INTERNET-DRAFT
Intended Status: Proposed Standard
Updates: 7177, 7178

Expires: August 18, 2018

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February 19, 2018

TRILL (Transparent Interconnection of Lots of Links) Over IP Transport

<draft-ietf-trill-over-ip-14.txt>

Abstract

The TRILL (Transparent Interconnection of Lots of Links) protocol supports both point-to-point and multi-access links and is designed so that a variety of link protocols can be used between TRILL switch ports. This document specifies transmission of encapsulated TRILL data and TRILL IS-IS over IP (v4 or v6) transport. so as to use an IP network as a TRILL link in a unified TRILL campus. This document updates RFC 7177 and updates RFC 7178.

Status of This Document

This Internet-Draft is submitted to IETF in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

TRILL switches (also know as RBridges) are devices that implement the IETF TRILL protocol [RFC6325] [RFC7177] [RFC7780]. TRILL provides transparent forwarding of frames within an arbitrary network topology, using least cost paths for unicast traffic. It supports VLANs and Fine Grained Labels [RFC7172] as well as multipathing of unicast and multi-destination traffic. It uses IS-IS [IS-IS] [RFC7176] link state routing with a TRILL header having a hop count.

RBridge ports can communicate with each other over various protocols, such as Ethernet [RFC6325], pseudowires [RFC7173], or PPP [RFC6361].

This document specifies transmission of encapsulated TRILL data and TRILL IS-IS over IP (v4 or v6 [RFC8200]) transport. so as to use an IP network as a TRILL link in a unified TRILL campus. One mandatory to implement UDP based encapsulation is specified along with two optional to implement encpsulations, one based on UDP and one based on TCP. Provision is made to negotiate other encapsulations. TRILL over IP transport allows RBridges with IP connectivity to form a single TRILL campus, or multiple TRILL networks to be connected as a single TRILL campus via a TRILL over IP transport backbone.

The protocol specified in this document connects RBridge ports using transport over IP transport in such a way that the ports with mutual IP connectivity appear to TRILL to be connected by a single multi-access link. If a set of more than two RBridge ports are connected via a single TRILL over IP transport link, each RBridge port in the set can communicate with every other RBridge port in the set.

To support the scenarios where RBridges are connected via IP paths (including those over the public Internet) that are not under the same administrative control as the TRILL campus and/or not physically secure, this document specifies the use of IPsec [RFC4301] Encapsulating Security Protocol (ESP) [RFC4303] as the mandatory to implement protocol for security (see appendix A).

To dynamically select a mutually supported TRILL over IP transport encapsulation, normally one with good fast path hardware support, a method is provided for agreement between adjacent TRILL switch ports as to what encapsulation to use. Alternatively, where a common encapsulation is known to be supported by the TRILL switch ports on a link, those ports can simply be configured to always use that encapsulation.

This document updates [RFC7177] and [RFC7178] as described in Sections 5 and 11.3 by making adjacency between TRILL over IP transport ports dependent on having a method of encapsulation in

common and by redefining an interval of RBridge Channel protocol numbers to indicate link technology specific capabilities, in this

case encapsulation methods supported for TRILL over IP transport.

2. Terminology

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.

The following terms and acronyms have the meaning indicated:

DEI - Drop Eligibility Indicator. Part of QoS, see Section 4.3.

DRB - Designated RBridge. The RBridge (TRILL switch) elected to be in charge of certain aspects of a TRILL link if that link is not configured as a point-to-point link [RFC6325] [RFC7177].

ENCAP Hdr - See "encapsulation header".

encapsulation header - Protocol header or headers appearing between the IP Header and the TRILL Header. See Sections 4 and 5.

ESP - IPsec Encapsulating Security Protocol [RFC4303].

FGL - Fine Grained Label [RFC7172].

Hdr - Used herein as an abbreviation for "Header".

link - In TRILL, a link connects TRILL ports and is transparent to TRILL data and TRILL IS-IS messages. It may, for example, be a bridged LAN.

HKDF - Hash based Key Derivation Function [RFC5869].

MTU - Maximum Transmission Unit.

QoS - Quality of Service.

RBridge - Routing Bridge. An alternative term for a TRILL switch. [RFC6325] [RFC7780]

SNPA - Sub-Network Point of Attachment.

Sz - The campus wide MTU [RFC6325] [RFC7780].

TMCE - Traffic-Managed Controlled Environment, see Section 8.1.1.

TRILL - Transparent Interconnection of Lots of Links or Tunneled Routing in the Link Layer. The protocol specified in [RFC6325], [RFC7177], [RFC7780], and related RFCs.

TRILL switch - A device implementing the TRILL protocol.

VNI - Virtual Network Identifier. In Virtual eXtensible Local Area Network (VXLAN) [RFC7348], the VXLAN Network Identifier.

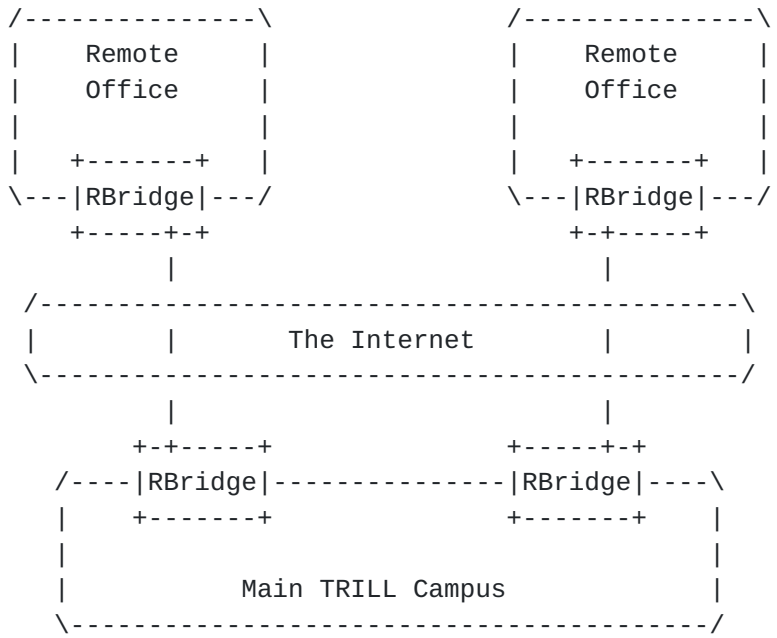
3. Use Cases for TRILL over IP Transport

This section introduces two application scenarios (a remote office scenario and an IP backbone scenario) which cover typical situations where network administrators may choose to use TRILL over an IP network to connect TRILL switches.

3.1 Remote Office Scenario

In the Remote Office Scenario, as shown in the example below, a remote TRILL network is connected to a TRILL campus across a multihop IP network, such as the public Internet. The TRILL network in the remote office becomes a part of the TRILL campus, and nodes in the remote office can be attached to the same VLANs or Fine Grained Labels [RFC7172] as local campus nodes. In many cases, a remote office may be attached to the TRILL campus by a single pair of RBridges, one on the campus end, and the other in the remote office.

In this use case, the TRILL over IP transport link will often cross logical and physical IP networks that do not support TRILL, and are not under the same administrative control as the TRILL campus.

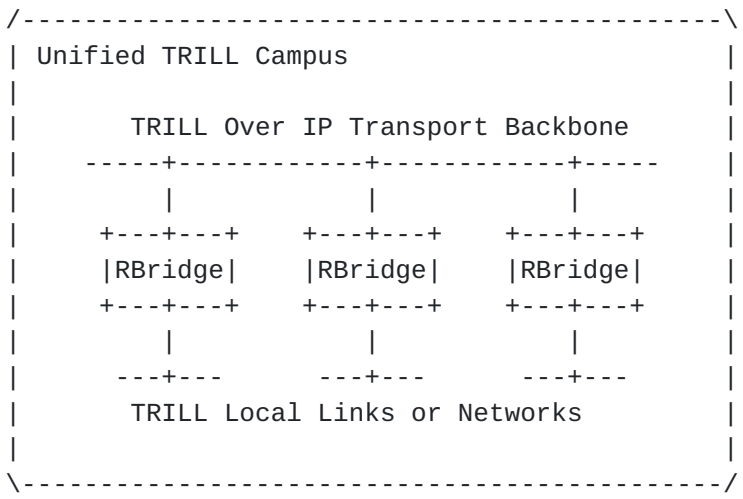


3.2 IP Backbone Scenario

In the IP Backbone Scenario, as shown in the example below, TRILL over IP transport is used to connect a number of TRILL networks to

form a single TRILL campus. For example, a TRILL over IP transport

backbone could be used to connect multiple TRILL networks on different floors of a large building, or to connect TRILL networks in separate buildings of a multi-building site. In this use case, there may often be several TRILL switches on a single TRILL over IP transport link, and the IP link(s) used by TRILL over IP transport are typically under the same administrative control as the rest of the TRILL campus.



3.3 Important Properties of the Scenarios

There are a number of differences between the above two application scenarios, some of which drive features of this specification. These differences are especially pertinent to the security requirements of the solution, how multicast data frames are handled, and how the TRILL switch ports discover each other.

3.3.1 Security Requirements

In the IP Backbone Scenario, TRILL over IP transport is used between a number of RBridge ports, on a network link that is in the same administrative control as the remainder of the TRILL campus. While it is desirable in this scenario to prevent the association of unauthorized RBridges, this can be accomplished using existing IS-IS security mechanisms. There may be no need to protect the data traffic, beyond any protections that are already in place on the local network.

In the Remote Office Scenario, TRILL over IP transport may run over a network that is not under the same administrative control as the TRILL network. It may appear to nodes on the network that they are

sending traffic locally, while that traffic is actually being sent,

in an IP tunnel, over the public Internet. It is necessary in this scenario to protect the integrity and confidentiality of user traffic, as well as ensuring that no unauthorized RBridges can gain access to the RBridge campus. The issues of protecting integrity and confidentiality of user traffic can be addressed by using IPsec for both TRILL IS-IS and TRILL Data packets between RBridges in this scenario.

3.3.2 Multicast Handling

In the IP Backbone scenario, native IP multicast may be supported on the TRILL over IP transport link. If so, it can be used to send TRILL IS-IS and multicast data packets, as discussed later in this document. Alternatively, multi-destination packets can be transmitted serially by IP unicast to the intended recipients.

In the Remote Office Scenario there will often be only one pair of RBridges connecting a given site and, even when multiple RBridges are used to connect a Remote Office to the TRILL campus, the intervening network may not provide reliable (or any) multicast connectivity. Issues such as complex key management also make it more difficult to provide strong data integrity and confidentiality protections for multicast traffic. For all of these reasons, the connections between local and remote RBridges will commonly be treated like point-to-point links, and all TRILL IS-IS control messages and multicast data packets that are transmitted between the Remote Office and the TRILL campus will be serially transmitted by IP unicast, as discussed later in this document.

3.3.3 Neighbor Discovery

In the IP Backbone Scenario, TRILL switches that use TRILL over IP transport can use the normal TRILL IS-IS Hello mechanisms to discover the existence of other TRILL switches on the link [RFC7177] and to establish authenticated communication with them.

In the Remote Office Scenario, an IPsec session will need to be established before TRILL IS-IS traffic can be exchanged, as discussed below. In this case, one end will need to be configured to establish a IPsec session with the other. This will typically be accomplished by configuring the TRILL switch or a border device at a Remote Office to initiate an IPsec session and subsequent TRILL exchanges with a TRILL over IP-enabled RBridge attached to the TRILL campus.

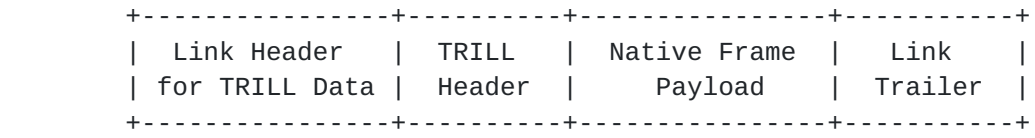
4. TRILL Packet Formats

To support TRILL two types of TRILL packets are transmitted between TRILL switches: TRILL Data packets and TRILL IS-IS packets.

Section 4.1 describes general TRILL packet formats for data and IS-IS independent of link technology. Section 4.2 specifies general TRILL over IP transport packet formats including IPsec ESP encapsulation. Section 4.3 provides QoS Considerations. Section 4.4 discusses broadcast links and multicast packets. And Section 4.5 provides TRILL IS-IS Hello SubNetwork Point of Attachment (SNPA) considerations for TRILL over IP transport.

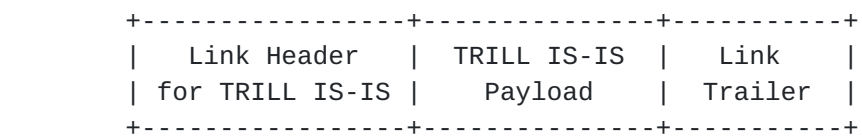
4.1 General Packet Formats

The on-the-wire form of a TRILL Data packet in transit between two neighboring TRILL switch ports is as shown below:



The encapsulated Native Frame Payload is similar to an Ethernet frame with a VLAN tag or Fine Grained Label [RFC7172] but with no trailing Frame Check Sequence (FCS).

TRILL IS-IS packets are formatted on-the-wire as follows:



The Link Header and Link Trailer in these formats depend on the specific link technology. The Link Header contains one or more fields that distinguish TRILL Data from TRILL IS-IS. For example, over Ethernet, the Link Header for TRILL Data ends with the TRILL Ethertype while the Link Header for TRILL IS-IS ends with the L2-IS-IS Ethertype; on the other hand, over PPP, there are no Ethertypes in the Link Header but different PPP protocol code points are included that distinguish TRILL Data from TRILL IS-IS.

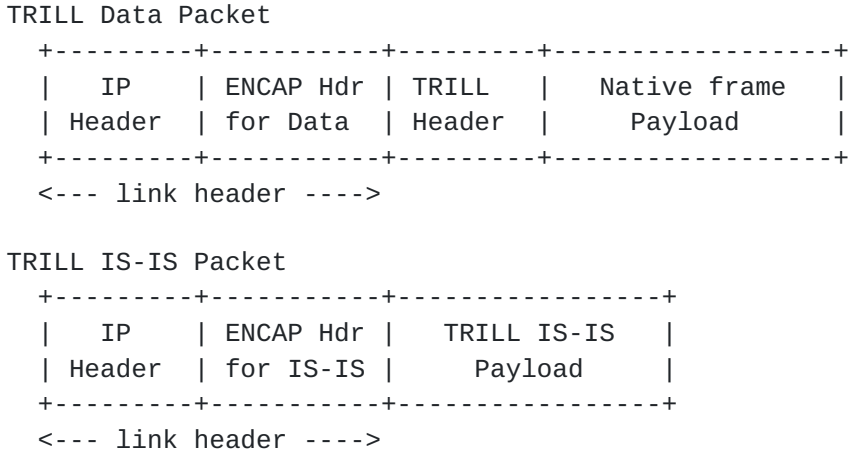
4.2 General TRILL Over IP Packet Formats

In TRILL over IP transport, we use an IP (v4 or v6) header followed by an encapsulation header, such as UDP, as the link header. (On the wire, the IP header will normally be preceded by the lower layer header of a protocol that is carrying IP; however, this does not concern us at the level of this document.)

There are multiple IP based encapsulations usable for TRILL over IP transport that differ in exactly what appears after the IP header and before the TRILL Header or the TRILL IS-IS Payload. Those encapsulations specified in this document are further detailed in Section 5. In the general specification below, those encapsulation fields will be represented as "ENCAP Hdr".

4.2.1 Without Security

When TRILL over IP transport link security is not being used, a TRILL over IP transport packet on the wire looks like one of the following:



As discussed above and further specified in Section 5, the ENCAP Hdr indicates whether the packet is TRILL Data or IS-IS.

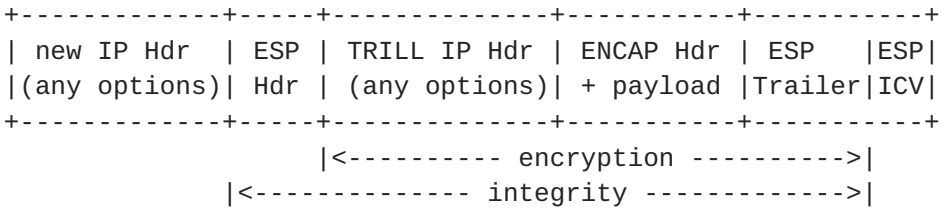
4.2.2 With Security

The mandatory to implement TRILL over IP transport link security is IPsec Encapsulating Security Protocol (ESP) in tunnel mode [RFC4303] (see Appendix A). Since TRILL over IP transport always starts with an IP Header (on the wire this appears after any lower layer header that might be required), the modifications for IPsec are independent of the TRILL over IP transport ENCAP Hdr that occurs after that IP

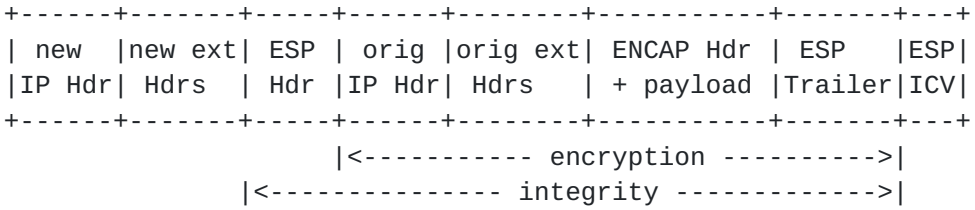
Header. The resulting packet formats are as follows for IPv4 and

IPv6:

With IPv4:



With IPv6:

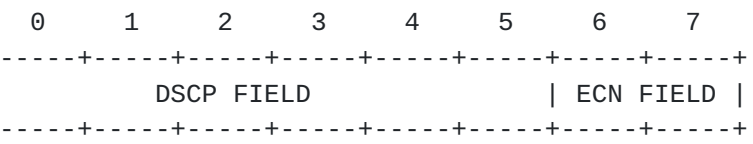


As shown above, IP Header options are considered part of the IPv4 Header but are extensions ("ext") of the IPv6 Header. For further information on the IPsec ESP Hdr, Trailer, and ICV, see [RFC4303] and Section 7 below. "ENCAP Hdr + payload" is the encapsulation header (Section 5) and TRILL data or the encapsulation header and IS-IS payload, that is, the material after the IP Header in the diagram in Section 4.2.1.

This architecture permits the ESP tunnel end point to be separated from the TRILL over IP transport RBridge port (see, for example, Section 1.1.3 of [RFC7296]).

4.3 QoS Considerations

In IP, QoS handling is indicated by the Differentiated Services Code Point (DSCP [RFC2474] [RFC3168]) in the IP Header. The former Type of Service (TOS) octet in the IPv4 Header and the Traffic Class octet in the IPv6 Header have been divided as shown in the following diagram adapted from [RFC3168]. (TRILL support of ECN is beyond the scope of this document. See [TRILLECN].)



DSCP: Differentiated Services Codepoint
ECN: Explicit Congestion Notification

Although recommendations are provided below for mapping from TRILL

priority to DSCP, behavior for various DSCP values on the general Internet is not predictable. The default mapping below is appropriate where the TRILL campus is under the control of a network manager or consists of islands connected by an Internet Service Provider where that manager and/or provider support the DSCPs below to provide the QoS indicated.

Within a TRILL switch, QoS is determined (1) by configuration for TRILL IS-IS packets and (2) by a three bit (0 through 7) priority field and a Drop Eligibility Indicator (DEI) bit (see Sections 8.2 and 7 of [RFC7780]) for TRILL Data packets. (Typically TRILL IS-IS is configured to use one of the highest two priorities depending on the particular IS-IS PDU.) The QoS affects queuing behavior at TRILL switch ports and may be encoded into the link header, particularly if there could be priority sensitive devices within the link. For example, if the link Ethner net and thus might be a bridged LAN, QoS is commonly encoded into an Outer.VLAN tag's priority and DEI fields.

TRILL over IP transport implementations MUST support setting the DSCP value in the outer IP Header of TRILL packets they send by mapping the TRILL priority and DEI to the DSCP. They MAY support, for a TRILL Data packet where the native frame payload is an IP packet, mapping the DSCP in this inner IP packet to the DSCP in the outer IP Header with the default for that mapping being to copy the DSCP without change.

The default TRILL priority and DEI to DSCP mapping, which may be configured per TRILL over IP transport port, is an follows. Note that the DEI value does not affect the default mapping and, to provide a potentially lower priority service than the default priority 0, priority 1 is considered lower priority than 0. So the priority sequence from lower to higher priority is 1, 0, 2, 3, 4, 5, 6, 7, as it is in [802.1Q].

TRILL Priority	DEI	DSCP Field (Binary/decimal)
0	0/1	000000 / 0
1	0/1	-TBD0- / TBD0
2	0/1	010000 / 16
3	0/1	011000 / 24
4	0/1	100000 / 32
5	0/1	101000 / 40
6	0/1	110000 / 48
7	0/1	111000 / 56

RFC Editor: Please change the TBD0 DSCP for TRILL Priority 1 in the above table and below text to the DSCP value that is recommended for the Lower Effort PHB (LE PHB) by draft-ietf-tsvwg-le-phb [LEphb]

draft when that draft is published as an RFC and delete this note.

The above all follow the recommended DSCP values from [RFC2474] except for the placing of priority 1 below priority 0, as specified in [802.1Q], and for the DSCP value of TBD0 binary for low effort as recommended in [LEphb].

4.4 Broadcast Links and Multicast Packets

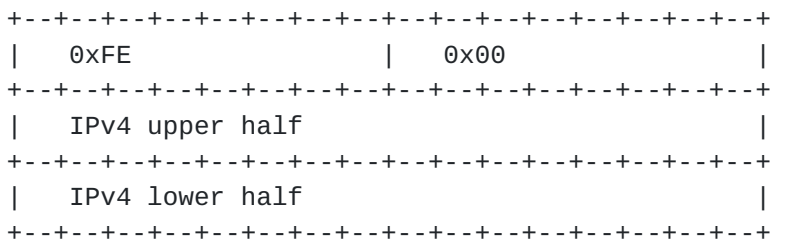
TRILL supports broadcast links. These are links to which more than two TRILL switch ports can be attached and where a packet can be broadcast or multicast from a port to all or a subset of the other ports on the link as well as unicast to a specific other port on the link.

As specified in [RFC6325], TRILL Data packets being forwarded between TRILL switches can be unicast on a link to a specific TRILL switch port or multicast on a link to all TRILL switch ports. TRILL IS-IS packets are always multicast to all other TRILL switches on the link except for IS-IS MTU PDUs, which may be unicast [RFC7177]. This distinction is not significant if the link is inherently point-to-point, such as a PPP link; however, on a broadcast link there will be a packet outer link address that will be unicast or multicast as appropriate. For example, over Ethernet links, the Ethernet multicast addresses All-RBridges and All-IS-IS-RBridges are used for multicasting TRILL Data and TRILL IS-IS respectively. For details on TRILL over IP transport handling of multicast, see Section 6.

4.5 TRILL Over IP Transport IS-IS SubNetwork Point of Attachment

IS-IS routers, including TRILL switches, establish adjacency through the exchange of Hello PDUs on a link [RFC7176] [RFC7177]. The Hellos transmitted out a port indicate what neighbor ports that port can see on the link by listing what IS-IS refers to as the neighbor port's SubNetwork Point of Attachment (SNPA). (For an Ethernet link, which may be a bridged network, the SNPA is the port MAC address.)

In TRILL Hello PDUs on a TRILL over IP transport link, the IP addresses of the IP ports connected to that link are their actual SNPA (SubNetwork Point of Attachment [IS-IS]) addresses and, for IPv6, the 16-byte IPv6 address is used as the SNPA; however, for ease in re-using code designed for the common case of 48-bit SNPAs, in TRILL over IPv4 a 48-bit synthetic SNPA that looks like a unicast MAC address is constructed for use in the SNPA field of TRILL Neighbor TLVs [RFC7176] [RFC7177] in such Hellos. This synthetic SNPA is derived from the port IPv4 address is as follows:



This synthetic SNPA (MAC) address has the local (0x02) bit on in the first byte and so cannot conflict with any globally unique 48-bit Ethernet MAC. However, when TRILL operates on an IP link as specified in this document, TRILL sees only IP ports on that link, not MAC stations, even if the TRILL over IP transport link is being carried over Ethernet. Therefore conflicts on the link between a real MAC address and a TRILL over IP transport synthetic SNPA (MAC) address are impossible.

5. TRILL over IP Transport Encapsulation Formats

There are a variety of TRILL over IP transport encapsulation formats possible. By default TRILL over IP transport adopts a hybrid encapsulation approach.

There is one format, called "native encapsulation" that MUST be implemented. Although native encapsulation does not typically have good fast path support, as a lowest common denominator it can be used by low bandwidth control traffic to determine a preferred encapsulation with better performance. In particular, by default, all TRILL IS-IS Hellos are sent using native encapsulation and those Hellos are used to determine the encapsulation used for all TRILL Data packets and all other TRILL IS-IS PDUs (with the exception of IS-IS MTU-probe and MTU-ack PDUs used to establish adjacency which also use native encapsulation by default).

Alternatively, the network operator can pre-configure a TRILL over IP transport port to use a particular encapsulation chosen for their particular network's needs and port capabilities. That encapsulation is then used for all TRILL Data and IS-IS packets, including Hellos, on ports so configured. This is expected to frequently be the case for a managed campus of TRILL switches.

Section 5.1 discusses general considerations for the TRILL over IP transport encapsulation format. Section 5.2 discusses encapsulation agreement. Section 5.3 discusses broadcast link encapsulation considerations. Section 5.4 and subsequent subsections discuss particular encapsulations.

5.1 Encapsulation Considerations

An encapsulation must provide a method to distinguish TRILL Data packets and TRILL IS-IS packets or it is not useful for TRILL. In addition, the following criteria can be helpful is choosing between different encapsulations:

a) Fast path support - For most applications, it is highly desirable to be able to encapsulate/decapsulate TRILL over IP transport at line speed. Thus a format where existing or anticipated fast path hardware can do that is best. This is commonly the dominant consideration.

b) Ease of multi-pathing - The IP path between TRILL over IP transport ports may include equal cost multipath routes internal to the IP link so a method of encapsulation that provides variable fields available for fast path hardware multi-pathing is

preferred.

c) Robust fragmentation and re-assembly - Fragmentation should generally be avoided; however, the MTU of the IP link may require fragmentation in which case an encapsulation with robust fragmentation and re-assembly is important. There are known problems with IPv4 fragmentation and re-assembly [RFC6864] which generally do not apply to IPv6. Some encapsulations can fix these problems but the encapsulations specified in this document do not. Therefore, if fragmentation is anticipated with the encapsulations specified in this document, the use of IPv6 is RECOMMENDED.

d) Checksum strength - Depending on the particular circumstances of the TRILL over IP transport link, a checksum provided by the encapsulation may be a significant factor. Use of IPsec can also provide a strong integrity check.

5.2 Encapsulation Agreement

TRILL Hellos sent out a TRILL over IP transport port indicate the encapsulations that port is willing to support through a mechanism initially specified in [RFC7178] and [RFC7176] that is hereby extended. Specifically, RBridge Channel Protocol numbers 0xFD0 through 0xFF7 are redefined to be link technology dependent flags that, for TRILL over IP transport, indicate support for different encapsulations, allowing support for up to 40 encapsulations to be specified. Support for an encapsulation is indicated in the Hello PDU in the same way that support for an RBridge Channel protocol was indicated. (See also section 11.3.) "Support" indicates willingness to use that encapsulation for TRILL Data and TRILL IS-IS packets (although TRILL IS-IS Hellos are still sent in native encapsulation by default unless the port is configured to always use some other encapsulation).

If, in a TRILL Hello on a TRILL over IP transport link, support is not indicated for any encapsulation, then the port from which it was sent is assumed to support native encapsulation only (see Section 5.4).

An adjacency can be formed between two TRILL over IP transport ports if the intersection of the sets of encapsulation methods they support is not null. If that intersection is null, then no adjacency is formed. In particular, for a TRILL over IP transport link, the adjacency state machine MUST NOT advance to the Report state unless the ports share an encapsulation [RFC7177]. If no encapsulation is shared, the adjacency state machine remains in the state from which it would otherwise have transitioned to the Report state when an event occurs that would have transitioned it to the Report state.

If a TRILL over IP transport port is using an encapsulation different

from that in which Hellos are being exchanged, it is RECOMMENDED that BFD [RFC7175] or some other protocol that confirms adjacency using TRILL Data packets be used. As provided in [RFC7177], adjacency is not actually obtained when such a confirmatory protocol is in use until that protocol succeeds.

If any TRILL over IP transport packet, other than an IS-IS Hello or MTU PDU in native encapsulation, is received in an encapsulation for which support is not being indicated by the receiver, that packet MUST be discarded (see Section 5.3).

If there are two or more encapsulations in common between two adjacent ports for unicast or across all of the set of adjacent ports for multicast, a transmitter is free to choose whichever of the encapsulations it wishes to use. Thus transmissions between adjacent ports P1 and P2 could use different encapsulations depending on which port is transmitting and which is receiving, that is to say, encapsulation usage could be asymmetric.

It is expected to be the normal case in a well-configured network that all the TRILL over IP transport ports connected to an IP link (i.e., an IP network) that are intended to communicate with each other support the same encapsulation(s).

5.3 Broadcast Link Encapsulation Considerations

To properly handle TRILL protocol packets on a TRILL over IP transport link in the general case, either native IP multicast mode is used on that link or multicast must be simulated using serial IP unicast, as discussed in Section 6. (Of course, if the IP link happens to actually be point-to-point no special provision is needed for handling IP multicast addressed packets.)

It is possible for the Hellos from a TRILL over IP transport port P1 to establish adjacency with multiple other TRILL over IP transport ports (P2, P3, ...) on a broadcast link. In a well-configured network one would expect all of the IP ports involved to support the same encapsulation; but, for example, if P1 supports multiple encapsulations, it is possible that P2 and P3, do not have an encapsulation in common that is also supported by P1. [IS-IS] can handle such non-transitive adjacencies that are reported as specified in [RFC7177]. This is generally done, albeit with reduced efficiency, by forwarding through the designated RBridge (router) on the link. Thus it is RECOMENDED that all TRILL over IP transport ports on an IP link be configured to support one encapsulation in common that has good fast path support.

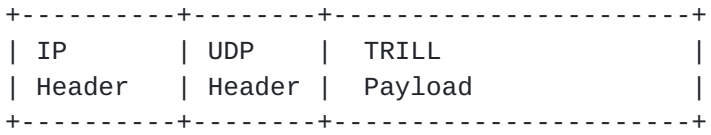
If serial IP unicast is being used by P1, it MAY use different

encapsulations for different transmissions.

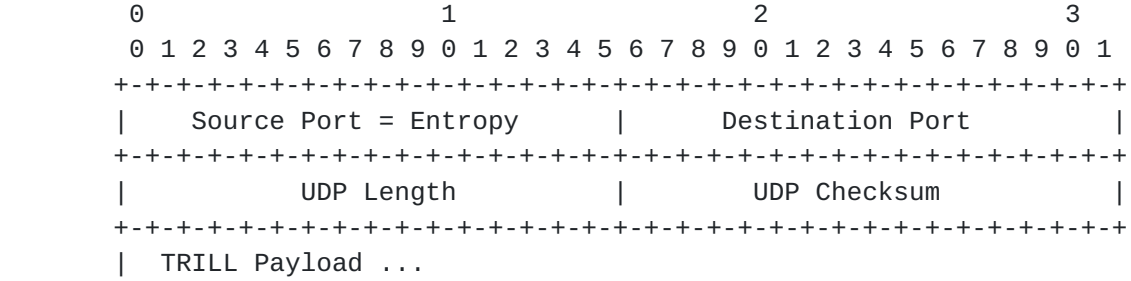
If multiple IP multicast encapsulations are available for use by P1, it can send one transmission per encapsulation method by which it has a disjoint set of adjacencies on the link. If the transmitting port has adjacencies with overlapping sets of ports that are adjacent using different encapsulations, use of native multicast with different encapsulations may result in packet duplication. It would always be possible to use native IP multicast for one encapsulation or multiple encapsulations supported by non-overlapping sets of receiving ports for which the transmitting port has adjacencies, perhaps the encapsulation(s) for which it has the largest number of adjacencies, and serially unicast to other receivers. These considerations are the reason that a TRILL over IP transport port MUST discard any packet received with an encapsulation for which it has not established an adjacency with the transmitter. Otherwise, packets might be further duplicated.

5.4 Native Encapsulation

The mandatory to implement "native encapsulation" format of a TRILL over IP transport packet, when used without security, is TRILL over UDP as shown below. This provides simple and direct access by TRILL to the native datagram service of IP.



Where he UDP Header is as follows:



Source Port - see Section 8.3.

Destination Port - indicates TRILL Data or IS-IS, see Section 11.1.

UDP Length - as specified in [RFC0768].

UDP Checksum - as specified in [RFC0768]. See discussion below.

The TRILL Payload starts with the TRILL Header (not including the TRILL Ethertype) for TRILL Data packets and starts with the 0x83 Intradomain Routeing Protocol Discriminator byte (thus not including the L2-IS-IS Ethertype) for TRILL IS-IS packets.

Note that if the mandatory to implement TRILL over IP transport security is in use, then traffic is not actually over UDP but rather over IPsec ESP. The authentication / integrity services provided protect against the processing of traffic by the wrong receiver even when the destination IP address / port is corrupted or the like and the confidentiality services provided by IPsec protect against compromise even if a receiver attempts to process packets not originally addressed to it.

5.4.1 IPv4 UDP Checksum Considerations

For UDP in IPv4, when a non-zero UDP checksum is used, the UDP checksum MUST be processed as specified in [RFC0768] and [RFC1122] for both transmit and receive. The IPv4 header includes a checksum that protects against misdelivery of the packet due to corruption of IP addresses. The UDP checksum potentially provides protection against corruption of the UDP header and TRILL payload. Disabling the use of checksums is a deployment consideration that should take into account the risk and effects of packet corruption.

When a port receives a TRILL over IP transport packet, the UDP checksum field MUST be processed. If the UDP checksum is non-zero, the port MUST verify the checksum before accepting the packet. By default, a TRILL over IP transport port SHOULD accept UDP packets with a zero checksum. A node MAY be configured to disallow zero checksums per [RFC1122]; this may be done selectively, for instance, disallowing zero checksums from certain adjacent ports that are known to be sending over paths subject to packet corruption. If verification of a non-zero checksum fails, a port lacks the capability to verify a non-zero checksum, or a packet with a zero checksum was received and the port is configured to disallow, the packet MUST be dropped and an event MAY be logged.

5.4.2 IPv6 UDP Checksum Considerations

For UDP in IPv6, the UDP checksum MUST be processed as specified in [RFC0768] and [RFC8200] for both transmit and receive.

When UDP is used over IPv6, the UDP checksum is relied upon to

protect both the IPv6 and UDP headers from corruption. As such, a default TRILL over IP transport port MUST perform UDP checksum; a traffic-managed controlled environment (TMCE) TRILL over IP transport port MAY be configured with UDP zero-checksum mode if the TMCE or a set of closely cooperating TMCEs (such as by network operators who have agreed to work together in order to jointly provide specific services) meet at least one of the following conditions:

a. It is known (perhaps through knowledge of equipment types and lower-layer checks) that packet corruption is exceptionally unlikely and where the operator is willing to take the risk of undetected packet corruption.

b. It is judged through observational measurements (perhaps of historic or current traffic flows that use a non-zero checksum) that the level of packet corruption is tolerably low and where the operator is willing to take the risk of undetected packet corruption.

c. Carrying applications that are tolerant of misdelivered or corrupted packets (perhaps through higher-layer checksum, validation, and retransmission or transmission redundancy) where the operator is willing to rely on the applications using the tunnel to survive any corrupt packets.

The following requirements apply to a TMCE TRILL over IP transport port that uses UDP zero-checksum mode:

a. Use of the UDP checksum MUST be the default configuration of all IPv6 TRILL over IP transport ports.

b. The port implementation MUST comply with all requirements specified in Section 4 of [RFC6936] and with requirement 1 specified in Section 5 of [RFC6936].

c. A receiving TRILL over IP transport port SHOULD only allow the use of UDP zero checksum mode for IPv6 that is sent to one of the two TRILL over IP UDP Destination Port numbers (see Section 11.1). The motivation for this requirement is possible corruption of the UDP Destination Port, which may cause packet delivery to the wrong UDP port. If that other UDP port requires the UDP checksum, the misdelivered packet will be discarded.

d. It is RECOMMENDED that the UDP zero-checksum mode for IPv6 only be enabled for TRILL over IP transport ports with a configured set of possible adjacencies. Because TRILL data is discarded unless it is received from a source address with which an adjacency exists, the receiving TRILL over IP transport port

will check the source IPv6 address and MUST check that the

destination IPv6 address is appropriate if UDP zero-checksum is being used and discard any packet for which these checks fails.

f. No middleboxes are allowed in the TRILL over IP transport link because Middlebox support is beyond the scope of this document.

h. Measures SHOULD be taken to prevent IPv6 traffic with zero UDP checksums from "escaping" to the general Internet.

i. IPv6 traffic with zero UDP checksums MUST be actively monitored for errors by the network operator. For example, the operator may monitor Ethernet-layer packet error rates.

j. If a packet with a non-zero checksum is received, the checksum MUST be verified before accepting the packet regardless of port configuration to use UDP zero-checksum mode.

The above requirements do not change either the requirements specified in [RFC8200] or the requirements specified in [RFC6936].

The requirements to check the source and destination IPv6 addresses provide some mitigation for the absence of UDP checksum coverage of the IPv6 header. A TMCE that satisfies at least one of three conditions listed at the beginning of this section provides additional assurance.

TRILL over IP/UDP is suitable for transmission over lower layers in TMCEs that are allowed by the exceptions stated above. The rate of corruption of the inner IP packet on such networks is not expected to increase by comparison to TRILL traffic that is not encapsulated in UDP. Typically lower layers do provide some integrity checking such as the FCS (Frame Check Sequence) at the end of Ethernet packets. This design is in accordance with requirements 2, 3, and 5 specified in Section 5 of [RFC6936].

TRILL over IP/UDP does not accumulate incorrect transport-layer state as a consequence of IP/UDP header corruption. Such corruption may result in either packet discard or packet forwarding but the IP/UDP header is stripped at the end of each TRILL over IP transport hop between RBridges so errors cannot accumulate. Active monitoring of TRILL over IP/UDP traffic for errors is REQUIRED, as the occurrence of errors will result in some accumulation of error information outside the protocol for operational and management purposes. This design is in accordance with requirement 4 specified in Section 5 of [RFC6936].

The remaining requirements specified in Section 5 of [RFC6936] are not applicable to TRILL over IP/UDP. Requirements 6 and 7 do not apply because TRILL over IP/UDP does not include a control feedback

mechanism. Requirements 8-10 are middlebox requirements that do not

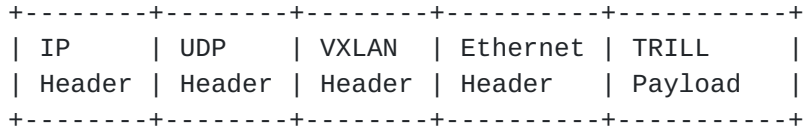
apply to TRILL over IP/UDP ports and, in any case, middleboxes are out of scope for this document.

It is worth mentioning that the use of a zero UDP checksum should present the equivalent risk of undetected packet corruption when sending a similar packet using unlerlying Layer 2 link protocols in the cases where those protocols do not have a checksum.

In summary, a TMCE TRILL over IP/UDP is allowed to use UDP zero-checksum mode for IPv6 when the conditions and requirements stated above are met. Otherwise, the UDP checksum needs to be used for IPv6 as specified in [RFC0768] and [RFC8200].

5.5 VXLAN Encapsulation

VXLAN [RFC7348] IP encapsulation of TRILL looks, on the wire, like TRILL over Ethernet over VXLAN over UDP over IP.



The outer UDP uses a destination port number indicating VXLAN and the outer UDP source port MAY be used for entropy as with native encapsulation (see Section 8.3). UDP checksum considerations are the same as in Section 5.4.

The VXLAN header after the outer UDP header adds a 24 bit Virtual Network Identifier (VNI). The Ethernet header after the VXLAN header and before the TRILL header consists of source MAC address, destination MAC address, and Ethertype. The Ethertype distinguishes TRILL Data from TRILL IS-IS. The destination and source MAC addresses in this Ethernet header are not used.

A TRILL over IP port using VXLAN encapsulation by default uses a VNI of 1 for TRILL IS-IS traffic and a VNI of 2 for TRILL data traffic but can be configured as described in Section 9.2.3.1 to use some other fixed VNIs or to map from VLAN/FGL to VNI for data traffic.

5.6 TCP Enacpulstion

TCP [RFC0793] may be used for TRILL over IP transport as specified below. Use of TCP is convenient to provide congestion control (see Section 8.1) and reduced packet loss but is likely to cause

substantial additional jitter and delay compared with a UDP based

encapsulation.

TCP supports only unicast communication. Thus, when TCP encapsulation is being used, multi-destination packets must be sent by serial unicast. Neighbor discovery cannot be done with TCP, so if discovery is to be supported at a TRILL over IP transport port (i.e., the set of potential adjacencies is not configured), Hellos must be sent with UDP native encapsulation. If a TRILL over IP transport port is configured to use TCP encapsulation for all trafic, a list of IP addresses that port might communicate with must be configured for the port (see Section 9).

All packets in a particular TCP stream MUST use the same DSCP codepoint as discussed in [RFC7657]. Therefore a TCP connection is needed per QoS to be provided between TRILL switches. Contiguous sets of priority levels MAY be mapped into a single TCP connection with a single DSCP code point. Lower priority traffic MUST NOT be given preference over higher priority traffic. It is RECOMMEDED that at least two TCP connections be provided, for example one for priority 6 and 7 traffic and one for priority 0 through 5 taffice, in order to insure that urgent control traffic, including control traffic related to establishing and maintaining adjacency, is not significantly delayed by lower priority traffic.

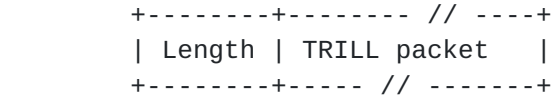
TCP is a stream protocol, not a record oriented protocol, so a TRILL data packet with its header or a TRILL IS-IS packet might be split across multiple TCP packet payloads or a single TCP packet payload could include multiple TRILL packets or the like. Thus a framing mechanism is needed, as specified below, so that a received TRILL stream can be parsed into TRILL packets.

In the TCP header, the source and destination port fields are as follows:

Source Port - along with Source IP, Destination IP, and Destination Port, idetifies a TCP flow.

Destination Port - indicates TRILL Data or IS-IS, see Section 11.1.

TRILL packets are framed for transmission over TCP as shown below.



Length - the length of the TRILL packet in bytes as a 2-byte unsigned integer in network order.

TRILL packet - The TRILL packet within framing starts with the

TRILL or the L2-IS-IS Ethertype (0x22F3 or 0x22F4). If the initial 2 bytes of the TRILL packet are not the correct Ethertype based on the Destination Port, then the receiver assumes that framing synchronization has been lost and MUST close that TCP connection. Note that the Hamming distance between these Ethertypes is 2 so that a single bit error cannot convert one into the other.

The sequence of framd TRILL packets is sliced as necessary into TCP packet payloads.

Depending on performance requirements, in many cases consideration should be given to tuning TCP. Methods for doing this are out of scope for this document. See [RFC7323].

5.6.1 TCP Connection Establishment

If a TRILL over IP transport port is configured to always use TCP it will also be configured with a list of IP addresses and MUST try to establish a TCP connections to each of them. It also MUST accept TCP connections from each of that list of IP addresses.

If a TRILL over IP port supports TCP but is using UDP for neighbor discovery and encapsulation negotiation, then it MUST try to establish a TCP connection to any adjacent port in the Report state (see [RFC7177] and Section 5.2) when TCP has been neogtiated with that port. It also MUST accept TCP connections from each such adjacent port.

Establishing a connection actually means to initiate TCP connections for each DSCP value that the TRILL over IP port is configured to use in TCP communication with the destination separately for TRILL Data and TRILL IS-IS as they have different destination ports, unless such a connection already exists. For example, port P1 could meet the requirements to establish a TCP connection to port P2 and find that such a connection already exists having been initiated by P2. A TCP connection can be used bi-directionally for TRILL traffic. However the timing and implementation details may be such that P! and P2 each establish a TCP connection to the other, in which case it might be that each of those connections would be used uni-directionally for TRILL traffic.

When a TCP connection is closed or reset, if the conditions are still met for that TCP port to establish that connection, it waits a configurable length of time that defaults to 80 milliseconds and tried to re-establish the connection. See Section 9.2.3.3.

5.7 Other Encapsulations

Additional TRILL over IP transport encapsulations may be specified in future documents and allocated a link technology specific flag bit as per Section 11.3. A primary consideration for whether it is worth the effort to specify use of an encapsulation by TRILL over IP transport is whether it has good existing or anticipated fast path support.

6. Handling Multicast

By default, both TRILL IS-IS packets and multi-destination TRILL Data packets are sent to an All-RBridges IPv4 or IPv6 IP multicast address as appropriate (see Section 11.2); however, a TRILL over IP transport port may be configured (see Section 9) to use a different multicast address or to use serial IP unicast with a list of one or more unicast IP addresses of other TRILL over IP transport ports to which multi-destination packets are sent. In the serial unicast case the outer IP header of each copy of the a TRILL Data packet sent shows an IP unicast destination address even through the TRILL header has the M bit set to one to indicate multi-destination. Serial unicast configuration is necessary if the TRILL over IP transport port is connected to an IP network that does not support IP multicast. In any case, unicast TRILL Data packets (those with the M bit in the TRILL Header set to zero) are sent by unicast IP. When TCP encapsulation is being used (see Section 5.4), serial unicast MUST be used. If a TRILL over IP transport port is configured to send all traffic with TCP, adjacency and data flow will only be possible with IP addresses in a configured list at that port (see Section 9).

Even if a TRILL over IP transport port is configured to send multi-destination packets with serial unicast, it MUST be prepared to receive IP multicast TRILL packets. TRILL over IP transport ports default to periodically transmitting appropriate IGMP (IPv4 [RFC3376]) or MLD (IPv6 [RFC2710]) packets, so that the TRILL multicast IP traffic can be sent to them, but MAY be configured not to do so.

Although TRILL fully supports broadcast links with more than 2 RBridge ports connected to the link, there may be good reasons for configuring TRILL over IP transport ports to use serial unicast even where native IP multicast is available. Use of serial unicast provides the network manager with more precise control over adjacencies and how TRILL over IP transport links will be formed in an IP network. In some networks, unicast is more reliable than multicast. If multiple point-to-point TRILL over IP transport connections between two parts of a TRILL campus are configured, TRILL will in any case spread traffic across them, treating them as parallel links, and appropriately fail over traffic if a link fails or incorporate a new link that comes up.

7. Use of IPsec and IKEv2

All TRILL ports that support TRILL over IP transport MUST implement IPsec [RFC4301] and support the use of IPsec Encapsulating Security Protocol (ESP [RFC4303]) in tunnel mode to secure both TRILL IS-IS and TRILL Data packets. When IPsec is used to secure a TRILL over IP transport link and no IS-IS security is enabled, the IPsec session MUST be fully established before any TRILL IS-IS or data packets are exchanged. When there is IS-IS security [RFC5310] provided, implementers SHOULD use IS-IS security to protect TRILL IS-IS packets. However, in this case, the IPsec session still MUST be fully established before any TRILL Data packets transmission, since IS-IS security does not provide any protection to data packets, and the IPsec session SHOULD be fully established before any TRILL IS-IS packet transmission other than IS-IS Hello or MTU PDUs.

All RBridges that support TRILL over IP transport MUST implement the Internet Key Exchange Protocol version 2 (IKEv2) for automated key management.

7.1 Keying

The following subsections discuss pairwise and group keying for TRILL over IP IPsec.

7.1.1 Pairwise Keying

When IS-IS security is in use, IKEv2 SHOULD use a pre-shared key that incorporates the IS-IS shared key in order to bind the TRILL data session to the IS-IS session. The pre-shared key that will be used for IKEv2 exchanges for TRILL over IP is determined as follows:

```
HKDF-Expand-SHA256 ( IS-IS-key,
   "TRILL IP" | P1-System-ID | P1-Port | P2-System-ID | P2-Port )
```

In the above "|" indicates concatenation, HKDF is as in [RFC5869], SHA256 is as in [RFC6234], and "TRILL IP" is the eight byte US ASCII [RFC0020] string indicated. "IS-IS-key" is an IS-IS key usable for IS-IS security of link local IS-IS PDUs such as Hello, CSNP, and PSNP. This SHOULD be a link scope IS-IS key. P1-System-ID and P2-System ID are the six byte System IDs of the two TRILL RBridges, and P1-Port and P2-Port are the TRILL Port IDs [RFC6325] of the ports in use on each end. System IDs are guaranteed to be unique within the TRILL campus. Both of the RBridges involved treat the larger magnitude System ID, comparing System IDs as unsigned integers, as P1

and the smaller as P2 so both will derive the same key.

With [RFC5310] there could be multiple keys identified with 16-bit key IDs. The key ID when an IS-IS key is in use is transmitted in an IKEv2 ID_KEY_ID identity field [RFC7296] with Identification Data length of 2 bytes (Payload Length 6 bytes). The Key ID of the IS-IS-key is used to identify the IKEv2 shared secret derived as above that is actually used. ID_KEY_ID identity field(s) of other lengths MAY occur but their use is beyond the scope of this document.

The IS-IS-shared key from which the IKEv2 shared secret is derived might expire and be updated as described in [RFC5310]. The IKEv2 pre-shared keys derived from an IS-IS shared key MUST expire within a lifetime no longer than the IS-IS-shared key from which they were derived. When the IKEv2 shared secret key expires, or earlier, the IKEv2 Security Association must be rekeyed using a new shared secret derived from a new IS-IS shared key.

IKEv2 with certificate based security MAY be used but details of certificate contents and use policy for this application of IKEv2 are beyond the scope of this document.

7.1.2 Group Keying

In the case of a TRILL over IP transport port configured as point-to-point (see Section 4.2.4.1 of [RFC6325]), there is no group keying and the pairwise keying determined as provided in Section 7.1.1 is used for multi-destination TRILL traffic, which is unicast across the link.

In the case of a TRILL over IP transport port configured as broadcast but where the port is configured to use serial unicast (see Section 8), there is no group keying and the pairwise keying determined as in Section 7.1.1 is used for multi-destination TRILL traffic, which is unicast across the link.

The case of a TRILL over IP transport port configured as broadcast and using native multicast is beyond the scope of this document and is expected to be covered in a future document [SGKPuses]. For security as provided in this document, multicast is handled via serial unicast.

7.2 Mandatory-to-Implement Algorithms

All RBridges that support TRILL over IP transport MUST implement IPsec ESP [RFC4303] in tunnel mode. The implementation requirements for ESP cryptographic algorithms are as specified for IPsec. That

specification is currently [RFC8221].

8. Transport Considerations

This section discusses a variety of important transport considerations. NAT traversal is out of scope for this document.

8.1 Congestion Considerations

This subsection discusses TRILL over UDP congestion considerations. These are applicable to the UDP based TRILL over IP transport encapsulation headers specified in detail in this document. Other encapsulations would likely have different congestion considerations and, in particlar, the TCP encapsulation specified in Section 5.6 does not need congestion control beyond that provided by TCP. Congestion considerations for additional TRILL encapsulations will be provided in the document specifying the encapsulation.

One motivation for including UDP or TCP as the outermost part of a TRILL over IP encapsulation header is to improve the use of multipath such as Equal Cost Multi-Path (ECMP) in cases where traffic is to traverse routers that are able to hash on Port and IP address through addition of entropy in the source port (see Section 8.3). In many cases this may reduce the occurrence of congestion and improve usage of available network capacity. However, it is also necessary to ensure that the network, including applications that use the network, responds appropriately in more difficult cases, such as when link or equipment failures have reduced the available capacity.

Section 3.1.11 of [RFC8085] discusses the congestion considerations for design and use of UDP tunnels; this is important because other flows could share the path with one or more UDP tunnels, necessitating congestion control [RFC2914] to avoid destructive interference.

The default initial determination of the TRILL over IP transport encapsulation to be used is through the exchange of TRILL IS-IS Hellos. This is a low bandwidth process. Hellos are not permitted to be sent any more often than once per second, and so are very unlikely to cause congestion. Thus no additional controls are needed for Hellos even if sent, as is the default, over UDP.

Congestion has potential impacts both on the rest of the network containing a UDP flow and on the traffic flows using the UDP encapsulation. These impacts depend upon what sort of traffic is carried in UDP, as well as the path it follows. The UDP based TRILL over IP transport encapsulations specified in this document do not provide any congestion control and are transmitted as regular UDP packets.

The use of serial unicast, where the transmission of a multi-destination TRILL packet is executed as multiple unicast transmission, potentially increases link load and could thus increase congestion. Rate limiting of multi-destination traffic that is to be transmitted in this fashion should be considered.

The subsections below discuss congestion for TRILL over IP transport traffic with UDP based encapsulation headers in traffic-managed controlled environments (TMCE, see [RFC8086]) and other environments.

8.1.1 Within a TMCE

Within a TMCE, that is, an IP network that is traffic-engineered and/or otherwise managed, for example via use of traffic rate limiters, to avoid congestion, UDP based TRILL over IP encapsulation headers are appropriate for carrying traffic that is not known to be congestion controlled. in such cases, operators of TMCE networks avoid congestion by careful provisioning of their networks, rate-limiting of user data traffic, and traffic engineering according to path capacity.

When TRILL over IP transport using a UDP based encapsulation header carries traffic that is not known to be congestion controlled in a TMCE network, the traffic path MUST be entirely within that network, and measures SHOULD be taken to prevent the traffic from "escaping" the network to the general Internet. Examples of such measures are:

- physical or logical isolation of the links carrying the traffic from the general Internet and
- deployment of packet filters that block the UDP ports assigned for TRILL over IP transport.

8.1.2 In Other Environments

Where UDP based encapsulation headers are used in TRILL over IP transport in environments other than those discussed in Section 8.1.1, specific congestion control mechanisms such as rate limiting are commonly needed. However, if the traffic being carried by the TRILL over IP transport link is already congestion controlled and the size and volatility of the TRILL IS-IS link state database is limited, then specific congestion control may not be needed. See [RFC8085] Section 3.1.11 for further guidance.

8.2 Recursive Ingress

TRILL is specified to transport data to and from end stations over Ethernet and IP is frequently transported over Ethernet. Thus, an end station native data Ethernet frame "EF" might get TRILL ingressed to a TRILL(EF) packet that was subsequently sent to a next hop RBridge out a TRILL over IP transport over Ethernet port resulting in a packet on the wire of the form Ethernet(IP(TRILL(EF))). There is a risk of such a packet being re-ingressed by the same TRILL campus, due to physical or logical misconfiguration, looping around, being further re-ingressed, and so on. (Or this might occur through a cycle of TRILL different campuses.) The packet would get discarded if it got too large unless fragmentation is enabled, in which case it would just keep getting split into fragments that would continue to loop and grow and re-fragment until the path was saturated with junk and packets were being discarded due to queue overflow. The TRILL Header TTL would provide no protection because each TRILL ingress adds a new TRILL header with a new TTL.

To protect against this scenario, a TRILL over IP transport port MUST, by default, test whether a TRILL packet it is about to transmit appears to be a TRILL ingress of a TRILL over IP transport over Ethernet packet. That is, is it of the form TRILL(Ethernet(IP(TRILL(...)))? If so, the default action of the TRILL over IP output port is to discard the packet rather than transmit it. However, there are cases where some level of nested ingress is desired so it MUST be possible to configure the port to allow such packets.

8.3 Fat Flows

For the purpose of load balancing, it is worthwhile to consider how to transport TRILL packets over any Equal Cost Multiple Paths (ECMPs) existing internal to the IP path between TRILL over IP transport ports.

The ECMP election for the IP traffic could be based, for example with IPv4, on the quintuple of the outer IP header { Source IP, Destination IP, Source Port, Destination Port, and IP protocol }. Such tuples, however, could be exactly the same for all TRILL Data packets between two RBridge ports, even if there is a huge amount of data being sent between a variety of ingress and egress RBridges. One solution to this is to use the UDP Source Port as an entropy field. (This idea is also introduced in [RFC8086].) For example, for TRILL Data, this entropy field could be based on some hash of the Inner.MacDA, Inner.MacSA, and Inner.VLAN or Inner.Label. These are

fields from the TRILL data payload which looks like an Ethernet frame (see [RFC7172] Figures 1 and 2).

8.4 MTU Considerations

In TRILL each RBridge advertises in its LSP number zero the largest LSP frame it can accept (but not less than 1,470 bytes) on any of its interfaces (at least those interfaces with adjacencies to other TRILL switches in the campus) through the originatingLSPBufferSize TLV [RFC6325] [RFC7177]. The campus minimum MTU (Maximum Transmission Unit), denoted Sz, is then established by taking the minimum of this advertised MTU for all RBridges in the campus. Links that cannot support the Sz MTU are not included in the routing topology. This protects the operation of IS-IS from links that would be unable to accommodate the largest LSPs.

A method of determining originatingLSPBufferSize for an RBridge is described in [RFC7780]. If that RBridge has a TRILL over IP transport port that either (1) can accommodate jumbo frames, (2) is a link on which IP fragmentation is enabled and acceptable, or (3) is configure to use TCP encapsulation for all packets, then it is unlikely that the port will be a constraint on the originatingLSPBufferSize of the RBridge. On the other hand, if the TRILL over port can only handle smaller frames, a UDP encapsulaton is in use at least for Hellos, and fragmentation is to be avoided when possible, a TRILL over IP transport port might have an MTU that contrained the RBridge's originatingLSPBufferSize.

Because TRILL sets the minimum value of Sz at 1,470 bytes, RBridges will not constrain LSPs or other TRILL IS-IS PDUs to a size smaller than that. Therefore there may be TRILL over IP transport ports that require that either fragmentation be enabled or that TCP based encapsultion for all TRILL packet be used if TRILL communication over that IP port is desired. When fragmentation is enabled or TCP is in use, the effective link MTU from the TRILL point of view is larger than the RBridge port to RBridge port path MTU from the IP point of view.

TRILL IS-IS MTU PDUs, as specified in Section 5 of [RFC6325] and in [RFC7177], MUST NOT be fragmented and can be used to obtain added assurance of the MTU of a link. The algorithm discussed in [RFC8249] should be useful in determining the IP MTU between a pair of RBridge ports that have IP connectivity with each other. See also [RFC4821].

An appropriate time to confirm MTU, or re-discover it if it has changed, is when an RBridge notices topology changes in a path between RBridge ports that is in use for TRILL over IP transport; however, MTU can change at other times. For example, if two RBridge ports are connected by a bridged LAN, topology or configuration changes within that bridged LAN could change the MTU between those RBridge ports.

For further discussion of these issues, see [IntareaTunnels].

9. TRILL over IP Transport Port Configuration

This section specifies the configuration information needed at a TRILL over IP transport port beyond that needed for a general RBridge port.

9.1 Per IP Port Configuration

Each RBridge port used for a TRILL over IP transport link should have at least one IP (v4 or v6) address. If no IP address is associated with the port, perhaps as a transient condition during re-configuration, the port is disabled. Implementations MAY allow a single port to operate as multiple IPv4 and/or IPv6 logical ports. Each IP address constitutes a different logical port and the RBridge with those ports MUST associate a different Port ID (see Section 4.4.2 of [RFC6325]) with each logical port.

By default a TRILL over IP transport port discards output packets that fail the possible recursive ingress test (see Section 10.1) unless configured to disable that test.

9.2 Additional per IP Address Configuration

The configuration information specified below is per TRILL over IP transport port IP address.

The mapping from TRILL packet priority to TRILL over IP transport Differentiated Services Code Point (DSCP [RFC2474]) can be configured. If supported, mapping from an inner DSCP code point, when the TRILL payload is IP, to the outer TRILL over IP transport DSCP can be configured. (See Section 4.3.)

Each TRILL over IP transport port has a list of acceptable encapsulations it will use as the basis of adjacency. By default this list consists of one entry for native encapsulation (see Section 7). Additional encapsulations MAY be configured and native encapsulation MAY be removed from this list by configuration. Additional configuration can be required or possible for specific encapsulations as described in Section 9.2.3.

Each IP address at a TRILL over IP transport port uses native IP multicast by default but may be configured whether to use serial IP unicast (Section 9.2.2) or native IP multicast (Section 9.2.1). Each IP address at a TRILL over IP transport port is configured whether or not to use IPsec (Section 9.2.4).

Regardless of whether they will send IP multicast, TRILL over IP transport ports emit appropriate IGMP (IPv4 [RFC3376]) or MLD (IPv6 [RFC2710]) packets unless configured not to do so. These are sent for the IP multicast group the port would use if it sent IP multicast.

9.2.1 Native Multicast Configuration

If a TRILL over IP transport port address is using native IP multicast for multi-destination TRILL packets (IS-IS and data), by default transmissions from that IP address use the IP multicast address (IPv4 or IPv6) specified in Section 11.2. The TRILL over IP transport port may be configured to use a different IP multicast address for multicasting packets.

9.2.2 Serial Unicast Configuration

If a TRILL over IP transport port address has been configured to use serial unicast for multi-destination packets (IS-IS and data), it has associated with it a non-empty list of unicast IP destination addresses with the same IP version as the version of the port's IP address (IPv4 or IPv6). Multi-destination TRILL packets are serially unicast to the addresses in this list. Such a TRILL over IP transport port will only be able to form adjacencies [RFC7177] with the RBridges at the addresses in this list as those are the only RBridges to which it will send TRILL Hellos. IP packets received from a source IP address not on the list are discarded.

If this list of destination IP addresses is empty, the port is disabled.

9.2.3 Encapsulation Specific Configuration

Specific TRILL over IP transport encapsulation methods may provide for further configuration as specified below.

9.2.3.1 UDP Source Port

As discussed above, the UDP based encapsulations (Sections 5.4 and 5.5) start with a header containing a source port number that can be used for entropy (Section 8.3). The range of source port values used defaults to the ephemeral port range (49152-65535) but can be

configured to any other range.

9.2.3.2 VXLAN Configuration

A TRILL over IP transport port using VXLAN encapsulation can be configured with non-default VXLAN Network Identifiers (VNIs) that are used in that field of the VXLAN header for all TRILL IS-IS and TRILL Data packets sent using the encapsulation and required in those received using the encapsulation. The default VNI is 1 for TRILL IS-IS and 2 for TRILL Data. A TRILL packet received with the an unknown VNI is discarded.

A TRILL over IP transport port using VXLAN encapsulation can also be configured to map the Inner.VLAN of a TRILL Data packet being transported to the value it places in the VNI field and/or to copy or map the Inner.FGL [RFC7172] of a TRILL Data packet to the VNI field.

9.2.3.3 TCP Configuration

A TRILL over IP transport port using TCP encapsulation is configurable as to the connection re-establishment delay in the range of 1 to 10,000 milliseconds that defaults to 80 milliseconds. See Section 5.6.1.

9.2.3.4 Other Encapsulation Configuration

Additional encapsulation methods, beyond those specified in this document, are expected to be specified in future documents and may require further configuration.

9.2.4 Security Configuration

A TRILL over IP transport port can be configured, for the case where IS-IS security [RFC5310] is in use, as to whether or not IPsec must be fully established and used for any TRILL IS-IS transmissions other than IS-IS Hello or MTU PDUs (see Section 7). There may also be configuration whose details are outside the scope of this document concerning certificate based IPsec or use of shared keys other than IS-IS based shared key or how to select the IS-IS based shared key to use.

10. Security Considerations

TRILL over IP transport is subject to all of the security considerations for the base TRILL protocol [RFC6325]. In addition, there are specific security requirements for different TRILL deployment scenarios, as discussed in the "Use Cases for TRILL over IP", Section 3 above.

For communication between end stations in a TRILL campus, security may be possible at three levels: end-to-end security between those end stations, edge-to-edge security between ingress and egress RBridges, and link security to protect a TRILL hop. Any combination of these can be used, including all three.

TRILL over IP transport link security protects the contents of TRILL Data and IS-IS packets over a single TRILL hop between RBridge ports, including protecting the identities of the end stations for data and the identities of the edge RBridges, from observers of the link and transit devices within the link such as bridges or IP routers, but does not encrypt the link local IP addresses used in a packet and does not protect against observation by the RBridges on the link.

Edge-to-edge TRILL security would protect the contents of TRILL data packets between the ingress and egress RBridges, including the identities of the end stations for data, from transit RBridges but does not encrypt the identities of the edge RBridges involved and does not protect against observation by those edge RBridges. Edge-to-edge TRILL security may be covered in future documents.

End-to-end security does not protect the identities of the end stations or edge RBridge involved but does protect the user data content of TRILL data packets from observation by all RBridges or other intervening devices between the end stations involved. End-to-end security should always be considered as an added layer of security to protect any particularly sensitive information from unintended disclosure. Such end-station to end-station security is generally outside the scope of TRILL

If VXLAN encapsulation is used, the unused Ethernet source and destination MAC addresses mentioned in Section 5.5, provide a 96 bit per packet side channel.

10.1 IPsec

This document specifies that all RBridges that support TRILL over IP transport links MUST implement IPsec for the security of such links,

and makes it clear that it is both wise and good to use IPsec in all

cases where a TRILL over IP transport link will traverse a network that is not under the same administrative control as the rest of the TRILL campus or is not secure. IPsec is important, in these cases, to protect the privacy and integrity of data traffic. However, in cases where IPsec is impractical due to lack of fast path support, use of TRILL edge-to-edge security or use by the end stations of end-to-end rsecurity can provide significant security.

Further Security Considerations for IPsec ESP and for the cryptographic algorithms used with IPsec can be found in the RFCs referenced by this document.

10.2 IS-IS Security

TRILL over IP transport is compatible with the use of IS-IS Security [RFC5310], which can be used to authenticate TRILL switches before allowing them to join a TRILL campus. This is sufficient to protect against rogue devices impersonating TRILL switches, but is not sufficient to protect data packets that may be sent in TRILL over IP transport outside of the local network or across the public Internet. To protect the privacy and integrity of that traffic, use IPsec.

In cases were IPsec is used, the use of IS-IS security may not be necessary, but there is nothing about this specification that would prevent using both IPsec and IS-IS security together.

11. IANA Considerations

IANA considerations are given below.

11.1 Port Assignments

IANA is requested to assign Ports in the Service Name and Transport Protocol Port Number Registry [PortRegistry] for TRILL IS-IS and TRILL Data as shown below. It is requested that the Hamming distance between the two port number be at least 2, that is, that at least two bits differ between the port numbers. For example, they could be an odd number and the following even number such that both of the bottom two bits would differ between them.

```
Service Name: TRILL-IS-IS
Transport Protocol: udp, tcp
Assignee: iesg@ietf.org
Contact: chair@ietf.org
Description: Transport of TRILL IS-IS control PDUs.
Reference: [this document]
Port Number: (TBD1)

Service Name: TRILL-data
Transport Protocol: udp, tcp
Assignee: iesg@ietf.org
Contact: chair@ietf.org
Description: Transport of TRILL Data packets.
Reference: [this document]
Port Number: (TBD2)
```

11.2 Multicast Address Assignments

IANA is requested to assign one IPv4 and one IPv6 multicast address, as shown below, which correspond to both the All-RBridges and All-IS-IS-RBridges multicast MAC addresses that have been assigned for TRILL. Because the low level hardware MAC address dispatch considerations for TRILL over Ethernet do not apply to TRILL over IP transport, one IP multicast address for each version of IP is sufficient.

(Value recommended to IANA in square brackets)

Name	IPv4	IPv6
All-RBridges	TBD3	TBD4[FF0X::BAC1]

The hex digit "X" in the IPv6 variable scope address indicates the scope and defaults to 8. The IPv6 All-RBridges IP address may be used with other values of X.

11.3 Encapsulation Method Support Indication

The existing "RBridge Channel Protocols" registry is re-named and a new sub-registry under that registry added as follows:

The TRILL Parameters registry for "RBridge Channel Protocols" is renamed the "RBridge Channel Protocols and Link Technology Specific Flags" registry. [this document] is added as a second reference for this registry. The first part of the table is changed to the following:

Range	Registration	Note
0x002-0x0FF	Standards Action	
0x100-0xFCF	RFC Required	allocation of a single value
0x100-0xFCF	IESG Approval	allocation of multiple values
0xFD0 0xFF7	see Note	link technology dependent, see subregistry

In the existing table of RBridge Channel Protocols, the following line is changed to two lines as shown:

OLD
0x007-0xFF7 Unassigned
NEW
0x007-0xFCF Unassigned
0xFD0-0xFF7 (link technology dependent, see subregistry)

A new indented subregistry under the re-named "RBridge Channel Protocols and Link Technology Specific Flags" registry is added as follows:

Name: TRILL over IP Transport Link Flags
Registration Procedure: Expert Review
Reference: [this document]

Flag	Meaning	Reference
0xFD0	Native encapsulation supported	[this document]
0xFD1	VXLAN encapsulation supported	[this document]
oxFD2	TCP encapsulation supported	[this document]
0xFD3-0xFF7	Unassigned	

Normative References

[IS-IS] - "Intermediate system to Intermediate system routeing information exchange protocol for use in conjunction with the Protocol for providing the Connectionless-mode Network Service (ISO 8473)", ISO/IEC 10589:2002, 2002".

[RFC0020] - Cerf, V., "ASCII format for network interchange", STD 80, RFC 20, DOI 10.17487/RFC0020, October 1969, <http://www.rfc-editor.org/info/rfc20>.

[RFC0768] - Postel, J., "User Datagram Protocol", STD 6, RFC 768, DOI 10.17487/RFC0768, August 1980, <http://www.rfc-editor.org/info/rfc768>.

[RFC0793] - Postel, J., "Transmission Control Protocol", STD 7, RFC 793, DOI 10.17487/RFC0793, September 1981, <http://www.rfc-editor.org/info/rfc793>.

[RFC1122] - Braden, R., Ed., "Requirements for Internet Hosts - Communication Layers", STD 3, RFC 1122, DOI 10.17487/RFC1122, October 1989, <https://www.rfc-editor.org/info/rfc1122>.

[RFC2119] - Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <http://www.rfc-editor.org/info/rfc2119>.

[RFC2474] - Nichols, K., Blake, S., Baker, F., and D. Black, "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers", RFC 2474, DOI 10.17487/RFC2474, December 1998, <http://www.rfc-editor.org/info/rfc2474>.

[RFC2710] - Deering, S., Fenner, W., and B. Haberman, "Multicast Listener Discovery (MLD) for IPv6", RFC 2710, DOI 10.17487/RFC2710, October 1999, <http://www.rfc-editor.org/info/rfc2710>.

[RFC2914] - Floyd, S., "Congestion Control Principles", BCP 41, RFC 2914, DOI 10.17487/RFC2914, September 2000, <http://www.rfc-editor.org/info/rfc2914>.

[RFC3168] - Ramakrishnan, K., Floyd, S., and D. Black, "The Addition of Explicit Congestion Notification (ECN) to IP", RFC 3168, DOI 10.17487/RFC3168, September 2001, <http://www.rfc-editor.org/info/rfc3168>.

[RFC3376] - Cain, B., Deering, S., Kouvelas, I., Fenner, B., and A. Thyagarajan, "Internet Group Management Protocol, Version 3", RFC 3376, DOI 10.17487/RFC3376, October 2002, <http://www.rfc-

editor.org/info/rfc3376>.

[RFC4301] - Kent, S. and K. Seo, "Security Architecture for the Internet Protocol", RFC 4301, DOI 10.17487/RFC4301, December 2005, <http://www.rfc-editor.org/info/rfc4301>.

[RFC4303] - Kent, S., "IP Encapsulating Security Payload (ESP)", RFC 4303, DOI 10.17487/RFC4303, December 2005, <http://www.rfc-editor.org/info/rfc4303>. <http://www.rfc-editor.org/info/rfc5304>.

[RFC5310] - Bhatia, M., Manral, V., Li, T., Atkinson, R., White, R., and M. Fanto, "IS-IS Generic Cryptographic Authentication", RFC 5310, DOI 10.17487/RFC5310, February 2009, <http://www.rfc-editor.org/info/rfc5310>.

[RFC5869] - Krawczyk, H. and P. Eronen, "HMAC-based Extract-and-Expand Key Derivation Function (HKDF)", RFC 5869, DOI 10.17487/RFC5869, May 2010, <http://www.rfc-editor.org/info/rfc5869>.

[RFC6325] - Perlman, R., Eastlake 3rd, D., Dutt, D., Gai, S., and A. Ghanwani, "Routing Bridges (RBridges): Base Protocol Specification", RFC 6325, DOI 10.17487/RFC6325, July 2011, <http://www.rfc-editor.org/info/rfc6325>.

[RFC7175] - Manral, V., Eastlake 3rd, D., Ward, D., and A. Banerjee, "Transparent Interconnection of Lots of Links (TRILL): Bidirectional Forwarding Detection (BFD) Support", RFC 7175, DOI 10.17487/RFC7175, May 2014, <http://www.rfc-editor.org/info/rfc7175>.

[RFC7176] - Eastlake 3rd, D., Senevirathne, T., Ghanwani, A., Dutt, D., and A. Banerjee, "Transparent Interconnection of Lots of Links (TRILL) Use of IS-IS", RFC 7176, DOI 10.17487/RFC7176, May 2014, <http://www.rfc-editor.org/info/rfc7176>.

[RFC7177] - Eastlake 3rd, D., Perlman, R., Ghanwani, A., Yang, H., and V. Manral, "Transparent Interconnection of Lots of Links (TRILL): Adjacency", RFC 7177, DOI 10.17487/RFC7177, May 2014, <http://www.rfc-editor.org/info/rfc7177>.

[RFC7178] - Eastlake 3rd, D., Manral, V., Li, Y., Aldrin, S., and D. Ward, "Transparent Interconnection of Lots of Links (TRILL): RBridge Channel Support", RFC 7178, DOI 10.17487/RFC7178, May 2014, <http://www.rfc-editor.org/info/rfc7178>.

[RFC7348] - Mahalingam, M., Dutt, D., Duda, K., Agarwal, P., Kreeger, L., Sridhar, T., Bursell, M., and C. Wright, "Virtual eXtensible Local Area Network (VXLAN): A Framework for Overlaying Virtualized Layer 2 Networks over Layer 3 Networks",

RFC 7348, DOI 10.17487/RFC7348, August 2014, <http://www.rfc-

editor.org/info/rfc7348>.

[RFC7780] - Eastlake 3rd, D., Zhang, M., Perlman, R., Banerjee, A., Ghanwani, A., and S. Gupta, "Transparent Interconnection of Lots of Links (TRILL): Clarifications, Corrections, and Updates", RFC 7780, DOI 10.17487/RFC7780, February 2016, <http://www.rfc-editor.org/info/rfc7780>.

[RFC8174] - Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8200] - Deering, S. and R. Hinden, "Internet Protocol, Version 6 (IPv6) Specification", STD 86, RFC 8200, DOI 10.17487/RFC8200, July 2017, <https://www.rfc-editor.org/info/rfc8200>.

[RFC8221] - Wouters, P., Migault, D., Mattsson, J., Nir, Y., and T. Kivinen, "Cryptographic Algorithm Implementation Requirements and Usage Guidance for Encapsulating Security Payload (ESP) and Authentication Header (AH)", RFC 8221, DOI 10.17487/RFC8221, October 2017, <https://www.rfc-editor.org/info/rfc8221>.

[RFC8249] - Zhang, M., Zhang, X., Eastlake 3rd, D., Perlman, R., and S. Chatterjee, "Transparent Interconnection of Lots of Links (TRILL): MTU Negotiation", RFC 8249, DOI 10.17487/RFC8249, September 2017, <https://www.rfc-editor.org/info/rfc8249>.

[LEphb] - R. Bless, "A Lower Effort Per-Hop Behavior)LE PHB)", draft-ietf-tsvwg-le-phb, work in progress.

Informative References

[RFC4821] - Mathis, M. and J. Heffner, "Packetization Layer Path MTU Discovery", RFC 4821, DOI 10.17487/RFC4821, March 2007, <http://www.rfc-editor.org/info/rfc4821>.

[RFC6234] - Eastlake 3rd, D. and T. Hansen, "US Secure Hash Algorithms (SHA and SHA-based HMAC and HKDF)", RFC 6234, DOI 10.17487/RFC6234, May 2011, <http://www.rfc-editor.org/info/rfc6234>.

[RFC6361] - Carlson, J. and D. Eastlake 3rd, "PPP Transparent Interconnection of Lots of Links (TRILL) Protocol Control Protocol", RFC 6361, DOI 10.17487/RFC6361, August 2011, <http://www.rfc-editor.org/info/rfc6361>.

[RFC6864] - Touch, J., "Updated Specification of the IPv4 ID Field",

RFC 6864, DOI 10.17487/RFC6864, February 2013, <http://www.rfc-

editor.org/info/rfc6864>.

[RFC6936] - Fairhurst, G. and M. Westerlund, "Applicability Statement for the Use of IPv6 UDP Datagrams with Zero Checksums", RFC 6936, DOI 10.17487/RFC6936, April 2013, <http://www.rfc-editor.org/info/rfc6936>.

[RFC7172] - Eastlake 3rd, D., Zhang, M., Agarwal, P., Perlman, R., and D. Dutt, "Transparent Interconnection of Lots of Links (TRILL): Fine-Grained Labeling", RFC 7172, DOI 10.17487/RFC7172, May 2014, <http://www.rfc-editor.org/info/rfc7172>.

[RFC7173] - Yong, L., Eastlake 3rd, D., Aldrin, S., and J. Hudson, "Transparent Interconnection of Lots of Links (TRILL) Transport Using Pseudowires", RFC 7173, DOI 10.17487/RFC7173, May 2014, <http://www.rfc-editor.org/info/rfc7173>.

[RFC7296] - Kaufman, C., Hoffman, P., Nir, Y., Eronen, P., and T. Kivinen, "Internet Key Exchange Protocol Version 2 (IKEv2)", STD 79, RFC 7296, DOI 10.17487/RFC7296, October 2014, <http://www.rfc-editor.org/info/rfc7296>.

[RFC7323] - Borman, D., Braden, B., Jacobson, V., and R. Scheffenegger, Ed., "TCP Extensions for High Performance", RFC 7323, DOI 10.17487/RFC7323, September 2014, <https://www.rfc-editor.org/info/rfc7323>.

[RFC7657] - Black, D., Ed., and P. Jones, "Differentiated Services (Diffserv) and Real-Time Communication", RFC 7657, DOI 10.17487/RFC7657, November 2015, <https://www.rfc-editor.org/info/rfc7657>.

[RFC8085] - Eggert, L., Fairhurst, G., and G. Shepherd, "UDP Usage Guidelines", BCP 145, RFC 8085, DOI 10.17487/RFC8085, March 2017, <http://www.rfc-editor.org/info/rfc8085>.

[RFC8086] - Yong, L., Ed., Crabbe, E., Xu, X., and T. Herbert, "GRE-in-UDP Encapsulation", RFC 8086, DOI 10.17487/RFC8086, March 2017, <http://www.rfc-editor.org/info/rfc8086>.

[IntareaTunnels] - J. Touch, M. Townsley, "IP Tunnels int he Internet Architecture", draft-ietf-intarea-tunnels, work in progress.

[TRILLECN] - Eastlake, D., B. Briscoe, "TRILL: ECN (Explicit Congestion Notification) Support", draft-ietf-trill-ecn-support, work in progress.

[SGKPuses] - D. Eastlake, D. Zhang, "Simple Group Keying Protocol

TRILL Use Profiles", draft-ietf-trill-link-gk-profiles, work in

progress.

[PortRegistry] - https://www.iana.org/assignments/service-names-port-numbers/service-names-port-numbers.xhtml

Appendix A: IP Security Choice

This informational appendix discusses the choice of mandatory to implement IP security protocol for TRILL over IP transport ports. Other security protocols can be used by agreeing TRILL over IP transport ports, but one protocol was selected as mandatory to implement for interoperability.

The TRILL WG considerd both DTLS and IPsec as the mandatory to implement IP security protocol. Perhaps the most extensive discussion occured at the TRILL WG meeting at IETF meeting 91. The WG decided to go with IPsec due to better hardware support which was considered an important factor for being able to operate at or near line speed. Tunnel mode was chosen as there appeared to be better support for it in offboard hardware devices.

Acknowledgements

The following people have provided useful feedback on the contents of this document: Sam Hartman, Adrian Farrel, Radia Perlman, Ines Robles, Mohammed Umair, Magnus Westerlund, and Lucy Yong.

Some of the material in this document is derived from [RFC8085] and [RFC8086].

The document was prepared in raw nroff. All macros used were defined within the source file.

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