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Transparent Interconnection of Lots of Links (TRILL): Clarifications, Corrections, and Updates

Abstract

Since the publication of the TRILL (Transparent Interconnection of Lots of Links) base protocol in 2011, active development and deployment of TRILL have revealed errata in RFC 6325 and areas that could use clarifications or updates. RFC 7177, RFC 7357, and an intended replacement of RFC 6439 provide clarifications and updates with respect to adjacency, the TRILL ESADI (End Station Address Distribution Information) protocol, and Appointed Forwarders, respectively. This document provides other known clarifications, corrections, and updates. It obsoletes RFC 7180 (the previous "TRILL clarifications, corrections, and updates" RFC), and it updates RFCs 6325, 7177, and 7179.

Status of This Memo

This is an Internet Standards Track document.

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1. Introduction (Changed)

Since the TRILL base protocol [RFC6325] was published in 2011, active development and deployment of TRILL have revealed errors in the specification [RFC6325] and several areas that could use clarifications or updates.

[RFC7177], [RFC7357], and [RFC6439bis] provide clarifications and updates with respect to adjacency, the TRILL ESADI (End Station Address Distribution Information) protocol, and Appointed Forwarders, respectively. This document provides other known clarifications, corrections, and updates to [RFC6325], [RFC7177], and [RFC7179]. This document obsoletes [RFC7180] (the previous TRILL "clarifications, corrections, and updates" document), updates [RFC6325], updates [RFC7177] as described in Section 9, and updates [RFC7179] as described in Sections 10.2 and 10.3. The changes to these RFCs are summarized in Appendix C.

Sections of this document are annotated as to whether they are "New" technical material, material that has been technically "Changed", or material that is technically "Unchanged", by the appearance of one of these three words in parentheses at the end of the section header. A section with only editorial changes is annotated as "(Unchanged)". If no such notation appears, then the first notation encountered on going to successively higher-level section headers (those with shorter section numbers) applies. Appendix C describes changes, summarizes material added, and lists material deleted.

1.1. Precedence (Changed)

In the event of any conflicts between this document and [RFC6325], [RFC7177], or [RFC7179], this document takes precedence.

In addition, Section 1.2 of [RFC6325] ("Normative Content and Precedence") is updated to provide a more complete precedence ordering of the sections of [RFC6325], as shown below, where sections to the left take precedence over sections to their right. There are no known conflicts between these sections; however, Sections 1 and 2 are less detailed and do not mention every corner case, while subsequent sections of [RFC6325] are more detailed. This precedence is specified as a fallback in case some conflict is found in the future.

4 > 3 > 7 > 5 > 2 > 6 > 1

1.2. Changes That Are Not Backward Compatible (Unchanged)

The change made by Section 3.4 below (unchanged from Section 3.4 of [RFC7180]) is not backward compatible with [RFC6325] but has nevertheless been adopted to reduce distribution tree changes resulting from topology changes.

Several other changes herein that are fixes to errata for [RFC6325] -- [Err3002], [Err3003], [Err3004], [Err3052], [Err3053], and [Err3508] -- may not be backward compatible with previous implementations that conformed to errors in the specification.

1.3. Terminology and Acronyms (Changed)

This document uses the acronyms defined in [RFC6325], some of which are repeated below for convenience, along with some additional acronyms and terms, as follows:

BFD - Bidirectional Forwarding Detection.

Campus - A TRILL network consisting of TRILL switches, links, and possibly bridges bounded by end stations and IP routers. For TRILL, there is no "academic" implication in the name "campus".

CFI - Canonical Format Indicator [802].

CSNP - Complete Sequence Number PDU.

DEI - Drop Eligibility Indicator [802.1Q-2014].

FGL - Fine-Grained Labeling [RFC7172].

FS-LSP - Flooding Scope LSP.

OOMF - Overload Originated Multi-destination Frame.

P2P - Point-to-point.

PDU - Protocol Data Unit.

PSNP - Partial Sequence Number PDU.

RBridge - Routing Bridge, an alternative name for a TRILL switch.

RPFC - Reverse Path Forwarding Check.

SNPA - Subnetwork Point of Attachment (for example, Media Access Control (MAC) address).

ToS - Type of Service.

TRILL - Transparent Interconnection of Lots of Links or Tunneled Routing in the Link Layer.

TRILL switch - A device implementing the TRILL protocol. An alternative name for an RBridge.

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 [RFC2119].

In this document, a "packet" usually refers to a TRILL Data packet or TRILL IS-IS packet received from or sent to a TRILL switch, while a "frame" usually refers to a native frame being received from or sent to an end station. (The word "frame" also occurs in other contexts, such as the "Frame Check Sequence" that is at the end of Ethernet transmissions.)

2. Overloaded and/or Unreachable RBridges (Unchanged)

In this section, the term "neighbor" refers only to actual RBridges and ignores pseudonodes.

RBridges may be in overload, as indicated by the [IS-IS] overload flag in their LSPs (Link State PDUs). This means that either (1) they are incapable of holding the entire link-state database and thus do not have a view of the entire topology or (2) they have been configured to have the overload bit set. Although networks should be engineered to avoid actual link-state overload, it might occur under various circumstances -- for example, if a very large campus included one or more low-end TRILL switches.

It is a common operational practice to set the overload bit in an [IS-IS] router (such as a TRILL switch) when performing maintenance on that router that might affect its ability to correctly forward packets; this will usually leave the router reachable for maintenance traffic, but transit traffic will not be routed through it. (Also, in some cases, TRILL provides for setting the overload bit in the pseudonode of a link to stop TRILL Data traffic on an access link (see Section 4.9.1 of [RFC6325]).)

[IS-IS] and TRILL make a reasonable effort to do what they can, even if some TRILL switches/routers are in overload. They can do reasonably well if a few scattered nodes are in overload. However, actual least-cost paths are no longer assured if any TRILL switches are in overload.

For the effect of overload on the appointment of forwarders, see [RFC6439bis].

2.1. Reachability

Packets are not least-cost routed through an overloaded TRILL switch, although they may originate or terminate at an overloaded TRILL switch. In addition, packets will not be least-cost routed over links with cost $2^{24} - 1$ [RFC5305]; such links are reserved for traffic-engineered packets, the handling of which is beyond the scope of this document.

As a result, a portion of the campus may be unreachable for least-cost routed TRILL Data because all paths to it would be either through a link with cost $2^{24} - 1$ or through an overloaded RBridge. For example, an RBridge (TRILL switch) RB1 is not reachable by TRILL Data if all of its neighbors are connected to RB1 by links with cost $2^{24} - 1$. Such RBridges are called "data unreachable".

The link-state database at an RBridge -- for example, RB1 -- can also contain information on TRILL switches that are unreachable by IS-IS link-state flooding due to link or RBridge failures. When such failures partition the campus, the TRILL switches adjacent to the failure and on the same side of the failure as RB1 will update their LSPs to show the lack of connectivity, and RB1 will receive those updates. As a result, RB1 will be aware of the partition. Nodes on the far side of the partition are both IS-IS unreachable and data unreachable from RB1. However, LSPs held by RB1 for TRILL switches on the far side of the failure will not be updated and may stay around until they time out, which could be tens of minutes or longer. (The default in [IS-IS] is twenty minutes.)

2.2. Distribution Trees

An RBridge in overload cannot be trusted to correctly calculate distribution trees or correctly perform the RPFC (Reverse Path Forwarding Check). Therefore, it cannot be trusted to forward multi-destination TRILL Data packets. It can only appear as a leaf node in a TRILL multi-destination distribution tree. Furthermore, if all the immediate neighbors of an RBridge are overloaded, then it is omitted from all trees in the campus and is unreachable by multi-destination packets.

When an RBridge determines what nicknames to use as the roots of the distribution trees it calculates, it MUST ignore all nicknames held by TRILL switches that are in overload or are data unreachable. When calculating RPFCs for multi-destination packets, an RBridge such as RB1 MAY, to avoid calculating unnecessary RPFC state information,

ignore any trees that cannot reach RB1, even if other RBridges list those trees as trees that other TRILL switches might use. (However, see Section 3.)

2.3. Overloaded Receipt of TRILL Data Packets

The receipt of TRILL Data packets by overloaded RBridge RB2 is discussed in the subsections below. In all cases, the normal Hop Count decrement is performed, and the TRILL Data packets are discarded if the result is less than one or if the Egress Nickname is illegal.

2.3.1. Known Unicast Receipt

RB2 will not usually receive unicast TRILL Data packets unless it is the egress, in which case it egresses and delivers the data normally. If RB2 receives a unicast TRILL Data packet for which it is not the egress, perhaps because a neighbor does not yet know it is in overload, RB2 MUST NOT discard the packet because the egress is an unknown nickname, as it might not know about all nicknames due to its overloaded condition. If any neighbor other than the neighbor from which it received the packet is not overloaded, it MUST attempt to forward the packet to one of those neighbors selected at random [RFC4086]. If there is no such neighbor, the packet is discarded.

2.3.2. Multi-Destination Receipt

If RB2 in overload receives a multi-destination TRILL Data packet, RB2 MUST NOT apply an RPFC because, due to overload, it might not do so correctly. RB2 egresses and delivers the frame locally where it is Appointed Forwarder for the frame's VLAN (or, if the packet is FGL, for the VLAN that FGL maps to at the port), subject to any multicast pruning. But because, as stated above, RB2 can only be the leaf of a distribution tree, it MUST NOT forward a multi-destination TRILL Data packet (except as an egressed native frame where RB2 is Appointed Forwarder).

2.4. Overloaded Origination of TRILL Data Packets

Overloaded origination of unicast TRILL Data packets with known egress and of multi-destination packets is discussed in the subsections below.

on the multi-access RB2-RB3-RB4 link. Since RB2 would, in general, not be able to tell that this was a frame it had tunneled for distribution, RB2 would decapsulate it and locally distribute it a second time.

- On the other hand, if there is no neighbor of RB2 offering RB2 the OOMF service, RB2 cannot tunnel the frame to a neighbor. In this case, RB2 MUST locally distribute the frame where it is Appointed Forwarder for the frame's VLAN and optionally subject to multicast pruning.

2.4.2.2. Indicating OOMF Support

An RBridge RB3 indicates its willingness to offer the OOMF service to RB2 in the TRILL Neighbor TLV in RB3's TRILL Hellos by setting a bit associated with the SNPA (Subnetwork Point of Attachment, also known as MAC address) of RB2 on the link (see the IANA Considerations section). Overloaded RBridge RB2 can only distribute multi-destination TRILL Data packets to the campus if a neighbor of RB2 not in overload offers RB2 the OOMF service. If RB2 does not have OOMF service available to it, RB2 can still receive multi-destination packets from non-overloaded neighbors, and if RB2 should originate or ingress such a frame, it distributes it locally in native form.

2.4.2.3. Using OOMF Service

If RB2 sees this OOMF (Overload Originated Multi-destination Frame) service advertised for it by any of its neighbors on any link to which RB2 connects, it selects one such neighbor by a means that is beyond the scope of this document. Assuming that RB2 selects RB3 to handle multi-destination packets it originates, RB2 MUST advertise in its LSP that it might use any of the distribution trees that RB3 advertises so that the RPFC will work in the rest of the campus. Thus, notwithstanding its overloaded state, RB2 MUST retain this information from RB3 LSPs, which it will receive, as it is directly connected to RB3.

RB2 then encapsulates such frames as TRILL Data packets to RB3 as follows: "M" bit = 0; Hop Count = 2; Ingress Nickname = a nickname held by RB2; and, since RB2 cannot tell what distribution tree RB3 will use, Egress Nickname = a special nickname indicating an OOMF packet (see the IANA Considerations section). RB2 then unicasts this TRILL Data packet to RB3. (Implementation of Item 4 in Section 4 below provides reasonable assurance that, notwithstanding its overloaded state, the ingress nickname used by RB2 will be unique within at least the portion of the campus that is IS-IS reachable from RB2.)

On receipt of such a packet, RB3 does the following:

- changes the Egress Nickname field to designate a distribution tree that RB3 normally uses,
- sets the "M" bit to one,
- changes the Hop Count to the value it would normally use if it were the ingress, and
- forwards the TRILL Data packet on that tree.

RB3 MAY rate-limit the number of packets for which it is providing this service by discarding some such packets from RB2. The provision of even limited bandwidth for OOMFs by RB3, perhaps via the slow path, may be important to the bootstrapping of services at RB2 or at end stations connected to RB2, such as supporting DHCP and ARP/ND (Address Resolution Protocol / Neighbor Discovery). (Everyone sometimes needs a little OOMF (pronounced "oomph") to get off the ground.)

3. Distribution Trees and RPF Check (Changed)

Two corrections, a clarification, and two updates related to distribution trees appear in the subsections below, along with an alternative, stronger RPF (Reverse Path Forwarding) check. See also Section 2.2.

3.1. Number of Distribution Trees (Unchanged)

In [RFC6325], Section 4.5.2, page 56, point 2, fourth paragraph, the parenthetical "(up to the maximum of {j,k})" is incorrect [Err3052]. It should read "(up to k if j is zero or the minimum of (j, k) if j is non-zero)".

3.2. Distribution Tree Update Clarification (Unchanged)

When a link-state database change causes a change in the distribution tree(s), several possible types of change can occur. If a tree root remains a tree root but the tree changes, then local forwarding and RPFC entries for that tree should be updated as soon as practical. Similarly, if a new nickname becomes a tree root, forwarding and RPFC entries for the new tree should be installed as soon as practical. However, if a nickname ceases to be a tree root and there is sufficient room in local tables, the forwarding and RPFC entries for the former tree MAY be retained so that any multi-destination TRILL Data packets already in flight on that tree have a higher probability of being delivered.

3.3. Multicast Pruning Based on IP Address (Unchanged)

The TRILL base protocol specification [RFC6325] provides for, and recommends the pruning of, multi-destination packet distribution trees based on the location of IP multicast routers and listeners; however, multicast listening is identified by derived MAC addresses as communicated in the Group MAC Address sub-TLV [RFC7176].

TRILL switches MAY communicate multicast listeners and prune distribution trees based on the actual IPv4 or IPv6 multicast addresses involved. Additional Group Address sub-TLVs are provided in [RFC7176] to carry this information. A TRILL switch that is only capable of pruning based on derived MAC addresses SHOULD calculate and use such derived MAC addresses from the multicast listener IPv4 or IPv6 address information it receives.

3.4. Numbering of Distribution Trees (Unchanged)

Section 4.5.1 of [RFC6325] specifies that, when building distribution tree number j , node (RBridge) N that has multiple possible parents in the tree is attached to possible parent number $j \bmod p$. Trees are numbered starting with 1, but possible parents are numbered starting with 0. As a result, if there are two trees and two possible parents, then in tree 1 parent 1 will be selected, and in tree 2 parent 0 will be selected.

This is changed so that the selected parent MUST be $(j-1) \bmod p$. As a result, in the case above, tree 1 will select parent 0, and tree 2 will select parent 1. This change is not backward compatible with [RFC6325]. If all RBridges in a campus do not determine distribution trees in the same way, then for most topologies, the RPFC will drop many multi-destination packets before they have been properly delivered.

3.5. Link Cost Directionality (Unchanged)

Distribution tree construction, like other least-cost aspects of TRILL, works even if link costs are asymmetric, so the cost of the hop from RB1 to RB2 is different from the cost of the hop from RB2 to RB1. However, it is essential that all RBridges calculate the same distribution trees, and thus all must use either the cost away from the tree root or the cost towards the tree root. The text in Section 4.5.1 of [RFC6325] is incorrect, as documented in [Err3508]. The text says:

In other words, the set of potential parents for N , for the tree rooted at R , consists of those that give equally minimal cost paths from N to R and ...

but the text should say "from R to N":

In other words, the set of potential parents for N, for the tree rooted at R, consists of those that give equally minimal cost paths from R to N and ...

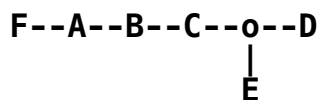
3.6. Alternative RPF Check (New)

[RFC6325] mandates a Reverse Path Forwarding (RPF) check on multi-destination TRILL Data packets to avoid possible multiplication and/or looping of multi-destination traffic during TRILL campus topology transients. This check is logically performed at each TRILL switch input port and determines whether it is arriving on the expected port based on where the packet started (the ingress nickname) and the tree on which it is being distributed. If not, the packet is silently discarded. This check is fine for point-to-point links; however, there are rare circumstances involving multi-access ("broadcast") links where a packet can be duplicated despite this RPF check and other checks performed by TRILL.

Section 3.6.1 gives an example of the potential problem, and Section 3.6.2 specifies a solution. This solution is an alternative, stronger RPF check that TRILL switches can implement in place of the RPF check discussed in [RFC6325].

3.6.1. Example of the Potential Problem

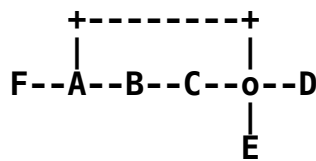
Consider this network:



All the links except the link between C, D, and E are point-to-point links. C, D, and E are connected over a broadcast link represented by the pseudonode "o". For example, they could be connected by a bridged LAN. (Bridged LANs are transparent to TRILL.)

Although the choice of root is unimportant here, assume that D or F is chosen as the root of a distribution tree so that it is obvious that the tree looks just like the diagram above.

Now assume that a link comes up from A to the same bridged LAN. The network then looks like this:



Let's say the resulting tree in steady state includes all links except the B-C link. After the network has converged, a packet that starts from F will go F->A. Then A will send one copy on the A-B link and another copy into the bridged LAN from which it will be received by C and D.

Now consider a transition stage where A and D have acted on the new LSPs and programmed their forwarding plane, while B and C have not yet done so. This means that B and C both consider the link between them to still be part of the tree. In this case, a packet that starts out from F and reaches A will be copied by A into the A-B link and to the bridged LAN. D's RPF check says to accept packets on this tree coming from F over its port on the bridged LAN, so it gets accepted. D is also adjacent to A on the tree, so the tree adjacency check, a separate check mandated by [RFC6325], also passes.

However, the packet that gets to B gets sent out by B to C. C's RPF check still has the old state, and it thinks the packet is OK. C sends the packet along the old tree, which sends the packet into the bridged LAN. D receives one more packet, but the tree adjacency check passes at D because C is adjacent to D in the new tree as well. The RPF check also passes at D because D's port on the bridged LAN is OK for receiving packets from F.

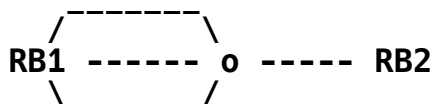
So, during this transient state, D gets duplicates of every multi-destination packet ingressed at F (unless the packet gets pruned) until B and C act on the new LSPs and program their forwarding tables.

3.6.2. Solution and Discussion

The problem stems from the RPF check described in [RFC6325] depending only on the port at which a TRILL Data packet is received, the ingress nickname, and the tree being used, that is, a check if {ingress nickname, tree, input port} is a valid combination according to the receiving TRILL switch's view of the campus topology. A multi-access link actually has multiple adjacencies overlaid on one physical link, and to avoid the problem shown in Section 3.6.1, a stronger check is needed that includes the Layer 2 source address of

the TRILL Data packet being received. (TRILL is a Layer 3 protocol, and TRILL switches are true routers that logically strip the Layer 2 header from any arriving TRILL Data packets and add the appropriate new Layer 2 header to any outgoing TRILL Data packet to get it to the next TRILL switch, so the Layer 2 source address in a TRILL Data packet identifies the immediately previous TRILL switch that forwarded the packet.)

What is needed, instead of checking the validity of the triplet {ingress nickname, tree, input port}, is to check that the quadruplet {ingress nickname, source SNPA, tree, input port} is valid (where "source SNPA" (Subnetwork Point of Attachment) is the Outer.MacSA for an Ethernet link). Although it is true that [RFC6325] also requires a check to ensure that a multi-destination TRILL Data packet is from a TRILL switch that is adjacent in the distribution tree being used, this check is separate from the RPF check, and these two independent checks are not as powerful as the single unified check for a valid quadruplet.



However, this stronger RPF check is not without cost. In the simple case of a multi-access link where each TRILL switch has only one port on the link, it merely increases the size of validity entries by adding the source SNPA (Outer.MacSA). However, assume that some TRILL switch RB1 has multiple ports attached to a multi-access link. In the figure above, RB1 is shown with three ports on the multi-access link. RB1 is permitted to load split multi-destination traffic it is sending into the multi-access link across those ports (Section 4.4.4 of [RFC6325]). Assume that RB2 is another TRILL switch on the link and RB2 is adjacent to RB1 in the distribution tree. The number of validity quadruplets at RB2 for ingress nicknames whose multi-destination traffic would arrive through RB1 is multiplied by the number of ports RB1 has on the access link, because RB2 has to accept such traffic from any such ports. Although such instances seem to be very rare in practice, the number of ports an RBridge has on a link could in principle be tens or even a hundred or more ports, vastly increasing the RPF check state at RB2 when this stronger RPF check is used.

Another potential cost of the stronger RPF check is increased transient loss of multi-destination TRILL Data packets during a topology change. For TRILL switch D, the new stronger RPF check is (tree->A, Outer.MacSA=A, ingress=A, arrival port=if1), while the old one was (tree->A, Outer.MacSA=C, ingress=A, arrival port=if1).

Suppose that both A and B have switched to the new tree for multicast forwarding but D has not updated its RPF check yet; the multicast packet will then be dropped at D's input port, because D still expects a packet from "Outer.MacSA=C". But we do not have this packet loss issue if the weaker triplet check (tree->A, ingress=A, arrival port=if1) is used. Thus, the stronger check can increase the RPF check discard of multi-destination packets during topology transients.

Because of these potential costs, implementation of this stronger RPF check is optional. The TRILL base protocol is updated to provide that TRILL switches MUST, for multi-destination packets, either implement the RPF and other checks as described in [RFC6325] or implement this stronger RPF check as a substitute for the [RFC6325] RPF and tree adjacency checks. There is no problem with a campus having a mixture of TRILL switches, some of which implement one of these RPF checks and some of which implement the other.

4. Nickname Selection (Unchanged)

Nickname selection is covered by Section 3.7.3 of [RFC6325]. However, the following should be noted:

1. The second sentence in the second bullet item in Section 3.7.3 of [RFC6325] on page 25 is erroneous [Err3002] and is corrected as follows:
 - o The occurrence of "IS-IS ID (LAN ID)" is replaced with "priority".
 - o The occurrence of "IS-IS System ID" is replaced with "7-byte IS-IS ID (LAN ID)".

The resulting corrected sentence in [RFC6325] reads as follows:

If RB1 chooses nickname x, and RB1 discovers, through receipt of an LSP for RB2 at any later time, that RB2 has also chosen x, then the RBridge or pseudonode with the numerically higher priority keeps the nickname, or if there is a tie in priority, the RBridge with the numerically higher 7-byte IS-IS ID (LAN ID) keeps the nickname, and the other RBridge MUST select a new nickname.

2. In examining the link-state database for nickname conflicts, nicknames held by IS-IS unreachable TRILL switches MUST be ignored, but nicknames held by IS-IS reachable TRILL switches MUST NOT be ignored even if they are data unreachable.

3. An RBridge may need to select a new nickname, either initially because it has none or because of a conflict. When doing so, the RBridge **MUST** consider as available all nicknames that do not appear in its link-state database or that appear to be held by IS-IS unreachable TRILL switches; however, it **SHOULD** give preference to selecting new nicknames that do not appear to be held by any TRILL switch in the campus, reachable or unreachable, so as to minimize conflicts if IS-IS unreachable TRILL switches later become reachable.
4. An RBridge, even after it has acquired a nickname for which there appears to be no conflicting claimant, **MUST** continue to monitor for conflicts with the nickname or nicknames it holds. It does so by monitoring any received LSPs that should update its link-state database for any occurrence of any of its nicknames held with higher priority by some other TRILL switch that is IS-IS reachable from it. If it finds such a conflict, it **MUST** select a new nickname, even when in overloaded state. (It is possible to receive an LSP that should update the link-state database but does not do so due to overload.)
5. In the very unlikely case that an RBridge is unable to obtain a nickname because all valid RBridge nicknames (0x0001 through 0xFFBF inclusive) are in use with higher priority by IS-IS reachable TRILL switches, it will be unable to act as an ingress, egress, or tree root but will still be able to function as a transit TRILL switch. Although it cannot be a tree root, such an RBridge is included in distribution trees computed for the campus unless all its neighbors are overloaded. It would not be possible to send a unicast RBridge Channel message specifically to such a TRILL switch [RFC7178]; however, it will receive unicast RBridge Channel messages sent by a neighbor to the Any-RBridge egress nickname and will receive appropriate multi-destination RBridge Channel messages.

5. MTU (Maximum Transmission Unit) (Unchanged)

MTU values in TRILL are derived from the `originatingL1LSPBufferSize` value communicated in the IS-IS `originatingLSPBufferSize` TLV [IS-IS]. The campus-wide value `Sz`, as described in Section 4.3.1 of [RFC6325], is the minimum value of `originatingL1LSPBufferSize` for the RBridges in a campus, but not less than 1470. The MTU testing mechanism and limiting LSPs to `Sz` assure that the LSPs can be flooded by IS-IS and thus that IS-IS can operate properly.

If an RBridge knows nothing about the MTU of the links or the `originatingL1LSPBufferSize` of other R Bridges in a campus, the `originatingL1LSPBufferSize` for that R Bridge should default to the minimum of the LSP size that its TRILL IS-IS software can handle and the minimum MTU of the ports that it might use to receive or transmit LSPs. If an R Bridge does have knowledge of link MTUs or other R Bridge `originatingL1LSPBufferSize`, then, to avoid the necessity of regenerating the local LSPs using a different maximum size, the R Bridge's `originatingL1LSPBufferSize` SHOULD be configured to the minimum of (1) the smallest value that other R Bridges are, or will be, announcing as their `originatingL1LSPBufferSize` and (2) a value small enough that the campus will not partition due to a significant number of links with limited MTUs. However, as specified in [RFC6325], in no case can `originatingL1LSPBufferSize` be less than 1470. In a well-configured campus, to minimize any LSP regeneration due to resizing, all R Bridges will be configured with the same `originatingL1LSPBufferSize`.

Section 5.1 below corrects errata in [RFC6325], and Section 5.2 clarifies the meaning of various MTU limits for TRILL Ethernet links.

5.1. MTU-Related Errata in RFC 6325

Three MTU-related errata in [RFC6325] are corrected in the subsections below.

5.1.1. MTU PDU Addressing

Section 4.3.2 of [RFC6325] incorrectly states that multi-destination MTU-probe and MTU-ack TRILL IS-IS PDUs are sent on Ethernet links with the All-R Bridges multicast address as the Outer.MacDA [Err3004]. As TRILL IS-IS PDUs, when multicast on an Ethernet link, these multi-destination MTU-probe and MTU-ack PDUs MUST be sent to the All-IS-IS-R Bridges multicast address.

5.1.2. MTU PDU Processing

As discussed in [RFC6325] and (in more detail) [RFC7177], MTU-probe and MTU-ack PDUs MAY be unicast; however, Section 4.6 of [RFC6325] erroneously does not allow for this possibility [Err3003]. It is corrected by replacing Item 1 in Section 4.6.2 of [RFC6325] with the following text, to which TRILL switches MUST conform:

1. If the Ethertype is L2-IS-IS and the Outer.MacDA is either All-IS-IS-RBridges or the unicast MAC address of the receiving RBridge port, the frame is handled as described in Section 4.6.2.1.

The reference to "Section 4.6.2.1" in the above text is to that section in [RFC6325].

5.1.3. MTU Testing

The last two sentences of Section 4.3.2 of [RFC6325] contain errors [Err3053]. They currently read as follows:

If X is not greater than Sz, then RB1 sets the "failed minimum MTU test" flag for RB2 in RB1's Hello. If size X succeeds, and $X > Sz$, then RB1 advertises the largest tested X for each adjacency in the TRILL Hellos RB1 sends on that link, and RB1 MAY advertise X as an attribute of the link to RB2 in RB1's LSP.

They should read as follows:

If X is not greater than or equal to Sz, then RB1 sets the "failed minimum MTU test" flag for RB2 in RB1's Hello. If size X succeeds, and $X \geq Sz$, then RB1 advertises the largest tested X for each adjacency in the TRILL Hellos RB1 sends on that link, and RB1 MAY advertise X as an attribute of the link to RB2 in RB1's LSP.

5.2. Ethernet MTU Values

originatingL1LSPBufferSize is the maximum permitted size of LSPs starting with and including the IS-IS 0x83 "Intradomain Routing Protocol Discriminator" byte. In Layer 3 IS-IS, originatingL1LSPBufferSize defaults to 1492 bytes. (This is because, in its previous life as DECnet Phase V, IS-IS was encoded using the SNAP SAP (Subnetwork Access Protocol Service Access Point) [RFC7042] format, which takes 8 bytes of overhead and $1492 + 8 = 1500$, the classic Ethernet maximum. When standardized by ISO/IEC [IS-IS] to use Logical Link Control (LLC) encoding, this default could have been increased by a few bytes but was not.)

In TRILL, `originatingL1LSPBufferSize` defaults to 1470 bytes. This allows 27 bytes of headroom or safety margin to accommodate legacy devices with the classic Ethernet maximum MTU, despite headers such as an `Outer.VLAN`.

Assuming that the campus-wide minimum link MTU is `Sz`, RBridges on Ethernet links MUST limit most TRILL IS-IS PDUs so that PDUz (the length of the PDU starting just after the L2-IS-IS Ethertype and ending just before the Ethernet Frame Check Sequence (FCS)) does not exceed `Sz`. The PDU exceptions are TRILL Hello PDUs, which MUST NOT exceed 1470 bytes, and MTU-probe and MTU-ack PDUs that are padded by an amount that depends on the size being tested (which may exceed `Sz`).

`Sz` does not limit TRILL Data packets. They are only limited by the MTU of the devices and links that they actually pass through; however, links that can accommodate IS-IS PDUs up to `Sz` would accommodate, with a generous safety margin, TRILL Data packet payloads of $(Sz - 24)$ bytes, starting after the `Inner.VLAN` and ending just before the FCS.

Most modern Ethernet equipment has ample headroom for frames with extensive headers and is sometimes engineered to accommodate 9 KB jumbo frames.

6. TRILL Port Modes (Unchanged)

Section 4.9.1 of [RFC6325] specifies four mode bits for RBridge ports but may not be completely clear on the effects of all combinations of bits in terms of allowed frame types.

The table below explicitly indicates the effects of all possible combinations of the TRILL port mode bits. "*" in one of the first four columns indicates that the bit can be either zero or one. The remaining columns indicate allowed frame types. The "disable bit" normally disables all frames; however, as an implementation choice, some or all low-level Layer 2 control messages can still be sent or received. Examples of Layer 2 control messages are those control frames for Ethernet identified in Section 1.4 of [RFC6325] or PPP link negotiation messages [RFC6361].

D i s a b l e	P 2 P	A c c e s s	T r u n k	Layer 2 Control	Native Ingress	Native Egress	TRILL Data LSP SNP MTU	TRILL Hello	P2P Hello
0	0	0	0	Yes	Yes	Yes	Yes	Yes	No
0	0	0	1	Yes	No	Yes	Yes	Yes	No
0	0	1	0	Yes	Yes	No	No	Yes	No
0	0	1	1	Yes	No	No	No	Yes	No
0	1	0	*	Yes	No	Yes	Yes	No	Yes
0	1	1	*	Yes	No	No	No	No	Yes
1	*	*	*	Optional	No	No	No	No	No

The formal name of the "access bit" above is the "TRILL traffic disable bit". The formal name of the "trunk bit" is the "end-station service disable bit" [RFC6325].

7. The CFI/DEI Bit (Unchanged)

In May 2011, the IEEE promulgated IEEE Std 802.1Q-2011, which changed the meaning of the bit between the priority and VLAN ID bits in the payload of C-VLAN tags. Previously, this bit was called the CFI (Canonical Format Indicator) bit [802] and had a special meaning in connection with IEEE 802.5 (Token Ring) frames. After 802.1Q-2011 and in subsequent versions of 802.1Q -- the most current of which is

[802.1Q-2014] -- this bit is now the DEI (Drop Eligibility Indicator) bit. (The corresponding bit in S-VLAN/B-VLAN tags has always been a DEI bit.)

The TRILL base protocol specification [RFC6325] assumed, in effect, that the link by which end stations are connected to TRILL switches and the restricted virtual link provided by the TRILL Data packet are IEEE 802.3 Ethernet links on which the CFI bit is always zero. Should an end station be attached by some other type of link, such as a Token Ring link, [RFC6325] implicitly assumed that such frames would be canonicalized to 802.3 frames before being ingressed, and similarly, on egress, such frames would be converted from 802.3 to the appropriate frame type for the link. Thus, [RFC6325] required that the CFI bit in the Inner.VLAN, which is shown as the "C" bit in Section 4.1.1 of [RFC6325], always be zero.

However, for TRILL switches with ports conforming to the change incorporated in the IEEE 802.1Q-2011 standard, the bit in the Inner.VLAN, now a DEI bit, MUST be set to the DEI value provided by the port interface on ingressing a native frame. Similarly, this bit MUST be provided to the port when transiting or egressing a TRILL Data packet. As with the 3-bit Priority field, the DEI bit to use in forwarding a transit packet MUST be taken from the Inner.VLAN. The exact effect on the Outer.VLAN DEI and priority bits, and whether or not an Outer.VLAN appears at all on the wire for output frames, may depend on output port configuration.

TRILL campuses with a mixture of ports, some compliant with versions of 802.1Q from IEEE Std 802.1Q-2011 onward and some compliant with pre-802.1Q-2011 standards, especially if they have actual Token Ring links, may operate incorrectly and may corrupt data, just as a bridged LAN with such mixed ports and links would.

8. Other IS-IS Considerations (Changed)

This section covers Extended Level 1 Flooding Scope (E-L1FS) support, control packet priorities, unknown PDUs, the Nickname Flags APPsub-TLV, graceful restart, and the Purge Originator Identification TLV.

8.1. E-L1FS Support (New)

TRILL switches **MUST** support E-L1FS PDUs [RFC7356] and **MUST** include a Scope Flooding Support TLV [RFC7356] in all TRILL Hellos they send indicating support for this scope and any other FS-LSP scopes that they support. This support increases the number of fragments available for link-state information by over two orders of magnitude. (See Section 9 for further information on support of the Scope Flooding Support TLV.)

In addition, TRILL switches **MUST** advertise their support of E-L1FS flooding in a TRILL-VER sub-TLV Capability Flag (see [RFC7176] and Section 12.2). This flag is used by a TRILL switch, say RB1, to determine support for E-L1FS by some remote RBx. The alternative of simply looking for an E-L1FS FS-LSP originated by RBx fails because (1) RBx might support E-L1FS flooding but is not originating any E-L1FS FS-LSPs and (2) even if RBx is originating E-L1FS FS-LSPs there might, due to legacy TRILL switches in the campus, be no path between RBx and RB1 through TRILL switches supporting E-L1FS flooding. If that were the case, no E-L1FS FS-LSP originated by RBx could get to RB1.

E-L1FS will commonly be used to flood TRILL GENINFO TLVs and enclosed TRILL APPsub-TLVs [RFC7357]. For robustness, E-L1FS fragment zero **MUST NOT** exceed 1470 bytes in length; however, if such a fragment is received that is larger, it is processed normally. It is anticipated that in the future some particularly important TRILL APPsub-TLVs will be specified as being flooded in E-L1FS fragment zero. TRILL GENINFO TLVs **MUST NOT** be sent in LSPs; however, if one is received in an LSP, it is processed normally.

8.1.1. Backward Compatibility

A TRILL campus might contain TRILL switches supporting E-L1FS flooding and legacy TRILL switches that do not support E-L1FS or perhaps do not support any [RFC7356] scopes.

A TRILL switch conformant to this document can always tell which adjacent TRILL switches support E-L1FS flooding from the adjacency table entries on its ports (see Section 9). In addition, such a TRILL switch can tell which remote TRILL switches in a campus support E-L1FS by the presence of a TRILL version sub-TLV in that TRILL switch's LSP with the E-L1FS support bit set in the Capabilities field; this capability bit is ignored for adjacent TRILL switches for which only the adjacency table entry is consulted to determine E-L1FS support.

TRILL specifications making use of E-L1FS MUST specify how situations involving a mixed TRILL campus of TRILL switches will be handled.

8.1.2. E-L1FS Use for Existing (Sub-)TLVs

In a campus where all TRILL switches support E-L1FS, all TRILL sub-TLVs listed in Section 2.3 of [RFC7176], except the TRILL version sub-TLV, MAY be advertised by inclusion in Router Capability or MT-Capability TLVs in E-L1FS FS-LSPs [RFC7356]. (The TRILL version sub-TLV still MUST appear in an LSP fragment zero.)

In a mixed campus where some TRILL switches support E-L1FS and some do not, then only the following four sub-TLVs of those listed in Section 2.3 of [RFC7176] can appear in E-L1FS, and then only under the conditions discussed below. In the following list, each sub-TLV is preceded by an abbreviated acronym used only in this section of this document:

IV: Interested VLANs and Spanning Tree Roots sub-TLV
VG: VLAN Group sub-TLV
IL: Interested Labels and Spanning Tree Roots sub-TLV
LG: Label Group sub-TLV

An IV or VG sub-TLV MUST NOT be advertised by TRILL switch RB1 in an E-L1FS FS-LSP (and should instead be advertised in an LSP) unless the following conditions are met:

- E-L1FS is supported by all of the TRILL switches that are data reachable from RB1 and are interested in the VLANs mentioned in the IV or VG sub-TLV, and
- there is E-L1FS connectivity between all such TRILL switches in the campus interested in the VLANs mentioned in the IV or VG sub-TLV (connectivity involving only intermediate TRILL switches that also support E-L1FS).

Any IV and VG sub-TLVs MAY still be advertised via core TRILL IS-IS LSPs by any TRILL switch that has enough room in its LSPs.

The conditions for using E-L1FS for the IL and LG sub-TLVs are the same as for IV and VG, but with Fine-Grained Labels [RFC7172] substituted for VLANs.

Note, for example, that the above would permit a contiguous subset of the campus that supported Fine-Grained Labels and E-L1FS to use E-L1FS to advertise IL and LG sub-TLVs, even if the remainder of the campus did not support Fine-Grained Labels or E-L1FS.

8.2. Control Packet Priorities (New)

When deciding what packet to send out a port, control packets used to establish and maintain adjacency between TRILL switches **SHOULD** be treated as being in the highest-priority category. This includes TRILL IS-IS Hello and MTU PDUs, and possibly other adjacency [RFC7177] or link-technology-specific packets. Other control and data packets **SHOULD** be given lower priority so that a flood of such other packets cannot lead to loss of, or inability to establish, adjacency. Loss of adjacency causes a topology transient that can result in reduced throughput; reordering; increased probability of loss of data; and, in the worst case, network partition if the adjacency is a cut point.

Other important control packets should be given second-highest priority. Lower priorities should be given to data or less important control packets.

Based on the above, control packets can be ordered into priority categories as shown below, based on the relative criticality of these types of messages, where the most critical control packets relate to the core routing between TRILL switches and the less critical control packets are closer to "application" information. (There may be additional control packets, not specifically listed in any category below, that **SHOULD** be handled as being in the most nearly analogous category.) Although few implementations will actually treat these four categories with different priority, an implementation **MAY** choose to prioritize more critical messages over less critical. However, an implementation **SHOULD NOT** send control packets in a lower-priority category with a priority above those in a higher-priority category because, under sufficiently congested conditions, this could block control packets in a higher-priority category, resulting in network disruption.

Priority Category	Description
-----	-----
4.	Hello, MTU-probe, MTU-ack, and other packets critical to establishing and maintaining adjacency. (Normally sent with highest priority, which is priority 7.)
3.	LSPs, CSNPs/PSNPs, and other important control packets.
2.	Circuit scoped FS-LSPs, FS-CSNPs, and FS-PSNPs.
1.	Non-circuit scoped FS-LSPs, FS-CSNPs, and FS-PSNPs.

8.3. Unknown PDUs (New)

TRILL switches **MUST** silently discard [IS-IS] PDUs they receive with PDU numbers they do not understand, just as they ignore TLVs and sub-TLVs they receive that have unknown Types and sub-Types; however, they **SHOULD** maintain a counter of how many such PDUs have been received, on a per-PDU-number basis. (This is not burdensome, as the PDU number is only a 5-bit field.)

Note: The set of valid [IS-IS] PDUs was stable for so long that some IS-IS implementations may treat PDUs with unknown PDU numbers as a serious error and, for example, an indication that other valid PDUs from the sender are not to be trusted or that they should drop adjacency to the sender if it was adjacent. However, the MTU-probe and MTU-ack PDUs were added by [RFC7176], and now [RFC7356] has added three more new PDUs. Although the authors of this document are not aware of any Internet-Drafts calling for further PDUs, the eventual addition of further new PDUs should not be surprising.

8.4. Nickname Flags APPsub-TLV (New)

An optional Nickname Flags APPsub-TLV within the TRILL GENINFO TLV [RFC7357] is specified below.

```

      1 1 1 1 1 1
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| Type = NickFlags (6)                                     | (2 bytes)
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| Length = 4*K                                           | (2 bytes)
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|   NICKFLAG RECORD 1                                   | (4 bytes)
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
...
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|   NICKFLAG RECORD K                                   | (4 bytes)
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

where each NICKFLAG RECORD has the following format:

```

    0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
|   Nickname                                           |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| IN |      RESV                                       |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+

```

- o Type: NickFlags TRILL APPsub-TLV, set to 6 (NICKFLAGS).
- o Length: 4 times the number of NICKFLAG RECORDS present.
- o Nickname: A 16-bit TRILL nickname held by the advertising TRILL switch ([RFC6325] and Section 4).
- o IN: Ingress. If this flag is one, it indicates that the advertising TRILL switch may use the nickname in the NICKFLAG RECORD as the Ingress Nickname of TRILL Headers it creates. If the flag is zero, that nickname will not be used for that purpose.
- o RESV: Reserved for additional flags to be specified in the future. MUST be sent as zero and ignored on receipt.

The entire NickFlags APPsub-TLV is ignored if the Length is not a multiple of 4. A NICKFLAG RECORD is ignored if the nickname it lists is not a nickname owned by the TRILL switch advertising the enclosing NickFlags APPsub-TLV.

If a TRILL switch intends to use a nickname in the Ingress Nickname field of TRILL Headers it constructs, it can advertise this through E-L1FS FS-LSPs (see Section 8.1) using a NickFlags APPsub-TLV entry with the IN flag set. If it owns only one nickname, there is no reason to do this because, if a TRILL switch advertises no NickFlags APPsub-TLVs with the IN flag set for nicknames it owns, it is assumed that the TRILL switch might use any or all nicknames it owns as the Ingress Nickname in TRILL Headers it constructs. If a TRILL switch advertises any NickFlags APPsub-TLV entries with the IN flag set, then it MUST NOT use any other nickname(s) it owns as the Ingress Nickname in TRILL Headers it constructs.

Every reasonable effort should be made to be sure that Nickname sub-TLVs [RFC7176] and NickFlags APPsub-TLVs remain in sync. If all TRILL switches in a campus support E-L1FS, so that Nickname sub-TLVs can be advertised in E-L1FS FS-LSPs, then the Nickname sub-TLV and any NickFlags APPsub-TLVs for any particular nickname SHOULD be advertised in the same fragment. If they are not in the same fragment, then, to the extent practical, all fragments involving those sub-TLVs for the same nickname should be propagated as an atomic action. If a TRILL switch sees multiple NickFlags APPsub-TLV entries for the same nickname, it assumes that that nickname might be used as the ingress in a TRILL Header if any of the NickFlags APPsub-TLV entries have the IN bit set.

It is possible that a NickFlags APPsub-TLV would not be propagated throughout the TRILL campus due to legacy TRILL switches not supporting E-L1FS. In that case, Nickname sub-TLVs MUST be advertised in LSPs, and TRILL switches not receiving NickFlags APPsub-TLVs having entries with the IN flag set will simply assume that the source TRILL switch might use any of its nicknames as the ingress in constructing TRILL Headers. Thus, the use of this optional APPsub-TLV is backward compatible with legacy lack of E-L1FS support.

(Additional flags are assigned from those labeled RESV above and specified in [TRILL-L3-GW] and [Centralized-Replication].)

8.5. Graceful Restart (Unchanged)

TRILL switches SHOULD support the features specified in [RFC5306], which describes a mechanism for a restarting IS-IS router to signal to its neighbors that it is restarting, allowing them to reestablish their adjacencies without cycling through the down state, while still correctly initiating link-state database synchronization. If this feature is not supported, it may increase the number of topology transients caused by a TRILL switch rebooting due to errors or maintenance.

8.6. Purge Originator Identification (New)

To ease debugging of any purge-related problems, TRILL switches SHOULD include the Purge Originator Identification TLV [RFC6232] in all purge PDUs in TRILL IS-IS. This includes Flooding Scope LSPs [RFC7356] and ESADI LSPs [RFC7357].

9. Updates to RFC 7177 (Adjacency) (Changed)

To support the E-L1FS flooding scope [RFC7356] mandated by Section 8.1 and backward compatibility with legacy RBridges not supporting E-L1FS flooding, this document updates [RFC7177] as follows:

1. The list in the second paragraph of Section 3.1 of [RFC7177] is updated by adding the following item:

- o The Scope Flooding Support TLV.

In addition, the sentence immediately after that list is updated by this document to read as follows:

Of course, (a) the priority, (b) the Desired Designated VLAN, (c) the Scope Flooding Support TLV, and whether or not the (d) PORT-TRILL-VER sub-TLV and/or (e) BFD-Enabled TLV are included, and their value if included, could change on occasion. However, if these change, the new value(s) must similarly be used in all TRILL Hellos on the LAN port, regardless of VLAN.

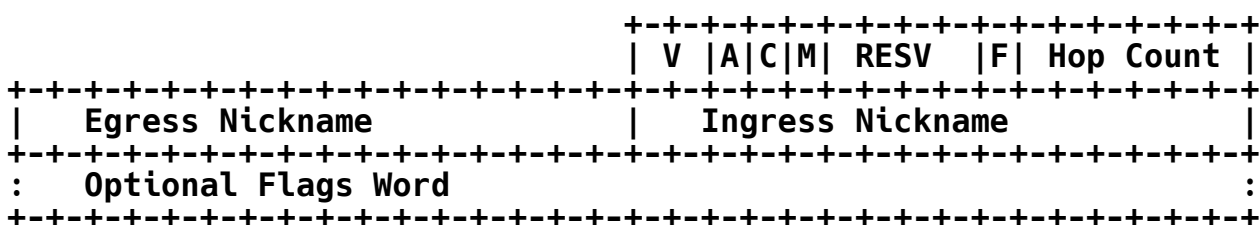
2. This document adds another bullet item to the end of Section 3.2 of [RFC7177], as follows:
 - o The value from the Scope Flooding Support TLV, or a null string if none was included.
3. Near the bottom of Section 3.3 of [RFC7177], this document adds the following bullet item:
 - o The variable-length value part of the Scope Flooding Support TLV in the Hello, or a null string if that TLV does not occur in the Hello.
4. At the beginning of Section 4 of [RFC7177], this document adds a bullet item to the list, as follows:
 - o The variable-length value part of the Scope Flooding Support TLV used in TRILL Hellos sent on the port.

5. This document adds a line to Table 4 ("TRILL Hello Contents") in Section 8.1 of [RFC7177], as follows:

LAN	P2P	Number	Content Item
---	---	-----	-----
M	M	1	Scope Flooding Support TLV

10. TRILL Header Update (New)

The TRILL Header has been updated from its original specification in [RFC6325] by [RFC7455] and [RFC7179] and is further updated by this document. The TRILL Header is now as shown in the figure below (which is followed by references for all of the fields). Those fields for which the reference is only to [RFC6325] are unchanged from that RFC.



In calculating a TRILL Data packet hash as part of equal-cost multipath selection, a TRILL switch MUST ignore the value of the "A" and "C" bits.

In [RFC6325] and [RFC7179], there is a TRILL Header Extension Length field called "Op-Length", which is hereby changed to consist of the RESV field and "F" bit shown above.

- o V (Version): 2-bit unsigned integer. See Section 3.2 of [RFC6325].
- o A (Alert): 1 bit. See [RFC7455].
- o C (Color): 1 bit. See Section 10.1.
- o M (Multi-destination): 1 bit. See Section 3.4 of [RFC6325].
- o RESV: 4 bits. These bits are reserved and MUST be sent as zero. Due to the previous use of these bits as specified in [RFC6325], most TRILL "fast path" hardware implementations trap and do not forward TRILL Data packets with these bits non-zero. A TRILL

switch receiving a TRILL Data packet with any of these bits non-zero MUST discard the packet unless the non-zero bit or bits have some future use specified that the TRILL switch understands.

- o F: 1 bit. If this field is non-zero, then the optional flags word described in Section 10.2 is present. If it is zero, the flags word is not present.
- o Hop Count: 6 bits. See Section 3.6 of [RFC6325] and Section 10.2.1 below.
- o Egress Nickname: See Section 3.7.1 of [RFC6325].
- o Ingress Nickname: See Section 3.7.2 of [RFC6325].
- o Optional Flags Word: See [RFC7179] and Section 10.2.

10.1. Color Bit

The Color bit provides an optional way by which ingress TRILL switches MAY mark TRILL Data packets for implementation-specific purposes. Transit TRILL switches MUST NOT change this bit. Transit and egress TRILL switches MAY use the Color bit for implementation-dependent traffic labeling, or for statistical analysis or other types of traffic study or analysis.

10.2. Flags Word Changes (Update to RFC 7179)

When the "F" bit in the TRILL Header is non-zero, the first 32 bits after the Ingress Nickname field provide additional flags. These bits are as specified in [RFC7179], except as changed by the subsections below, in which the Extended Hop Count and Extended Color fields are described. See Section 10.3 for a diagram and summary of these fields.

10.2.1. Extended Hop Count

The TRILL base protocol [RFC6325] specifies the Hop Count field in the header, to avoid packets persisting in the network due to looping or the like. However, the Hop Count field size (6 bits) limits the maximum hops a TRILL Data packet can traverse to 64. Optionally, TRILL switches can use a field composed of bits 14 through 16 in the flags word, as specified below, to extend this field to 9 bits. This increases the maximum Hop Count to 512. Except in rare circumstances, reliable use of Hop Counts in excess of 64 requires support of this optional capability at all TRILL switches along the path of a TRILL Data packet.

10.2.1.1. Advertising Support

It may be that not all the TRILL switches support the Extended Hop Count mechanism in a TRILL campus and in that campus more than 64 hops are required either for the distribution tree calculated path or for the unicast calculated path plus a reasonable allowance for alternate pathing. As such, it is required that TRILL switches advertise their support by setting bit 14 in the TRILL Version Sub-TLV Capabilities and Header Flags Supported field [RFC7176]; bits 15 and 16 of that field are now specified as Unassigned (see Section 12.2.5).

10.2.1.2. Ingress Behavior

If an ingress TRILL switch determines that it should set the Hop Count for a TRILL Data packet to 63 or less, then behavior is as specified in the TRILL base protocol [RFC6325]. If the optional TRILL Header flags word is present, bits 14, 15, and 16 and the critical reserved bit of the critical summary bits are zero.

If the Hop Count for a TRILL Data packet should be set to some value greater than 63 but less than 512 and all TRILL switches that the packet is reasonably likely to encounter support Extended Hop Count, then the resulting TRILL Header has the flags word extension present, the high-order 3 bits of the desired Hop Count are stored in the Extended Hop Count field in the flags word, the low-order 5 bits are stored in the Hop Count field in the first word of the TRILL Header, and bit two (the critical reserved bit of the critical summary bits) in the flags word is set to one.

For known unicast traffic (TRILL Header "M" bit zero), an ingress TRILL switch discards the frame if it determines that the least-cost path to the egress is (1) more than 64 hops and not all TRILL switches on that path support the Extended Hop Count feature or (2) more than 512 hops.

For multi-destination traffic, when a TRILL switch determines that one or more tree paths from the ingress are more than 64 hops and not all TRILL switches in the campus support the Extended Hop Count feature, the encapsulation uses a total Hop Count of 63 to obtain at least partial distribution of the traffic.

10.2.1.3. Transit Behavior

A transit TRILL switch supporting Extended Hop Count behaves like a base protocol [RFC6325] TRILL switch in decrementing the Hop Count, except that it considers the Hop Count to be a 9-bit field where the Extended Hop Count field constitutes the high-order 3 bits.

To be more precise: a TRILL switch supporting Extended Hop Count takes the first of the following actions that is applicable:

1. If both the Hop Count and Extended Hop Count fields are zero, the packet is discarded.
2. If the Hop Count is non-zero, it is decremented. As long as the Extended Hop Count is non-zero, no special action is taken. If the result of this decrement is zero, the packet is processed normally.
3. If the Hop Count is zero, it is set to the maximum value of 63, and the Extended Hop Count is decremented. If this results in the Extended Hop Count being zero, the critical reserved bit in the critical summary bits is set to zero.

10.2.1.4. Egress Behavior

No special behavior is required when egressing a TRILL Data packet that uses the Extended Hop Count. The flags word, if present, is removed along with the rest of the TRILL Header during decapsulation.

10.2.2. Extended Color Field

Flags word bits 27 and 28 are specified to be a 2-bit Extended Color field (see Section 10.3). These bits are in the non-critical ingress-to-egress region of the flags word.

The Extended Color field provides an optional way by which ingress TRILL switches MAY mark TRILL Data packets for implementation-specific purposes. Transit TRILL switches MUST NOT change these bits. Transit and egress TRILL switches MAY use the Extended Color bits for implementation-dependent traffic labeling, or for statistical analysis or other types of traffic study or analysis.

Per Section 2.3.1 of [RFC7176], support for these bits is indicated by the same bits (27 and 28) in the Capabilities and Header Flags Supported field of the TRILL version sub-TLV. If these bits are zero in those capabilities, Extended Color is not supported. A TRILL switch that does not support Extended Color will ignore the corresponding bits in any TRILL Header flags word it receives as part of a TRILL Data packet and will set those bits to zero in any TRILL Header flags word it creates. A TRILL switch that sets or senses the Extended Color field on transmitting or receiving TRILL Data packets MUST set the corresponding 2-bit field in the TRILL version sub-TLV to a non-zero value. Any difference in the meaning of the three possible non-zero values of this 2-bit capability field (0b01, 0b10, or 0b11) is implementation dependent.

10.3. Updated Flags Word Summary

With the changes above, the 32-bit flags word extension to the TRILL Header [RFC7179], which is detailed in the "TRILL Extended Header Flags" registry on the "Transparent Interconnection of Lots of Links (TRILL) Parameters" IANA web page, is now as follows:

0			1							2							3																											
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1													
Crit.			CHbH							NCHbH							CRSV							NCRSV							CItE							NCItE						
.....															
C	C	C								C	N								Ext								Ext																	
R	R	R								R	C								Hop																									
H	I	R								C	C								Cnt																									
b	t	s								A	A																																	
H	E	v								F	F																																	

Bits 0, 1, and 2 are the critical summary bits, as specified in [RFC7179], consisting of the critical hop-by-hop, critical ingress-to-egress, and critical reserved bits, respectively. The next two fields are specific critical and non-critical hop-by-hop bits -- CHbH and NCHbH, respectively -- containing the Critical and Non-critical Channel Alert flags as specified in [RFC7179]. The next field is the critical reserved bits (CRSV), which are specified herein to be the Extended Hop Count. The non-critical reserved bits (NCRSV) and the critical ingress-to-egress bits (CItE) as specified in [RFC7179] follow. Finally, there is the non-critical ingress-to-egress field, including bits 27 and 28, which are specified herein as the Extended Color field.

11. Appointed Forwarder Status Lost Counter (New)

Strict conformance to the provisions of Section 4.8.3 of [RFC6325] on the value of the Appointed Forwarder Status Lost Counter can result in the splitting of Interested VLANs and Spanning Tree Roots sub-TLVs [RFC7176] (or the corresponding Interested Labels and Spanning Tree Roots sub-TLVs where a VLAN is mapped to an FGL) due to differences in this counter value for adjacent VLAN IDs (or 24-bit FGLs). This counter is a mechanism to optimize data-plane learning by trimming the expiration timer for learned addresses on a per-VLAN/FGL basis under some circumstances.

The requirement to increment this counter by one whenever a TRILL switch loses Appointed Forwarder status on a port is hereby changed from the mandatory provisions of [RFC6325] to the enumerated provisions below. To the extent that this might cause the Appointed

Forwarder Status Lost Counter to be increased when [RFC6325] indicates that it should not, this will cause data-plane address learning timeouts at remote TRILL switches to be reduced. To the extent that this might cause the Appointed Forwarder Status Lost Counter to remain unchanged when [RFC6325] indicates that it should be increased, this will defeat a reduction in such timeouts that would otherwise occur.

- (1) If any of the following apply, either data-plane address learning is not in use or Appointed Forwarder status is irrelevant. In these cases, the Appointed Forwarder Status Lost Counter MAY be left at zero or set to any convenient value such as the value of the Appointed Forwarder Status Lost Counter for an adjacent VLAN ID or FGL.
 - (1a) The TRILL switch port has been configured with the "end-station service disable" bit (also known as the trunk bit) on.
 - (1b) The TRILL switch port has been configured in IS-IS as an IS-IS point-to-point link.
 - (1c) The TRILL switch is relying on ESADI [RFC7357] or Directory Assist [RFC7067] and not using data-plane learning.
- (2) In cases other than those enumerated in point 1 above, the Appointed Forwarder Status Lost Counter SHOULD be incremented as described in [RFC6325]. Such incrementing has the advantage of optimizing data-plane learning. Alternatively, the value of the Appointed Forwarder Status Lost Counter can deviate from that value -- for example, to make it match the value for an adjacent VLAN ID (or FGL), so as to permit greater aggregation of Interested VLANs and Spanning Tree Roots sub-TLVs.

12. IANA Considerations (Changed)

This section lists IANA actions previously completed and new IANA actions.

12.1. Previously Completed IANA Actions (Unchanged)

The following IANA actions were completed as part of [RFC7180] and are included here for completeness, since this document obsoletes [RFC7180].

1. The nickname 0xFFC1, which was reserved by [RFC6325], is allocated for use in the TRILL Header Egress Nickname field to indicate an OOMF (Overload Originated Multi-destination Frame).
2. Bit 1 from the seven previously reserved (RESV) bits in the per-neighbor "Neighbor RECORD" in the TRILL Neighbor TLV [RFC7176] is allocated to indicate that the RBridge sending the TRILL Hello volunteers to provide the OOMF forwarding service described in Section 2.4.2 to such frames originated by the TRILL switch whose SNPA (MAC address) appears in that Neighbor RECORD. The description of this bit is "Offering OOMF service".
3. Bit 0 is allocated from the capability bits in the PORT-TRILL-VER sub-TLV [RFC7176] to indicate support of the VLANs Appointed sub-TLV [RFC7176] and the VLAN inhibition setting mechanisms specified in [RFC6439bis]. The description of this bit is "Hello reduction support".

12.2. New IANA Actions (New)

The following are new IANA actions for this document.

12.2.1. Reference Updated

All references to [RFC7180] in the "Transparent Interconnection of Lots of Links (TRILL) Parameters" registry have been replaced with references to this document, except that the Reference for bit 0 in the PORT-TRILL-VER Sub-TLV Capability Flags has been changed to [RFC6439bis].

12.2.2. The "E" Capability Bit

There is an existing TRILL version sub-TLV, sub-TLV #13, under both TLV #242 and TLV #144 [RFC7176]. This TRILL version sub-TLV contains a capability bits field for which assignments are documented in the "TRILL-VER Sub-TLV Capability Flags" registry on the TRILL Parameters IANA web page. IANA has allocated 4 from the previously reserved

bits in this "TRILL-VER Sub-TLV Capability Flags" registry to indicate support of the E-L1FS flooding scope as specified in Section 8.1. This capability bit is referred to as the "E" bit. The following is the addition to the "TRILL-VER Sub-TLV Capability Flags" registry:

Bit	Description	References
----	-----	-----
4	E-L1FS FS-LSP support	[RFC7356], RFC 7780

12.2.3. NickFlags APPsub-TLV Number and Registry

IANA has assigned an APPsub-TLV number, as follows, under the TRILL GENINFO TLV from the range less than 255.

Type	Name	References
----	-----	-----
6	NICKFLAGS	RFC 7780

In addition, IANA has created a registry on its TRILL Parameters web page for NickFlags bit assignments, as follows:

Name: NickFlags Bits
 Registration Procedure: IETF Review [RFC5226]
 Reference: RFC 7780

Bit	Mnemonic	Description	Reference
----	-----	-----	-----
0	IN	Used as ingress	RFC 7780
1-15	-	Unassigned	RFC 7780

12.2.4. Updated TRILL Extended Header Flags

The "TRILL Extended Header Flags" registry has been updated as follows:

Bits	Purpose	Reference
----	-----	-----
14-16	Extended Hop Count	RFC 7780
27-28	Extended Color	RFC 7780
29-31	Available non-critical ingress-to-egress flags	[RFC7179], RFC 7780

12.2.5. TRILL-VER Sub-TLV Capability Flags

The "TRILL-VER Sub-TLV Capability Flags" registry has been updated as follows:

Bit	Description	Reference
-----	-----	-----
14	Extended Hop Count support	RFC 7780
15-16	Unassigned	RFC 7780
27-28	Extended Color support	RFC 7780
29-31	Extended header flag support	[RFC7179], RFC 7780

12.2.6. Example Nicknames

As shown in the table below, IANA has assigned a block of eight nicknames for use as examples in documentation. Appendix B shows a use of some of these nicknames. The "TRILL Nicknames" registry has been updated by changing the previous "0xFFC2-0xFFFFE Unassigned" line to the following:

Name	Description	Reference
-----	-----	-----
0xFFC2-0xFFD7	Unassigned	
0xFFD8-0xFFDF	For use in documentation examples	RFC 7780
0xFFE0-0xFFFFE	Unassigned	

13. Security Considerations (Changed)

See [RFC6325] for general TRILL security considerations.

This memo improves the documentation of the TRILL protocol; corrects six errata in [RFC6325]; updates [RFC6325], [RFC7177], and [RFC7179]; and obsoletes [RFC7180]. It does not change the security considerations of those RFCs, except as follows:

- o E-L1FS FS-LSPs can be authenticated with IS-IS security [RFC5310], that is, through the inclusion of an IS-IS Authentication TLV in E-L1FS PDUs.
- o As discussed in Section 3.6, when using an allowed weaker RPF check under very rare topologies and transient conditions, multi-destination TRILL Data packets can be duplicated; this could have security consequences for some protocols.

14. References

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Appendix A. Life Cycle of a TRILL Switch Port (New)

Text from <<http://www.ietf.org/mail-archive/web/trill/current/msg06355.html>> is paraphrased in this informational appendix.

Question:

Suppose we are developing a TRILL implementation to run on different machines. Then what happens first? Is LSP flooding or ESADI started first? -> Link-state database creation -> Designated RBridge election (How to set priority? Any fixed process that depends on user settings?) -> etc.

Answer:

The first thing that happens on a port/link is any link setup that is needed. For example, on a PPP link [RFC6361], you need to negotiate that you will be using TRILL. However, if you have Ethernet links [RFC6325], which are probably the most common type, there isn't any link setup needed.

As soon as the port is set up, it can ingress or egress native frames if end-station service is being offered on that port. Offering end-station service is the default. However, if the port trunk bit (end-station service disable) is set or the port is configured as an IS-IS point-to-point link port, then end-station service is not offered; therefore, native frames received are ignored, and native frames are not egressed.

TRILL IS-IS Hellos then get sent out the port to be exchanged with any other TRILL switches on the link [RFC7177]. Only the Hellos are required; optionally, you might also exchange MTU-probe/ack PDUs [RFC7177], BFD PDUs [RFC7175], or other link test packets.

TRILL doesn't send any TRILL Data or TRILL IS-IS packets out the port to the link, except for Hellos, until the link gets to the 2-Way or Report state [RFC7177].

If a link is configured as a point-to-point link, there is no Designated RBridge (DRB) election. By default, an Ethernet link is considered a LAN link, and the DRB election occurs when the link is in any state other than Down. You don't have to configure priorities for each TRILL switch (RBridge) to be the DRB. Things will work fine with all the RBridges on a link using default priority. But if the network manager wants to control this, there should be a way for them to configure the priority to be the DRB of the TRILL switch ports on the link.

(To avoid complexity, this appendix generally describes the life cycle for a link that only has two TRILL switches on it. But TRILL works fine as currently specified on a broadcast link with multiple TRILL switches on it -- actually, multiple TRILL switch ports -- since a TRILL switch can have multiple ports connected to the same link. The most likely way to get such a multi-access link with current technology and the existing TRILL standards is to have more than two TRILL switch Ethernet ports connected to a bridged LAN. The TRILL protocol operates above all bridging; in general, the bridged LAN looks like a transparent broadcast link to TRILL.)

When a link gets to the 2-Way or Report state, LSPs, CSNPs, and PSNPs will start to flow on the link (as well as FS-LSPs, FS-CSNPs, and FS-PSNPs for E-L1FS (see Section 8.1)).

When a link gets to the Report state, there is adjacency. The existence of that adjacency is flooded (reported) to the campus in LSPs. TRILL Data packets can then start to flow on the link as TRILL switches recalculate the least-cost paths and distribution trees to take the new adjacency into account. Until it gets to the Report state, there is no adjacency, and no TRILL Data packets can flow over that link (with the minor corner case exception that an RBridge Channel message can, for its first hop only, be sent on a port where there is no adjacency (Section 2.4 of [RFC7178])). (Although this paragraph seems to be talking about link state, it is actually port state. It is possible for different TRILL switch ports on the same link to temporarily be in different states. The adjacency state machinery runs independently on each port.)

ESADI [RFC7357] is built on top of the regular TRILL Data routing. Since ESADI PDUs look, to transit TRILL switches, like regular TRILL Data packets, no ESADI PDUs can flow until adjacencies are established and TRILL Data is flowing. Of course, ESADI is optional and is not used unless configured.

Question:

Does it require TRILL Full Headers at the time TRILL LSPs start being broadcast on a link? Because at that time it's not defined egress and ingress nicknames.

Answer:

TRILL Headers are only for TRILL Data packets. TRILL IS-IS packets, such as TRILL LSPs, are sent in a different way that does not use a TRILL Header and does not depend on nicknames.

Probably, in most implementations, a TRILL switch will start up using the same nickname it had when it shut down or last got disconnected from a campus. If you want, you can implement TRILL to come up initially not reporting any nickname (by not including a Nickname sub-TLV in its LSPs) until you get the link-state database or most of the link-state database, and then choose a nickname no other TRILL switch in the campus is using. Of course, if a TRILL switch does not have a nickname, then it cannot ingress data, cannot egress known unicast data, and cannot be a tree root.

TRILL IS-IS PDUs such as LSPs, and the link-state database, all work based on the 7-byte IS-IS System ID (sometimes called the LAN ID [IS-IS]). Since topology determination uses System IDs, which are always unique across the campus, it is not affected by the nickname assignment state. The nickname system is built on top of that.

Appendix B. Example TRILL PDUs (New)

This appendix shows example TRILL IS-IS PDUs. The primary purpose of these examples is to clarify issues related to bit ordering.

The examples in this appendix concentrate on the format of the packet header and trailer. There are frequently unspecified optional items or data in the packet that would affect header or trailer fields like the packet length or checksum. Thus, an "Xed out" placeholder is used for such fields, where each X represents one hex nibble.

B.1. LAN Hello over Ethernet

A TRILL Hello sent from a TRILL switch (RBridge) with 7-byte System ID 0x30033003300300 holding nickname 0xFFDE over Ethernet from a port with MAC address 0x00005E0053DE on VLAN 1 at priority 7. There is one neighbor that is the DRB. The neighbor's port MAC is 0x00005E0053E3, and the neighbor's System ID is 0x44444444444400.

Ethernet Header

Outer.MacDA, Outer.MacSA

0x0180C2000041 All-IS-IS-RBridges Destination MAC Address

0x00005E0053DE Source MAC Address

Outer VLAN Tag (optional)

0x8100 C-VLAN Ethertype [802.1Q-2014]

0xE001 Priority 7, Outer.VLAN

IS-IS

0x22F4 L2-IS-IS Ethertype

IS-IS Payload

Common Header

0x83 Intradomain Routing Protocol Discriminator

0x08 Header Length

0x01 IS-IS Version Number

0x06 ID Length of 6 Bytes

0x0F PDU Type (Level 1 LAN Hello)

0x01 Version

0x00 Reserved

0x01 Maximum Area Addresses

Hello PDU Specific Fields

0x01 Circuit Type (Level 1)

0x30033003300300 Source System ID

0x0009 Holding Time

0xFFFF PDU Length

0x40 Priority to be DRB

0x44444444444400 LAN ID

TLVs (the following order of TLVs or of sub-TLVs in a TLV is not significant)


```

Area Addresses TLV
  0x01      Area Addresses Type
  0x02      Length of Value
  0x01      Length of Address
  0x00      The fixed TRILL Area Address
MT Port Capabilities TLV
  0x8F      MT Port Capabilities Type
  0x0011    Length of Value
  0x0000    Topology
    Special VLANs and Flags Sub-TLV
      0x01      Sub-TLV Type
      0x08      Length
      0x0123    Port ID
      0xFFDE    Sender Nickname
      0x0001    Outer.VLAN
      0x0001    Designated VLAN
    Enabled VLANs Sub-TLV (optional)
      0x02      Sub-TLV Type
      0x03      Length
      0x0001    Start VLAN 1
      0x80      VLAN 1
TRILL Neighbor TLV
  0x91      Neighbor Type
  0x0A      Length of Value
  0xC0      S Flag = 1, L Flag = 1, SIZE field 0
    NEIGHBOR RECORD
      0x00      Flags
      0x2328    MTU = 9 KB
      0x00005E0053E3 Neighbor MAC Address
Scope Flooding Support TLV
  0xF3      Scope Flooding Support Type
  0x01      Length of Value
  0x40      E-L1FS Flooding Scope
More TLVs (optional)
...
Ethernet Trailer
  0xFFFFFFFF Ethernet Frame Check Sequence (FCS)

```

B.2. LSP over PPP

Here is an example of a TRILL LSP sent over a PPP link by the same source TRILL switch as the example in Appendix B.1.

PPP Header	
0x405D	PPP TRILL Link State Protocol
IS-IS Payload	
Common Header	
0x83	Intradomain Routing Protocol Discriminator
0x08	Header Length
0x01	IS-IS Version Number
0x06	ID Length of 6 Bytes
0x12	PDU Type (Level 1 LSP)
0x01	Version
0x00	Reserved
0x01	Maximum Area Addresses
LSP Specific Fields	
0xFFFF	PDU Length
0x0123	Remaining Lifetime
0x3003300330030009	LSP ID (fragment 9)
0x00001234	Sequence Number
0xFFFF	Checksum
0x01	Flags = Level 1
TLVs (the following order of TLVs or of sub-TLVs in a TLV is not significant)	
Router Capability TLV	
0xF2	Router Capability Type
0x0F	Length of Value
0x00	Flags
Nickname Sub-TLV	
0x06	Sub-TLV Type
0x05	Length of Value
NICKNAME RECORD	
0x33	Nickname Priority
0x1234	Tree Root Priority
0xFFDE	Nickname
TRILL Version Sub-TLV	
0x0D	Sub-TLV Type
0x05	
0x00	Max Version
0x40000000	Flags = FGL Support
More TLVs (optional)	
PPP Trailer	
0xXXXXXX	PPP Frame Check Sequence (FCS)

B.3. TRILL Data over Ethernet

Below is an IPv4 ICMP Echo [RFC792] sent in a TRILL Data packet from the TRILL switch that sent the Hello in Appendix B.1 to the neighbor TRILL switch on the link used in Appendix B.1.

```

Ethernet Header
  Outer.MacDA, Outer.MacSA
    0x00005E0053E3  Destination MAC Address
    0x00005E0053DE  Source MAC Address
  Outer VLAN Tag (optional)
    0x8100          C-VLAN Ethertype [802.1Q-2014]
    0x0001          Priority 0, Outer.VLAN 1
  TRILL
    0x22F3          TRILL Ethertype
  TRILL Header
    0X000E          Flags, Hop Count 14
    0xFFDF          Egress Nickname
    0xFFDC          Ingress Nickname
  Inner Ethernet Header
    Inner.MacDA, Inner.MacSA
      0x00005E005322  Destination MAC Address
      0x00005E005344  Source MAC Address
    Inner VLAN Tag
      0x8100          C-VLAN Ethertype
      0x0022          Priority 0, Inner.VLAN 34
    Ethertype
      0x0800          IPv4 Ethertype
  IP Header
    0x4500          Version 4, Header Length 5, ToS 0
    0xFFFF          Total Length
    0x3579          Identification
    0x0000          Flags, Fragment Offset
    0x1101          TTL 17, ICMP = Protocol 1
    0xFFFF          Header Checksum
    0xC0000207      Source IP 192.0.2.7
    0xC000020D      Destination IP 192.0.2.13
    0x00000000      Options, Padding
  ICMP
    0x0800          ICMP Echo
    0XXXXX          Checksum
    0x87654321      Identifier, Sequence Number
    ...            Echo Data
  Ethernet Trailer
    0XXXXXXXXXX      Ethernet Frame Check Sequence (FCS)

```

B.4. TRILL Data over PPP

Below is an ARP Request [RFC826] sent in a TRILL Data packet from the TRILL switch that sent the Hello in Appendix B.1 over a PPP link.

```

PPP Header
  0x005D          PPP TRILL Network Protocol
TRILL Header
  0X080D          Flags (M = 1), Hop Count 13
  0xFFDD          Distribution Tree Root Nickname
  0xFFDC          Ingress Nickname
Inner Ethernet Header
  Inner.MacDA, Inner.MacSA
  0xFFFFFFFFFFFF Destination MAC Address
  0x00005E005344 Source MAC Address
  Inner VLAN Tag
  0x8100          C-VLAN Ethertype
  0x0022          Priority 0, Inner.VLAN 34
  Ethertype
  0x0806          ARP Ethertype
ARP
  0x0001          Hardware Address Space = Ethernet
  0x0001          Protocol Address Space = IPv4
  0x06            Size of Hardware Address
  0x04            Size of Protocol Address
  0x0001          OpCode = Request
  0x00005E005344 Sender Hardware Address
  0xC0000207      Sender Protocol Address 192.0.2.7
  0x000000000000 Target Hardware Address
  0xC000020D      Target Protocol Address 192.0.2.13
PPP Trailer
  0xXXXXXX       PPP Frame Check Sequence (FCS)

```

Appendix C. Changes to Previous RFCs (New)

C.1. Changes to Obsoleted RFC 7180

This section summarizes the changes, augmentations, and excisions this document specifies for [RFC7180], which it obsoletes and replaces.

C.1.1. Changes

For each section header in this document ending with "(Changed)", this section summarizes the changes that are made by this document:

Section 1 ("Introduction"): Numerous changes to reflect the overall changes in contents.

Section 1.1 ("Precedence"): Changed to add mention of [RFC7179].

Section 1.3 ("Terminology and Acronyms"): Numerous terms added.

Section 3 ("Distribution Trees and RPF Check"): Changed by the addition of the new material in Section 3.6. See Appendix C.1.2, Item 1.

Section 8 ("Other IS-IS Considerations"): Changed by the addition of Sections 8.1, 8.2, 8.3, and 8.4. See Appendix C.1.2 -- Items 2, 3, 4, and 5, respectively.

Section 9 ("Updates to RFC 7177 (Adjacency)": Changes and additions to [RFC7177] to support E-L1FS. See Appendix C.1.2, Item 2.

Section 12 ("IANA Considerations"): Changed by the addition of material in Section 12.2. See Appendix C.1.2, Item 7.

Section 13 ("Security Considerations"): Minor changes in the RFCs listed.

C.1.2. Additions

This document contains the following material not present in [RFC7180]:

1. Support for an alternative Reverse Path Forwarding Check (RPFC), along with considerations for deciding between the original [RFC6325] RPFC and this alternative RPFC. This alternative RPFC was originally discussed on the TRILL WG mailing list in <http://www.ietf.org/mail-archive/web/trill/current/msg01852.html> and subsequent messages (Section 3.6).

2. Mandatory E-L1FS [RFC7356] support (Sections 8.1 and 9).
3. Recommendations concerning control packet priorities (Section 8.2).
4. Implementation requirements concerning unknown IS-IS PDU types (Section 8.3).
5. Specification of an optional Nickname Flags APPsub-TLV and an ingress flag within that APPsub-TLV (Section 8.4).
6. Update to the TRILL Header to allocate a Color bit (Section 10.1), and update to the optional TRILL Header Extension flags word to allocate a 2-bit Extended Color field (Section 10.2).
7. Some new IANA Considerations in Section 12.2, including reservation of nicknames for use as examples in documentation.
8. A new "Appointed Forwarder Status Lost Counter" section (Section 11 of this document) that loosens the mandatory update requirements specified in [RFC6325].
9. Informative Appendix A on the life cycle of a TRILL port.
10. A new Appendix B containing example TRILL PDUs.
11. Recommendation to use the Purge Originator Identification TLV (Section 8.6).

C.1.3. Deletions

This document omits the following material that was present in [RFC7180]:

1. All updates to [RFC6327] that occurred in [RFC7180]. These have been rolled into [RFC7177], which obsoletes [RFC6327]. However, new updates to [RFC7177] are included (see Appendix C.3).
2. All updates to [RFC6439]. These have been rolled into [RFC6439bis], which is intended to obsolete [RFC6439].

C.2. Changes to RFC 6325

This document contains many normative updates to [RFC6325], some of which were also in [RFC7180], which this document replaces. These changes include the following:

1. Changing nickname allocation to ignore conflicts with RBridges that are IS-IS unreachable.
2. Fixing errors: [Err3002], [Err3003], [Err3004], [Err3052], [Err3053], and [Err3508].
3. Changing the requirement to use the RPF check described in [RFC6325] for multi-destination TRILL Data packets by providing an alternative stronger RPF check.
4. Adoption of the change of the CFI bit, which was required to be zero in the inner frame, to the DEI bit, which is obtained from inner frame ingress or creation.
5. Requiring that all RBridges support E-L1FS FS-LSP flooding.
6. Reducing the variable-length TRILL Header extensions area to one optional flags word. The Extension Length field (called "Op-Length" in [RFC6325]) is reduced to 1 bit that indicates whether the flags word is present. The rest of that Length field is now reserved.
7. Changing the mandatory Appointed Forwarder Status Lost Counter increment provisions, as specified in Section 11.

C.3. Changes to RFC 7177

All of the updates to [RFC7177] herein are in Section 9. Basically, this document requires that a Scope Flooding Support TLV [RFC7356] appear in all Hellos and that TRILL switches retain in their adjacency state the information received in that TLV.

C.4. Changes to RFC 7179

The updates to [RFC7179] herein are in Sections 10.2 and 10.3.

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