bfd-types:bfd-diagnostic
      +--ro time-of-last-state-change?  yang:date-and-time
      +--ro dest-addr?                  inet:ip-address
      +--ro source-addr?                inet:ip-address
      +--ro session-index?              uint32
      +--ro path-type?                  identityref
      +--ro lag-name?                   if:interface-ref
      +--ro member-link?                if:interface-ref
```

2.9. BFD over MPLS LSPs hierarchy

An "mpls" node is added under the "bfd" node in control-plane-protocol. The configuration is per MPLS FEC under this "mpls" node. In the operational model we support multiple BFD sessions per MPLS FEC (ECMP), the local discriminator is used as key. The "mpls" node can be used in a network device (top-level), or mounted in an LNE or in a network instance.

```
module: ietf-bfd-mpls
augment /rt:routing/rt:control-plane-protocols
        /rt:control-plane-protocol/bfd:bfd:
   +--rw mpls
      +--ro bfd-session-statistics
      |  +--ro session-count?              uint32
      |  +--ro session-up-count?           uint32
      |  +--ro session-down-count?         uint32
      |  +--ro session-admin-down-count?   uint32
      +--rw egress
      |  +--rw local-multiplier?           bfd-multiplier
      |  +--rw (interval-config-type)?
      |  |  +--:(tx-rx-intervals)
      |  |  |  +--rw desired-min-tx-interval     uint32
      |  |  |  +--rw required-min-rx-interval    uint32
      |  |  +--:(single-interval)
      |  |     +--rw min-interval                uint32
      |  +--rw authentication-parms! {bfd-authentication}?
      |     +--rw key-chain?           kc:key-chain-ref
      |     +--rw replay-protection?   identityref
      +--rw session-group* [mpls-fec]
         +--rw mpls-fec                    inet:ip-prefix
         +--rw local-multiplier?           bfd-multiplier
         +--rw (interval-config-type)?
         |  +--:(tx-rx-intervals)
         |  |  +--rw desired-min-tx-interval     uint32
         |  |  +--rw required-min-rx-interval    uint32
         |  +--:(single-interval)
         |     +--rw min-interval                uint32
         +--rw demand-enabled?             boolean {bfd-demand-mode}?
         +--rw admin-down?                 boolean
         +--rw authentication-parms! {bfd-authentication}?
         |  +--rw key-chain?           kc:key-chain-ref
         |  +--rw replay-protection?   identityref
         +--ro sessions*
            +--ro path-type?              identityref
            +--ro ip-encapsulation?       boolean
            +--ro local-discriminator?    bfd-discriminator
            +--ro remote-discriminator?   bfd-discriminator
```

```
            +--ro remote-multiplier?      bfd-multiplier
            +--ro demand-capability?      boolean {bfd-demand-mode}?
            +--ro source-port?            inet:port-number
            +--ro dest-port?              inet:port-number
            +--ro session-running
            |  +--ro session-index?               uint32
            |  +--ro local-state?                 bfd-state
            |  +--ro remote-state?                bfd-state
            |  +--ro local-diagnostic?            iana-bfd-types:
                                                  bfd-diagnostic
            |  +--ro remote-diagnostic?           iana-bfd-types:
                                                  bfd-diagnostic
            |  +--ro remote-authenticated?        boolean
            |  +--ro remote-authentication-type?  iana-bfd-types:
                                                  bfd-auth-type
            |  +--ro detection-mode?              enumeration
            |  +--ro negotiated-tx-interval?      uint32
            |  +--ro negotiated-rx-interval?      uint32
            |  +--ro detection-time?              uint32
            |  +--ro echo-tx-interval-in-use?     uint32
                                                  {bfd-echo-mode}?
            +--ro sesssion-statistics
            |  +--ro create-time?           yang:date-and-time
            |  +--ro last-down-time?        yang:date-and-time
            |  +--ro last-up-time?          yang:date-and-time
            |  +--ro down-count?            uint32
            |  +--ro admin-down-count?      uint32
            |  +--ro receive-packet-count?  uint64
            |  +--ro send-packet-count?     uint64
            |  +--ro receive-bad-packet?    uint64
            |  +--ro send-failed-packet?    uint64
            +--ro mpls-dest-address?     inet:ip-address
 notifications:
    +---n bfd-mpls-notification
       +--ro local-discr?                bfd-discriminator
       +--ro remote-discr?               bfd-discriminator
       +--ro new-state?                  bfd-state
       +--ro state-change-reason?        iana-bfd-types:bfd-diagnostic
       +--ro time-of-last-state-change?  yang:date-and-time
       +--ro dest-addr?                  inet:ip-address
       +--ro source-addr?                inet:ip-address
       +--ro session-index?              uint32
       +--ro path-type?                  identityref
       +--ro mpls-dest-address?          inet:ip-address
```

2.10. BFD over MPLS-TE hierarchy

YANG Data Model for TE Topologies [I-D.ietf-teas-yang-te] is augmented. BFD is configured per MPLS-TE tunnel, and BFD session operational data is provided per MPLS-TE LSP.

```
module: ietf-bfd-mpls-te
augment /rt:routing/rt:control-plane-protocols
        /rt:control-plane-protocol/bfd:bfd:
   +--rw mpls-te
      +--rw config
      |  +--rw egress
      |     +--rw local-multiplier?           bfd-multiplier
      |     +--rw (interval-config-type)?
      |     |  +--:(tx-rx-intervals)
      |     |  |  +--rw desired-min-tx-interval     uint32
      |     |  |  +--rw required-min-rx-interval    uint32
      |     |  +--:(single-interval)
      |     |     +--rw min-interval                uint32
      |     +--rw authentication-parms! {bfd-authentication}?
      |        +--rw key-chain?           kc:key-chain-ref
      |        +--rw replay-protection?   identityref
      +--ro oper
         +--ro bfd-session-statistics
            +--ro session-count?              uint32
            +--ro session-up-count?           uint32
            +--ro session-down-count?         uint32
            +--ro session-admin-down-count?   uint32
augment /te:te/te:tunnels/te:tunnel/te:config:
   +--rw local-multiplier?           bfd-multiplier
   +--rw (interval-config-type)?
   |  +--:(tx-rx-intervals)
   |  |  +--rw desired-min-tx-interval     uint32
   |  |  +--rw required-min-rx-interval    uint32
   |  +--:(single-interval)
   |     +--rw min-interval                uint32
   +--rw demand-enabled?             boolean {bfd-demand-mode}?
   +--rw admin-down?                 boolean
   +--rw authentication-parms! {bfd-authentication}?
   |  +--rw key-chain?           kc:key-chain-ref
   |  +--rw replay-protection?   identityref
   +--rw encap?                      identityref
augment /te:te/te:lsps-state/te:lsp:
   +--ro path-type?              identityref
   +--ro ip-encapsulation?       boolean
   +--ro local-discriminator?    bfd-discriminator
   +--ro remote-discriminator?   bfd-discriminator
   +--ro remote-multiplier?      bfd-multiplier
```

```
    +--ro demand-capability?      boolean {bfd-demand-mode}?
    +--ro source-port?            inet:port-number
    +--ro dest-port?              inet:port-number
    +--ro session-running
    |  +--ro session-index?               uint32
    |  +--ro local-state?                 bfd-state
    |  +--ro remote-state?                bfd-state
    |  +--ro local-diagnostic?            iana-bfd-types:bfd-diagnostic
    |  +--ro remote-diagnostic?           iana-bfd-types:bfd-diagnostic
    |  +--ro remote-authenticated?        boolean
    |  +--ro remote-authentication-type?  iana-bfd-types:bfd-auth-type
    |                                     {bfd-authentication}?
    |  +--ro detection-mode?              enumeration
    |  +--ro negotiated-tx-interval?      uint32
    |  +--ro negotiated-rx-interval?      uint32
    |  +--ro detection-time?              uint32
    |  +--ro echo-tx-interval-in-use?     uint32 {bfd-echo-mode}?
    +--ro sesssion-statistics
    |  +--ro create-time?           yang:date-and-time
    |  +--ro last-down-time?        yang:date-and-time
    |  +--ro last-up-time?          yang:date-and-time
    |  +--ro down-count?            uint32
    |  +--ro admin-down-count?      uint32
    |  +--ro receive-packet-count?  uint64
    |  +--ro send-packet-count?     uint64
    |  +--ro receive-bad-packet?    uint64
    |  +--ro send-failed-packet?    uint64
    +--ro mpls-dest-address?      inet:ip-address
notifications:
    +---n bfd-mpls-te-notification
       +--ro local-discr?                bfd-discriminator
       +--ro remote-discr?               bfd-discriminator
       +--ro new-state?                  bfd-state
       +--ro state-change-reason?        iana-bfd-types:bfd-diagnostic
       +--ro time-of-last-state-change?  yang:date-and-time
       +--ro dest-addr?                  inet:ip-address
       +--ro source-addr?                inet:ip-address
       +--ro session-index?              uint32
       +--ro path-type?                  identityref
       +--ro mpls-dest-address?          inet:ip-address
       +--ro tunnel-name?                string
```

2.11. Interaction with other YANG modules

Generic YANG Data Model for Connectionless OAM protocols [I-D.ietf-lime-yang-connectionless-oam] describes how the LIME connectionless OAM model could be extended to support BFD.

Also, the operation of the BFD data model depends on configuration parameters that are defined in other YANG modules.

2.11.1. Module ietf-interfaces

The following boolean configuration is defined in A YANG Data Model for Interface Management [RFC7223]:

/if:interfaces/if:interface/if:enabled
If this configuration is set to "false", no BFD packets can be transmitted or received on that interface.

2.11.2. Module ietf-ip

The following boolean configuration is defined in A YANG Data Model for IP Management [RFC7277]:

/if:interfaces/if:interface/ip:ipv4/ip:enabled
If this configuration is set to "false", no BFD IPv4 packets can be transmitted or received on that interface.

/if:interfaces/if:interface/ip:ipv4/ip:forwarding
If this configuration is set to "false", no BFD IPv4 packets can be transmitted or received on that interface.

/if:interfaces/if:interface/ip:ipv6/ip:enabled
If this configuration is set to "false", no BFD IPv6 packets can be transmitted or received on that interface.

/if:interfaces/if:interface/ip:ipv6/ip:forwarding
If this configuration is set to "false", no BFD IPv6 packets can be transmitted or received on that interface.

2.11.3. Module ietf-mpls

The following boolean configuration is defined in A YANG Data Model for MPLS Base [I-D.ietf-mpls-base-yang]:

/rt:routing/mpls:mpls/mpls:interface/mpls:config/mpls:enabled
If this configuration is set to "false", no BFD MPLS packets can be transmitted or received on that interface.

2.11.4. Module ietf-te

The following configuration is defined in the "ietf-te" YANG module YANG Data Model for TE Topology [I-D.ietf-teas-yang-te]:

```
   /ietf-te:te/ietf-te:tunnels/ietf-te:tunnel/ietf-te:config/ietf-
   te:admin-status
           If this configuration is not set to "state-up", no BFD MPLS
           packets can be transmitted or received on that tunnel.
```

2.12. IANA BFD YANG Module

```
  <CODE BEGINS> file "iana-bfd-types@2017-06-30.yang"

  module iana-bfd-types {
    namespace "urn:ietf:params:xml:ns:yang:iana-bfd-types";

    prefix "iana-bfd-types";

    organization "IANA";

    contact
      "        Internet Assigned Numbers Authority

      Postal: ICANN
              4676 Admiralty Way, Suite 330
              Marina del Rey, CA 90292

      Tel:    +1 310 823 9358
      <mailto:iana@iana.org>";

    description
      "This module contains a collection of YANG data types
       considered defined by IANA and used for BFD.

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       identified as authors of the code.  All rights reserved.

       Redistribution and use in source and binary forms, with or
       without modification, is permitted pursuant to, and subject
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       Relating to IETF Documents
       (http://trustee.ietf.org/license-info).

       This version of this YANG module is part of RFC XXXX; see
       the RFC itself for full legal notices.";

    revision 2017-06-30 {
      description "Initial revision.";
      reference "RFC XXXX: IANA BFD YANG Data Types.";
    }
```

```
    // RFC Ed.: replace XXXX with actual RFC number and remove this
    // note


    typedef bfd-diagnostic {
      type enumeration {
        enum none {
          value 0;
          description "None";
        }
        enum control-expiry {
          value 1;
          description "Control timer expiry";
        }
        enum echo-failed {
          value 2;
          description "Echo failure";
        }
        enum neighbor-down {
          value 3;
          description "Neighbor down";
        }
        enum forwarding-reset {
          value 4;
          description "Forwarding reset";
        }
        enum path-down {
          value 5;
          description "Path down";
        }
        enum concatenated-path-down {
          value 6;
          description "Concatenated path down";
        }
        enum admin-down {
          value 7;
          description "Admin down";
        }
        enum reverse-concatenated-path-down {
          value 8;
          description "Reverse concatenated path down";
        }
        enum mis-connectivity-defect {
          value 9;
          description "Mis-connectivity defect as specified in RFC6428";
        }
      }
      description
```

```
        "BFD diagnostic as defined in RFC5880. Range is 0 to 31.";
    }

    typedef bfd-auth-type {
      type enumeration {
        enum reserved {
          value 0;
          description "Reserved";
        }
        enum simple-password {
          value 1;
          description "Simple password";
        }
        enum keyed-md5 {
          value 2;
          description "Keyed MD5";
        }
        enum meticulous-keyed-md5 {
          value 3;
          description "Meticulous keyed MD5";
        }
        enum keyed-sha1 {
          value 4;
          description "Keyed SHA1";
        }
        enum meticulous-keyed-sha1 {
          value 5;
          description "Meticulous keyed SHA1";
        }
      }
      description
        "BFD authentication type as defined in RFC5880. Range is 0 to
         255.";
    }

  }

  <CODE ENDS>
```

2.13. BFD top-level YANG Module

```
 <CODE BEGINS> file "ietf-bfd@2017-06-30.yang"

 module ietf-bfd {
   namespace "urn:ietf:params:xml:ns:yang:ietf-bfd";

   prefix "bfd";
```

```
   import iana-bfd-types {
     prefix "iana-bfd-types";
   }

   import ietf-inet-types {
     prefix "inet";
   }

   import ietf-yang-types {
     prefix "yang";
   }

   import ietf-routing {
     prefix "rt";
   }

   import ietf-key-chain {
     prefix "kc";
   }

   organization "IETF BFD Working Group";

   contact
     "WG Web:   <http://tools.ietf.org/wg/bfd>
      WG List:  <rtg-bfd@ietf.org>

      Editors:  Reshad Rahman (rrahman@cisco.com),
                Lianshu Zheng (vero.zheng@huawei.com),
                Mahesh Jethanandani (mjethanandani@gmail.com)";

   description
     "This module contains the YANG definition for BFD parameters as
      per RFC5880.

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      identified as authors of the code.  All rights reserved.

      Redistribution and use in source and binary forms, with or
      without modification, is permitted pursuant to, and subject
      to the license terms contained in, the Simplified BSD License
      set forth in Section 4.c of the IETF Trust's Legal Provisions
      Relating to IETF Documents
      (http://trustee.ietf.org/license-info).

      This version of this YANG module is part of RFC XXXX; see
      the RFC itself for full legal notices.";

   revision 2017-06-30 {
```

```
    description "Initial revision.";
    reference "RFC XXXX: A YANG data model for BFD";
  }

  // RFC Ed.: replace XXXX with actual RFC number and remove this
  // note

  identity bfdv1 {
    base "rt:control-plane-protocol";
    description "BFD protocol version 1 as per RFC5880.";
  }

  typedef bfd-discriminator {
    type uint32 {
      range 1..4294967295;
    }
    description "BFD discriminator";
  }

  typedef bfd-state {
    type enumeration {
      enum adminDown {
        value 0;
        description "admindown";
      }
      enum down {
        value 1;
        description "down";
      }
      enum init {
        value 2;
        description "init";
      }
      enum up {
        value 3;
        description "up";
      }
    }
    description "BFD state as defined in RFC5880";
  }

  typedef bfd-multiplier {
    type uint8 {
      range 1..255;
    }
    description "Multiplier";
  }
```

```
   typedef hops {
     type uint8 {
       range 1..255;
     }
     description
       "This corresponds to Time To Live for IPv4 and corresponds to hop
        limit for IPv6";
   }

   /*
    * Identity definitions
    */
   identity bfd-path-type {
     description
       "Base identity for BFD path type. The session type indicates
        the type of path on which BFD is running";
   }
   identity bfd-path-ip-sh {
     base bfd-path-type;
     description "BFD on IP single hop";
   }
   identity bfd-path-ip-mh {
     base bfd-path-type;
     description "BFD on IP multi hop";
   }
   identity bfd-path-mpls-te {
     base bfd-path-type;
     description "BFD on MPLS Traffic Engineering";
   }
   identity bfd-path-mpls-lsp {
     base bfd-path-type;
     description "BFD on MPLS Label Switched Path";
   }
   identity bfd-path-lag {
     base bfd-path-type;
     description "Micro-BFD on LAG member links";
   }

   identity bfd-encap-type {
     description
       "Base identity for BFD encapsulation type.";
   }
   identity bfd-encap-ip {
     base bfd-encap-type;
     description "BFD with IP encapsulation.";
   }

   identity bfd-auth-replay-protection {
```

```
    description
      "Base identity for BFD authentication replay protection. " +
      "See section 6.7 of RFC5880.";
  }
  identity bfd-auth-replay-protection-non-meticulous {
    base bfd-auth-replay-protection;
    description "Non-meticulous (see section 6.7.3 of RFC5880)";
  }
  identity bfd-auth-replay-protection-meticulous {
    base bfd-auth-replay-protection;
    description "Meticulous (see section 6.7.3 of RFC5880)";
  }

  /*
   * Feature definitions.
   */
  feature bfd-authentication {
          description "BFD authentication supported";
        }

  feature bfd-demand-mode {
    description "BFD demand mode supported";
  }

  feature bfd-echo-mode {
    description "BFD echo mode supported";
  }

  /*
   * Groupings
   */
  grouping bfd-auth-parms {
    description
      "Grouping for BFD authentication parameters
       (see section 6.7 of RFC5880).";
    container authentication-parms {
      if-feature bfd-authentication;
      presence
        "Enables BFD authentication (see section 6.7 of RFC5880).";
      description "Parameters for BFD authentication";

      leaf key-chain {
        type kc:key-chain-ref;
        description "Name of key-chain";
      }

      leaf replay-protection {
        type identityref {
```

```
          base bfd-auth-replay-protection;
        }
        description
          "Protection against replays";
      }
    }
  }

  grouping bfd-grouping-base-cfg-parms {
    description "BFD grouping for base config parameters";
    leaf local-multiplier {
      type bfd-multiplier;
      default 3;
      description "Multiplier transmitted by local system";
    }

    choice interval-config-type {
      description
        "Two interval values or 1 value used for both tx and rx";
      case tx-rx-intervals {
        leaf desired-min-tx-interval {
          type uint32;
          units microseconds;
          mandatory true;
          description
            "Desired minimum transmit interval of control packets";
        }

        leaf required-min-rx-interval {
          type uint32;
          units microseconds;
          mandatory true;
          description
            "Required minimum receive interval of control packets";
        }
      }
      case single-interval {
        leaf min-interval {
          type uint32;
          units microseconds;
          mandatory true;
          description
            "Desired minimum transmit interval and required " +
            "minimum receive interval of control packets";
        }
      }
    }
  }
```

```
   grouping bfd-grouping-common-cfg-parms {
     description "BFD grouping for common config parameters";

     uses bfd-grouping-base-cfg-parms;

     leaf demand-enabled {
       if-feature bfd-demand-mode;
       type boolean;
       default false;
       description "To enable demand mode";
     }

     leaf admin-down {
       type boolean;
       default false;
       description
         "Is the BFD session administratively down";
     }
     uses bfd-auth-parms;
   }

   grouping bfd-grouping-echo-cfg-parms {
     description "BFD grouping for echo config parameters";
     leaf desired-min-echo-tx-interval {
       type uint32;
       units microseconds;
       default 0;
       description "Desired minumum transmit interval for echo";
     }

     leaf required-min-echo-rx-interval {
       type uint32;
       units microseconds;
       default 0;
       description "Required minimum receive interval for echo";
     }
   }

   grouping bfd-client-base-cfg-parms {
     description
       "BFD grouping which could be used by a protocol which
        is a client of BFD to enable its use of BFD";

     container bfd-cfg {
       description "BFD configuration";
       leaf enabled {
         type boolean;
         default false;
```

```
        description "True if BFD is enabled";
      }
    }
  }

  grouping bfd-all-session {
    description "BFD session operational information";
    leaf path-type {
      type identityref {
        base bfd-path-type;
      }
      config "false";
      description
        "BFD session type, this indicates the path type that BFD is
        running on";
    }
    leaf ip-encapsulation {
      type boolean;
      config "false";
      description "Whether BFD encapsulation uses IP";
    }
    leaf local-discriminator {
      type bfd-discriminator;
      config "false";
      description "Local discriminator";
    }
    leaf remote-discriminator {
      type bfd-discriminator;
      config "false";
      description "Remote discriminator";
    }
    leaf remote-multiplier {
      type bfd-multiplier;
      config "false";
      description "Remote multiplier";
    }
    leaf demand-capability {
      if-feature bfd-demand-mode;
      type boolean;
      config "false";
      description "Local demand mode capability";
    }
    leaf source-port {
      when "../ip-encapsulation = 'true'" {
        description
          "Source port valid only when IP encapsulation is used";
      }
      type inet:port-number;
```

```
      config "false";
      description "Source UDP port";
    }
    leaf dest-port {
      when "../ip-encapsulation = 'true'" {
        description
          "Destination port valid only when IP encapsulation is used";
      }
      type inet:port-number;
      config "false";
      description "Destination UDP port";
    }

    container session-running {
      config "false";
      description "BFD session running information";
      leaf session-index {
        type uint32;
        description
          "An index used to uniquely identify BFD sessions";
      }
      leaf local-state {
        type bfd-state;
        description "Local state";
      }
      leaf remote-state {
        type bfd-state;
        description "Remote state";
      }
      leaf local-diagnostic {
        type iana-bfd-types:bfd-diagnostic;
        description "Local diagnostic";
      }
      leaf remote-diagnostic {
        type iana-bfd-types:bfd-diagnostic;
        description "Remote diagnostic";
      }
      leaf remote-authenticated {
        type boolean;
        description
          "Indicates whether incoming BFD control packets are
          authenticated";
      }
      leaf remote-authentication-type {
        when "../remote-authenticated = 'true'" {
          description
            "Only valid when incoming BFD control packets are
             authenticated";
```

```
        }
        if-feature bfd-authentication;
        type iana-bfd-types:bfd-auth-type;
        description
          "Authentication type of incoming BFD control packets";
      }
      leaf detection-mode {
        type enumeration {
          enum async-with-echo {
            value "1";
            description "Async with echo";
          }
          enum async-without-echo {
            value "2";
            description "Async without echo";
          }
          enum demand-with-echo {
            value "3";
            description "Demand with echo";
          }
          enum demand-without-echo {
            value "4";
            description "Demand without echo";
          }
        }
        description "Detection mode";
      }
      leaf negotiated-tx-interval {
        type uint32;
        units microseconds;
        description "Negotiated transmit interval";
      }
      leaf negotiated-rx-interval {
        type uint32;
        units microseconds;
        description "Negotiated receive interval";
      }
      leaf detection-time {
        type uint32;
        units microseconds;
        description "Detection time";
      }
      leaf echo-tx-interval-in-use {
        when "../../path-type = 'bfd-path-ip-sh'" {
          description
            "Echo is supported for IP single-hop only.";
        }
        if-feature bfd-echo-mode;
```

```
        type uint32;
        units microseconds;
        description "Echo transmit interval in use";
      }
    }

    container sesssion-statistics {
      config "false";
      description "BFD per-session statistics";

      leaf create-time {
        type yang:date-and-time;
        description
          "Time and date when session was created";
      }
      leaf last-down-time {
        type yang:date-and-time;
        description
          "Time and date of last time the session went down";
      }
      leaf last-up-time {
        type yang:date-and-time;
        description
          "Time and date of last time the session went up";
      }
      leaf down-count {
        type uint32;
        description "Session Down Count";
      }
      leaf admin-down-count {
        type uint32;
        description "Session Admin-Down Count";
      }
      leaf receive-packet-count {
        type uint64;
        description "Received Packet Count";
      }
      leaf send-packet-count {
        type uint64;
        description "Sent Packet Count";
      }
      leaf receive-bad-packet {
        type uint64;
        description "Received bad packet count";
      }
      leaf send-failed-packet {
        type uint64;
        description "Packet Failed to Send Count";
```

```
      }
    }
  }

  grouping bfd-session-statistics {
    description "Grouping for session counters";
    container bfd-session-statistics {
      config false;
      description "BFD session counters";
      leaf session-count {
        type uint32;
        description "Number of sessions";
      }
      leaf session-up-count {
        type uint32;
        description "Count of sessions which are up";
      }
      leaf session-down-count {
        type uint32;
        description "Count of sessions which are down";
      }
      leaf session-admin-down-count {
        type uint32;
        description "Count of sessions which are admin-down";
      }
    }
  }

  grouping bfd-notification-parms {
    description
      "This group describes common parameters that will be sent " +
      "as part of BFD notification";

    leaf local-discr {
      type bfd-discriminator;
      description "BFD local discriminator";
    }

    leaf remote-discr {
      type bfd-discriminator;
      description "BFD remote discriminator";
    }

    leaf new-state {
      type bfd-state;
      description "Current BFD state";
    }
```

```
    leaf state-change-reason {
      type iana-bfd-types:bfd-diagnostic;
      description "BFD state change reason";
    }

    leaf time-of-last-state-change {
      type yang:date-and-time;
      description
        "Calendar time of previous state change";
    }

    leaf dest-addr {
      type inet:ip-address;
      description "BFD peer address";
    }

    leaf source-addr {
      type inet:ip-address;
      description "BFD local address";
    }

    leaf session-index {
      type uint32;
      description "An index used to uniquely identify BFD sessions";
    }

    leaf path-type {
      type identityref {
        base bfd-path-type;
      }
      description "BFD path type";
    }
  }

  augment "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol" {
     when "rt:type = 'bfd:bfdv1'" {
      description
        "This augmentation is only valid for a control-plane protocol
         instance of BFD (type 'bfdv1').";
    }
    description "BFD augmentation.";

    container bfd {
      description "BFD top level container";

      uses bfd-session-statistics;
    }
```

```
   }
 }

 <CODE ENDS>
```

2.14. BFD IP single-hop YANG Module

```
   <CODE BEGINS> file "ietf-bfd-ip-sh@2017-06-30.yang"

   module ietf-bfd-ip-sh {
     namespace "urn:ietf:params:xml:ns:yang:ietf-bfd-ip-sh";

     prefix "bfd-ip-sh";

     import ietf-bfd {
       prefix "bfd";
     }

     import ietf-interfaces {
       prefix "if";
     }

     import ietf-inet-types {
       prefix "inet";
     }

     import ietf-routing {
       prefix "rt";
     }

     organization "IETF BFD Working Group";

     contact
       "WG Web:   <http://tools.ietf.org/wg/bfd>
        WG List:  <rtg-bfd@ietf.org>

        Editors:  Reshad Rahman (rrahman@cisco.com),
                  Lianshu Zheng (vero.zheng@huawei.com),
                  Mahesh Jethanandani (mjethanandani@gmail.com)";

     description
       "This module contains the YANG definition for BFD IP single-hop
        as per RFC5881.

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```

```
  revision 2017-06-30 {
    description "Initial revision.";
    reference "RFC XXXX: A YANG data model for BFD IP single-hop";
  }

  // RFC Ed.: replace XXXX with actual RFC number and remove this
  // note

  augment "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol/bfd:bfd" {
    description "BFD augmentation for IP single-hop";
    container ip-sh {
      description "BFD IP single-hop top level container";

      uses bfd:bfd-session-statistics;

      list sessions {
        key "interface dest-addr";
        description "List of IP single-hop sessions";
        leaf interface {
          type if:interface-ref;
          description
            "Interface on which the BFD session is running.";
        }
        leaf dest-addr {
          type inet:ip-address;
          description "IP address of the peer";
        }
        leaf source-addr {
          type inet:ip-address;
          description "Local address";
        }

        uses bfd:bfd-grouping-common-cfg-parms;

        uses bfd:bfd-grouping-echo-cfg-parms;

        uses bfd:bfd-all-session;
      }
```

```
      }
    }

    notification bfd-singlehop-notification {
      description
        "Notification for BFD single-hop session state change. An " +
        "implementation may rate-limit notifications, e.g. when a" +
        "session is continuously changing state.";

      uses bfd:bfd-notification-parms;

      leaf interface {
        type if:interface-ref;
        description "Interface to which this BFD session belongs to";
      }

      leaf echo-enabled {
        type boolean;
        description "Was echo enabled for BFD";
      }
    }

  }

  <CODE ENDS>
```

2.15. BFD IP multi-hop YANG Module

```
<CODE BEGINS> file "ietf-bfd-ip-mh@2017-06-30.yang"

module ietf-bfd-ip-mh {
  namespace "urn:ietf:params:xml:ns:yang:ietf-bfd-ip-mh";
  // replace with IANA namespace when assigned
  prefix "bfd-ip-mh";

  import ietf-bfd {
    prefix "bfd";
  }

  import ietf-inet-types {
    prefix "inet";
  }

  import ietf-routing {
    prefix "rt";
  }

  organization "IETF BFD Working Group";
```

```
  contact
    "WG Web:   <http://tools.ietf.org/wg/bfd>
     WG List:  <rtg-bfd@ietf.org>

     Editors:  Reshad Rahman (rrahman@cisco.com),
               Lianshu Zheng (vero.zheng@huawei.com),
               Mahesh Jethanandani (mjethanandani@gmail.com)";

  description
    "This module contains the YANG definition for BFD IP multi-hop
     as per RFC5883.

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     (http://trustee.ietf.org/license-info).

     This version of this YANG module is part of RFC XXXX; see
     the RFC itself for full legal notices.";

  revision 2017-06-30 {
    description "Initial revision.";
    reference "RFC XXXX: A YANG data model for BFD IP multi-hop";
  }

  // RFC Ed.: replace XXXX with actual RFC number and remove this
  // note

  augment "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol/bfd:bfd" {
    description "BFD augmentation for IP multi-hop";
    container ip-mh {
      description "BFD IP multi-hop top level container";

      uses bfd:bfd-session-statistics;

      list session-group {
        key "source-addr dest-addr";
              description
                "Group of BFD IP multi-hop sessions (for ECMP). A " +
          "group of sessions is between 1 source and 1  " +
          "destination, each session has a different field " +
          "in UDP/IP hdr for ECMP.";
```

```
        leaf source-addr {
          type inet:ip-address;
          description
            "Local IP address";
        }
        leaf dest-addr {
          type inet:ip-address;
          description
            "IP address of the peer";
        }
        uses bfd:bfd-grouping-common-cfg-parms;

        leaf tx-ttl {
          type bfd:hops;
          default 255;
          description "Hop count of outgoing BFD control packets";
        }
        leaf rx-ttl {
          type bfd:hops;
          mandatory true;
          description
            "Minimum allowed hop count value for incoming BFD control
             packets. Control packets whose hop count is lower than this
                   value are dropped.";
        }
        list sessions {
                config false;
          description
            "The multiple BFD sessions between a source and a " +
            "destination.";
          uses bfd:bfd-all-session;
        }
      }
    }
  }

  notification bfd-multihop-notification {
    description
      "Notification for BFD multi-hop session state change. An " +
      "implementation may rate-limit notifications, e.g. when a" +
      "session is continuously changing state.";

    uses bfd:bfd-notification-parms;
  }
}

<CODE ENDS>
```

2.16. BFD over LAG YANG Module

```
<CODE BEGINS> file "ietf-bfd-lag@2017-06-30.yang"

module ietf-bfd-lag {
  namespace "urn:ietf:params:xml:ns:yang:ietf-bfd-lag";
  // replace with IANA namespace when assigned
  prefix "bfd-lag";

  import ietf-bfd {
    prefix "bfd";
  }

  import ietf-interfaces {
    prefix "if";
  }

  import ietf-inet-types {
    prefix "inet";
  }

  import ietf-routing {
    prefix "rt";
  }

  organization "IETF BFD Working Group";

  contact
    "WG Web:   <http://tools.ietf.org/wg/bfd>
     WG List:  <rtg-bfd@ietf.org>

     Editors:  Reshad Rahman (rrahman@cisco.com),
               Lianshu Zheng vero.zheng@huawei.com),
               Mahesh Jethanandani (mjethanandani@gmail.com)";

  description
    "This module contains the YANG definition for BFD over LAG
     interfaces as per RFC7130.

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     (http://trustee.ietf.org/license-info).
```

```
        This version of this YANG module is part of RFC XXXX; see
        the RFC itself for full legal notices.";

    revision 2017-06-30 {
      description "Initial revision.";
      reference "RFC XXXX: A YANG data model for BFD over LAG";
    }

    // RFC Ed.: replace XXXX with actual RFC number and remove this
    // note

    augment "/rt:routing/rt:control-plane-protocols/"
          + "rt:control-plane-protocol/bfd:bfd" {
      description "BFD augmentation for LAG";
      container lag {
        description "BFD over LAG top level container";

        container micro-bfd-ipv4-session-statistics {
          description "Micro-BFD IPv4 session counters";
          uses bfd:bfd-session-statistics;
        }
        container micro-bfd-ipv6-session-statistics {
          description "Micro-BFD IPv6 session counters";
          uses bfd:bfd-session-statistics;
        }

        list sessions {
          key "lag-name";
          description "A LAG interface on which BFD is running";
          leaf lag-name {
            type if:interface-ref ;
            description "Name of the LAG";
          }
          leaf ipv4-dest-addr {
            type inet:ipv4-address;
            description
              "IPv4 address of the peer, for IPv4 micro-BFD.";
          }
          leaf ipv6-dest-addr {
            type inet:ipv6-address;
            description
              "IPv6 address of the peer, for IPv6 micro-BFD.";
          }
          uses bfd:bfd-grouping-common-cfg-parms;

          leaf use-ipv4 {
            type boolean;
            description "Using IPv4 micro-BFD.";
```

```
          }
          leaf use-ipv6 {
            type boolean;
            description "Using IPv6 micro-BFD.";
          }

          list member-links {
            key "member-link";
            config false;
            description
              "Micro-BFD over LAG. This represents one member link";

            leaf member-link {
              type if:interface-ref;
              description
                "Member link on which micro-BFD is running";
            }
            container micro-bfd-ipv4 {
              when "../../use-ipv4 = 'true'" {
                description "Needed only if IPv4 is used.";
              }
              description
                "Micro-BFD IPv4 session state on member link";
              uses bfd:bfd-all-session;
            }
            container micro-bfd-ipv6 {
              when "../../use-ipv6 = 'true'" {
                description "Needed only if IPv6 is used.";
              }
              description
                "Micro-BFD IPv6 session state on member link";
              uses bfd:bfd-all-session;
            }
          }
        }
      }

      notification bfd-lag-notification {
        description
          "Notification for BFD over LAG session state change. " +
          "An implementation may rate-limit notifications, e.g. when a" +
          "session is continuously changing state.";

        uses bfd:bfd-notification-parms;

        leaf lag-name {
          type if:interface-ref;
```

```
        description "LAG interface name";
      }

      leaf member-link {
        type if:interface-ref;
        description "Member link on which BFD is running";
      }
    }
  }

  <CODE ENDS>
```

2.17. BFD over MPLS YANG Module

```
  <CODE BEGINS> file "ietf-bfd-mpls@2017-06-30.yang"

  module ietf-bfd-mpls {
    namespace "urn:ietf:params:xml:ns:yang:ietf-bfd-mpls";
    // replace with IANA namespace when assigned
    prefix "bfd-mpls";

    import ietf-bfd {
      prefix "bfd";
    }

    import ietf-inet-types {
      prefix "inet";
    }

    import ietf-routing {
      prefix "rt";
    }

    organization "IETF BFD Working Group";

    contact
      "WG Web:   <http://tools.ietf.org/wg/bfd>
       WG List:  <rtg-bfd@ietf.org>

       Editors:   Reshad Rahman (rrahman@cisco.com),
                  Lianshu Zheng (vero.zheng@huawei.com),
                  Mahesh Jethanandani (mjethanandani@gmail.com)";

    description
      "This module contains the YANG definition for BFD parameters for
       MPLS LSPs as per RFC5884.

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```

```
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        the RFC itself for full legal notices.";

    revision 2017-06-30 {
      description "Initial revision.";
      reference "RFC XXXX: A YANG data model for BFD over MPLS LSPs";
    }

    // RFC Ed.: replace XXXX with actual RFC number and remove this
    // note

    identity bfd-encap-gach {
      base bfd:bfd-encap-type;
      description
        "BFD with G-ACh encapsulation as per RFC5586.";
    }

    identity bfd-encap-ip-gach {
      base bfd:bfd-encap-type;
      description
        "BFD with IP and G-ACh encapsulation as per RFC5586.";
    }

    grouping bfd-encap-cfg {
      description "Configuration for BFD encapsulation";

      leaf encap {
        type identityref {
          base bfd:bfd-encap-type;
        }
        default bfd:bfd-encap-ip;
        description "BFD encapsulation";
      }
    }

    grouping bfd-mpls-dest-address {
      description "Destination address as per RFC5884";

      leaf mpls-dest-address {
```

```
        type inet:ip-address;
        config "false";
        description
          "Destination address as per RFC5884.
           Needed if IP encapsulation is used";
      }
    }


    augment "/rt:routing/rt:control-plane-protocols/"
          + "rt:control-plane-protocol/bfd:bfd" {
      description "BFD augmentation for MPLS";
      container mpls {
        description "BFD MPLS top level container";

        uses bfd:bfd-session-statistics;

        container egress {
          description "Egress configuration";

          uses bfd:bfd-grouping-base-cfg-parms;

          uses bfd:bfd-auth-parms;
        }

        list session-group {
          key "mpls-fec";
          description
            "Group of BFD MPLS sessions (for ECMP). A group of " +
            "sessions is for 1 FEC, each session has a different " +
            "field in UDP/IP hdr for ECMP.";
          leaf mpls-fec {
            type inet:ip-prefix;
            description "MPLS FEC";
          }

          uses bfd:bfd-grouping-common-cfg-parms;

          list sessions {
                  config false;
            description
              "The BFD sessions for an MPLS FEC. Local " +
              "discriminator is unique for each session in the " +
              "group.";
            uses bfd:bfd-all-session;

            uses bfd-mpls:bfd-mpls-dest-address;
          }
```

```
        }
      }
    }

    notification bfd-mpls-notification {
      description
        "Notification for BFD over MPLS FEC session state change. " +
        "An implementation may rate-limit notifications, e.g. when a" +
        "session is continuously changing state.";

      uses bfd:bfd-notification-parms;

      leaf mpls-dest-address {
        type inet:ip-address;
        description
          "Destination address as per RFC5884.
           Needed if IP encapsulation is used";
      }
    }
  }

  <CODE ENDS>
```

2.18. BFD over MPLS-TE YANG Module

```
  <CODE BEGINS> file "ietf-bfd-mpls-te@2017-06-30.yang"

  module ietf-bfd-mpls-te {
    namespace "urn:ietf:params:xml:ns:yang:ietf-bfd-mpls-te";
    // replace with IANA namespace when assigned
    prefix "bfd-mpls-te";

    import ietf-bfd {
      prefix "bfd";
    }

    import ietf-bfd-mpls {
      prefix "bfd-mpls";
    }

    import ietf-te {
      prefix "te";
    }

    import ietf-routing {
      prefix "rt";
    }
```

```
     organization "IETF BFD Working Group";

     contact
       "WG Web:   <http://tools.ietf.org/wg/bfd>
        WG List:  <rtg-bfd@ietf.org>

        Editors:  Reshad Rahman (rrahman@cisco.com),
                  Lianshu Zheng (vero.zheng@huawei.com),
                  Mahesh Jethanandani (mjethanandani@gmail.com)";

     description
       "This module contains the YANG definition for BFD parameters for
        MPLS Traffic Engineering as per RFC5884.

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        (http://trustee.ietf.org/license-info).

        This version of this YANG module is part of RFC XXXX; see
        the RFC itself for full legal notices.";

     revision 2017-06-30 {
       description "Initial revision.";
       reference "RFC XXXX: A YANG data model for BFD over MPLS-TE";
     }

     // RFC Ed.: replace XXXX with actual RFC number and remove this
     // note

     augment "/rt:routing/rt:control-plane-protocols/"
           + "rt:control-plane-protocol/bfd:bfd" {
       description "BFD augmentation for MPLS-TE";
       container mpls-te {
         description "BFD MPLS-TE top level container";

         container config {
           description "BFD MPLS-TE configuration container";

           container egress {
             description "Egress configuration";

             uses bfd:bfd-grouping-base-cfg-parms;
```

```
            uses bfd:bfd-auth-parms;
          }
        }

        container oper {
          config "false";
          description "BFD operational container";
          uses bfd:bfd-session-statistics;
        }
      }
    }

    augment "/te:te/te:tunnels/te:tunnel/te:config" {
      description "BFD configuration on MPLS-TE tunnel.";

      uses bfd:bfd-grouping-common-cfg-parms;

      uses bfd-mpls:bfd-encap-cfg;
    }

    augment "/te:te/te:lsps-state/te:lsp" {
      when "/te:te/te:lsps-state/te:lsp/te:origin-type != 'transit'" {
        description "BFD information not needed at transit points";
      }
      description "BFD state information on MPLS-TE LSP.";

      uses bfd:bfd-all-session;

      uses bfd-mpls:bfd-mpls-dest-address;
    }


    notification bfd-mpls-te-notification {
      description
        "Notification for BFD over MPLS-TE session state change. " +
        "An implementation may rate-limit notifications, e.g. when a" +
        "session is continuously changing state.";

      uses bfd:bfd-notification-parms;

      uses bfd-mpls:bfd-mpls-dest-address;

      leaf tunnel-name {
        type string;
        description "MPLS-TE tunnel on which BFD was running.";
      }
    }
  }
```

<CODE ENDS>

2.19. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory to implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operations and content.

The YANG module has writeable data nodes which can be used for creation of BFD sessions and modification of BFD session parameters. The system should "police" creation of BFD sessions to prevent new sessions from causing existing BFD sessions to fail. For BFD session modification, the BFD protocol has mechanisms in place which allow for in service modification.

2.20. IANA Considerations

The IANA is requested to as assign a new namespace URI from the IETF XML registry.

This document registers the following namesace URIs in the IETF XML registry [RFC3688]:

URI: urn:ietf:params:xml:ns:yang:ietf-bfd

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-bfd-ip-sh

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-bfd-mh

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-bfd-lag

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-bfd-mpls

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-bfd-mpls-te

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

2.20.1. IANA-Maintained iana-bfd-types module

This document defines the initial version of the IANA-maintained iana-bfd-types YANG module.

The iana-bfd-types YANG module is intended to reflect the "BFD Diagnostic Codes" registry and "BFD Authentication Types" registry at https://www.iana.org/assignments/bfd-parameters/bfd-parameters.xhtml

2.21. Acknowledgements

We would also like to thank Nobo Akiya and Jeff Haas for their encouragement on this work. We would also like to thank Rakesh Gandhi and Tarek Saad for their help on the MPLS-TE model. We would also like to thank Acee Lindem for his guidance.

3. References

3.1. Normative References

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Appendix A. Echo function configuration example

The following intervals are added for the echo function (if supported):

desired-min-echo-tx-interval

```
          This is the minimum interval that the local system would like
          to use when transmitting BFD echo packets.  If 0, the echo
          function as defined in BFD [RFC5880] is disabled.

   required-min-echo-rx-interval
          This is the Required Min Echo RX Interval as defined in BFD
          [RFC5880].

 module: example-bfd-echo
 augment /rt:routing/rt:control-plane-protocols/rt:control-plane-protoco
 l/bfd:bfd/bfd-ip-sh:ip-sh/bfd-ip-sh:sessions:
    +--rw echo {bfd-echo-mode}?
       +--rw desired-min-echo-tx-interval?    uint32
       +--rw required-min-echo-rx-interval?   uint32
```

A.1. Example YANG module for BFD echo function

```
module example-bfd-echo {
  namespace "tag:example.com,2017:example-bfd-echo";

  prefix "example-bfd-echo";

  import ietf-bfd {
    prefix "bfd";
  }

  import ietf-bfd-ip-sh {
    prefix "bfd-ip-sh";
  }

  import ietf-routing {
    prefix "rt";
  }

  organization "IETF BFD Working Group";

  contact
    "WG Web:   <http://tools.ietf.org/wg/bfd>
     WG List:  <rtg-bfd@ietf.org>

     Editors:  Reshad Rahman (rrahman@cisco.com),
               Lianshu Zheng (vero.zheng@huawei.com),
               Mahesh Jethanandani (mjethanandani@gmail.com)";

  description
    "This module contains an example YANG augmentation for configuration
     of BFD echo function.
```

```
  revision 2017-06-30 {
    description "Initial revision.";
    reference
      "RFC XXXX: A YANG data model example augmentation for BFD echo
       function";
  }

  // RFC Ed.: replace XXXX with actual RFC number and remove this
  // note

  /*
   * Groupings
   */
  grouping bfd-grouping-echo-cfg-parms {
    description "BFD grouping for echo config parameters";
    leaf desired-min-echo-tx-interval {
      type uint32;
      units microseconds;
      default 0;
      description "Desired minumum transmit interval for echo";
    }

    leaf required-min-echo-rx-interval {
      type uint32;
      units microseconds;
      default 0;
      description "Required minimum receive interval for echo";
    }
  }

  augment "/rt:routing/rt:control-plane-protocols/"
        + "rt:control-plane-protocol/bfd:bfd/bfd-ip-sh:ip-sh/"
        + "bfd-ip-sh:sessions" {
    description "Augmentation for BFD echo fucntion.";
```

```
    container echo {
      if-feature bfd-echo-mode;

      description "BFD echo function container";

      uses bfd-grouping-echo-cfg-parms;
    }
  }
}
```

Appendix B. Change log

RFC Editor: Remove this section upon publication as an RFC.

B.1. Changes between versions -05 and -06

- Adhere to NMDA-guidelines.
- Echo function config moved to appendix as example.
- Added IANA YANG modules.
- Addressed various comments.

B.2. Changes between versions -04 and -05

- "bfd" node in augment of control-plane-protocol as per A YANG Data Model for Routing Management [RFC8022].
- Removed augment of network-instance. Replaced by schema-mount.
- Added information on interaction with other YANG modules.

B.3. Changes between versions -03 and -04

- Updated author information.
- Fixed YANG compile error in ietf-bfd-lag.yang which was due to incorrect when statement.

B.4. Changes between versions -02 and -03

- Fixed YANG compilation warning due to incorrect revision date in ietf-bfd-ip-sh module.

B.5. Changes between versions -01 and -02

- Replace routing-instance, which has been removed from A YANG Data Model for Routing Management [RFC8022], with network-instance from YANG Network Instances [I-D.ietf-rtgwg-ni-model]

B.6. Changes between versions -00 and -01

- Remove BFD configuration parameters from BFD clients, all BFD configuration parameters in BFD
- YANG module split in multiple YANG modules (one per type of forwarding path)
- For BFD over MPLS-TE we augment MPLS-TE model
- For BFD authentication we now use YANG Data Model for Key Chains [RFC8177]

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