

Internet Engineering Task Force (IETF)
Request for Comments: 8361
Updates: 6325
Category: Standards Track
ISSN: 2070-1721

W. Hao
Y. Li
Huawei Technologies
M. Durrani
Equinix
S. Gupta
IP Infusion
A. Qu
MediaTec
April 2018

**Transparent Interconnection of Lots of Links (TRILL):
Centralized Replication for Active-Active
Broadcast, Unknown Unicast, and Multicast (BUM) Traffic**

Abstract

In Transparent Interconnection of Lots of Links (TRILL) active-active access, a Reverse Path Forwarding (RPF) check failure issue may occur when using the pseudo-nickname mechanism specified in RFC 7781. This document describes a solution to resolve this RPF check failure issue through centralized replication. All ingress Routing Bridges (RBridges) send Broadcast, Unknown Unicast, and Multicast (BUM) traffic to a centralized node with unicast TRILL encapsulation. When the centralized node receives the BUM traffic, it decapsulates the packets and forwards them to their destination RBridges using a distribution tree established per the TRILL base protocol (RFC 6325). To avoid RPF check failure on an RBridge sitting between the ingress RBridge and the centralized replication node, some change in the RPF calculation algorithm is required. RPF checks on each RBridge MUST be calculated as if the centralized node was the ingress RBridge, instead of being calculated using the actual ingress RBridge. This document updates RFC 6325.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <https://www.rfc-editor.org/info/rfc8361>.

Copyright Notice

Copyright (c) 2018 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

Table of Contents

1. Introduction	2
2. Conventions Used in This Document	3
3. Centralized Replication Solution Overview	4
4. Frame Duplication from Remote RBridge	6
5. Local Forwarding Behavior on Ingress RBridge	6
6. Loop Prevention among RBridges in an Edge Group	8
7. Centralized Replication Forwarding Process	9
8. BUM Traffic Load-Balancing among Multiple Centralized Nodes	10
9. Coexisting with the CMT Solution (RFC 7783)	11
10. Network Upgrade Analysis	12
11. TRILL Protocol Extensions	13
11.1. "R" and "C" Flag in the Nickname Flags APPsub-TLV	13
12. Security Considerations	14
13. IANA Considerations	14
14. References	15
14.1. Normative References	15
14.2. Informative References	16
Acknowledgments	17
Authors' Addresses	17

1. Introduction

The IETF TRILL protocol [RFC6325] provides multipath data forwarding that is loop free and per-hop based with minimum configuration. TRILL uses IS-IS [RFC6165] [RFC7176] as its control plane routing protocol and defines a TRILL-specific header for user data.

Customer Equipment (CE) devices can be multihomed to a set of edge RBridges forming an edge group where active-active service can be provided. In that case, all of the uplinks from a CE are handled via a Local Active-Active Link Protocol (LAALP) [RFC7379] such as Multi-

Chassis Link Aggregation (MC-LAG) or Distributed Resilient Network Interconnect (DRNI) [IEEE802.1AX]. An active-active flow-based load-sharing mechanism can achieve better load-balancing and high reliability. A CE device can be a Layer 3 (L3) end system by itself or a bridge switch through which L3 end systems access the TRILL campus.

In active-active access, the pseudo-nickname solution in [RFC7781] can be used to avoid Media Access Control (MAC) flip-flop on remote R Bridges. The basic idea is to use a virtual R Bridge (RBv) with a single pseudo-nickname to represent an edge group. Any member R Bridge of that edge group uses this pseudo-nickname rather than its own nickname as the ingress nickname when it injects TRILL data frames to the TRILL campus. The use of the nickname solves the address flip-flop issue by setting the nickname learned by a remote R Bridge to be the pseudo-nickname. However, it introduces another issue of incorrect packet dropping as follows: When a pseudo-nickname is used by an edge R Bridge as the ingress nickname to forward BUM traffic, any R Bridges (RBn) sitting between the ingress R Bridge and the distribution tree root will treat the traffic as if it were ingressed from the RBv. If the same distribution tree is used by different edge R Bridges of the same RBv, the traffic may arrive at some RBn from different ports. Then, the Reverse Path Forwarding (RPF) check required by TRILL [RFC6325] fails, and the BUM traffic received on unexpected ports will be dropped by RBn.

This document specifies a centralized replication solution for BUM traffic forwarding to resolve the issue of incorrect packet drop caused by the RPF check failure in the virtual R Bridge case. The basic idea is that all ingress R Bridges send BUM traffic to a centralized node, which MUST be a distribution tree root, using unicast TRILL encapsulation. When the centralized node receives the packets, it decapsulates and forwards them to their destination R Bridges using a distribution tree established as per the TRILL base protocol. This document updates [RFC6325]; per [RFC6325], multi-destination traffic is ingressed to a multi-destination TRILL data packet. However, per this document, when using the centralized replication feature, multi-destination traffic is initially ingressed to a unicast TRILL data packet.

2. Conventions Used in This Document

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 abbreviations and terminology in [RFC6325] are used herein with the following additions:

BUM:	Broadcast, Unknown unicast, and Multicast
CE:	Customer Equipment (as in [RFC7783]), as relates to a device (end station or bridge). The device can be either physical or virtual equipment.
Data Label:	VLAN or Fine-Grained Labeled (FGL) [RFC7172]
DF:	Designated Forwarder [RFC7781]
FGL:	Fine-Grained Label [RFC7172]
LAALP:	Local Active-Active Link Protocol [RFC7379]
MAC flip flop:	A problem where the attachment point of a MAC address appears to a remote switch to keep changing. See Section 3.3 of [RFC7379].
MC-LAG:	Multi-Chassis Link Aggregation
RPF:	Reverse Path Forwarding

3. Centralized Replication Solution Overview

When an edge RBridge receives BUM traffic from a CE device, it uses unicast TRILL encapsulation instead of multicast encapsulation to send the packets to a centralized node. The centralized node **MUST** be a distribution tree root. Distribution tree roots are normally chosen to be high-capacity core RBridges with many high-bandwidth adjacencies. This constraint makes it practical, as described below, to support centralized replication with only software changes to transit RBridges.

The TRILL header of the unicast TRILL encapsulation contains an "ingress RBridge nickname" field and an "egress RBridge nickname" field [RFC6325]. If the ingress RBridge receives the BUM packet from a port that is in an active-active edge group using [RFC7781], it sets the ingress RBridge nickname to be the pseudo-nickname rather than its own nickname to avoid MAC flip-flop (see Section 3.3 of [RFC7379]) on remote RBridges. The egress RBridge nickname is set to a special nickname of the centralized node that is used to differentiate the centralized replication purpose unicast TRILL encapsulation from a normal unicast TRILL encapsulation. This special nickname is called an "R-nickname".

When the centralized RBridge receives a unicast TRILL-encapsulated packet with its R-nickname as the egress nickname, it decapsulates the packet. Then, the centralized RBridge replicates and forwards the BUM packet to the packet's destination RBridges using one of the distribution trees established per the TRILL base protocol [RFC6325]. It MUST use a distribution tree whose tree root is the centralized RBridge itself. (An RBridge may be the root of more than one tree.) When the centralized RBridge forwards the BUM traffic, it simply sends it on the distribution tree as if it were a locally ingressed frame, except that the ingress nickname remains the same as that in the packet it received to ensure that the MAC address learning by all egress RBridges is bound to the pseudo-nickname.

When the replicated packet is forwarded by each RBridge along the distribution tree starting from the centralized node, an RPF check is performed per [RFC6325]. For any RBridge sitting between the ingress RBridge and the centralized replication node, the incoming port of such a BUM packet should be the centralized-node-facing port, as the multicast traffic always comes from the centralized node in this solution. However, the RPF port as the result of distribution tree calculation as specified in [RFC6325] will be the real ingress RBridge-facing port, as it uses the edge group's virtual RBridge as the ingress RBridge, so the RPF check will fail.

To solve this problem, some change in the RPF test is required. In this case, the RPF calculation on each RBridge should use the centralized node as the ingress RBridge for each tree for which that node is the root instead of the real ingress virtual RBridge to perform the calculation. As a result, the RPF check will accept traffic on the centralized-node-facing port of the RBridge for multi-destination traffic. This prevents incorrect frame drops by the RPF check.

The change in the actual RPF check on a received multi-destination TRILL data packet is easy. The RPF check from [RFC6325] is a check to see if a triple of {ingress nickname, tree, receiving RBridge port} is allowed. (The tree is indicated by the nickname of its root, which is stored in the TRILL Header "egress nickname" field.) When determining the RPF check, if "ingress nickname" is using centralized replication (indicated by a C-nickname, see Section 9), then the check is based on distribution from the tree root. If "ingress nickname" is not using centralized replication, then the check is based on distribution from the RBridge having the ingress nickname.

To differentiate the centralized replication unicast TRILL encapsulation from normal unicast TRILL encapsulation, the R-nickname is introduced for centralized replication. When the centralized node

receives unicast TRILL encapsulation traffic with the egress nickname R-nickname, it decapsulates the packet and then forwards the packet to the destination RBridges through a distribution tree for which it is the root by re-encapsulation as aforementioned. In TRILL, RBridges can hold multiple nicknames, so the centralized RBridge simply obtains another nickname to use as the R-nickname. The centralized RBridge or RBridges should announce their R-nickname to all TRILL campuses through the TRILL Link State PDU (LSP) extension specified in Section 11.

4. Frame Duplication from Remote RBridge

Frame duplication may occur when a remote host sends a multi-destination frame to a local CE that has an active-active connection to the TRILL campus. To avoid the local CE receiving multiple copies from a remote RBridge, the Designated Forwarder (DF) mechanism is supported for egress-direction multicast traffic.

The DF election mechanism [RFC7781] allows only one port of one RBridge in an active-active group to forward multicast traffic from the TRILL campus to the local access side for each VLAN. The basic idea of using DF is to elect one RBridge per VLAN from an edge group to be responsible for egressing the BUM traffic. [RFC7781] describes the DF election mechanism among member RBridges involved in an edge group.

If the DF election mechanism is used for frame-duplication prevention, access ports on an RBridge are categorized as one of three types: non-group, group DF port, and group non-DF port. The last two types can be called group ports. Each of the group ports is associated with a pseudo-nickname. If consistent nickname allocation to edge group RBridges is used, it is possible that the same pseudo-nickname is associated with more than one port on a single RBridge. A typical scenario is that CE1 is connected to RB1 and RB2 by LAALP1, whereas CE2 is connected to RB1 and RB2 by LAALP2. In order to conserve the number of pseudo-nicknames used, member ports for both LAALP1 and LAALP2 on RB1 and RB2 are all associated with the same pseudo-nickname.

5. Local Forwarding Behavior on Ingress RBridge

When an ingress RBridge (RB1) receives BUM traffic from a local active-active connected CE (CE1) device, the traffic will be injected into the TRILL campus with TRILL encapsulation; it will be replicated and forwarded to all destination RBridges through central replication, including the ingress RBridge itself, along a TRILL

distribution tree. To avoid the traffic looping back to the original sender CE, an ingress nickname of the CE group's pseudo-nickname is used for traffic filtering.

However, if there are two CEs, say CE1 and CE2, connecting to the ingress RB1 and each associated with the same pseudo-nickname, RB1 needs to locally replicate and forward to CE2, because another copy of the BUM traffic between CE1 and CE2 through the TRILL campus will be blocked by the traffic filtering.

If CE1 and CE2 are not associated with the same pseudo-nickname, the copy of the BUM traffic between CE1 and CE2 through the TRILL campus won't be blocked by the traffic filtering. To avoid duplicated traffic on receiver CE, there cannot be local replicated BUM traffic between these two CEs on ingress RB1.

In summary, to ensure correct BUM traffic forwarding behavior for each CE, the local replication behavior on the ingress RBridge is as follows:

1. Replicate to the active-active group ports associated with the same pseudo-nickname as that associated with the incoming port.
2. Do not replicate to active-active group ports associated with other pseudo-nicknames.
3. Do not replicate to non-edge-group ports.

The above local forwarding behavior on the ingress RBridge of RB1 can be called "centralized replication local forwarding behavior A".

If ingress RBridge RB1 itself is the centralized replication node, BUM traffic injected by RB1 into the TRILL campus won't loop back to RB1. In this case, the local forwarding behavior is called centralized replication local forwarding behavior B. Behavior B on RB1 is as follows:

1. Local replication to the ports associated with the same pseudo-nickname as that associated with the incoming port.
2. Local replication to the group DF port associated with different pseudo-nicknames. Do not replicate to group non-DF ports associated with different pseudo-nicknames.
3. Local replication to non-edge-group ports.

6. Loop Prevention among R Bridges in an Edge Group

If a CE sends a BUM packet through a DF port to an ingress R Bridge, that R Bridge will forward that packet to all or a subset of the other R Bridges that only have non-DF ports for that active-active group. Because BUM traffic forwarding to non-DF ports isn't allowed, in this case, the frame won't loop back to the CE.

If a CE sends a BUM packet through a non-DF port to an ingress R Bridge, say RB1, then RB1 will forward that packet to other R Bridges that have a DF port for that active-active group. In this case, the frame will loop back to the CE and the traffic split-horizon filtering mechanism is used to avoid looping back among R Bridges in the edge group.

This split-horizon mechanism relies on the ingress nickname field in the TRILL header to check if a packet's egress port belongs to the same active-active group as the packet's incoming port to the TRILL campus.

When the ingress R Bridge receives BUM traffic from an active-active connected CE device, the traffic will be sent through the TRILL campus with TRILL encapsulation to a centralized R Bridge. There it will be replicated and forwarded to its destination R Bridges, which include the ingress R Bridge itself, through a TRILL distribution tree. If the same pseudo-nickname is used for two active-active access CEs as the ingress nickname, an egress R Bridge can use that nickname to filter traffic forwarding to all local CEs. In this case, the traffic between these two CEs goes through the local R Bridge and another copy of the traffic from the TRILL campus is filtered. If different ingress nicknames are used for two connecting CE devices, the access ports connecting to these two CEs should be isolated from each other. The BUM traffic between these two CEs should go through the TRILL campus; otherwise, the destination CE connected to same R Bridge with the sender CE will receive two copies of the traffic.

7. Centralized Replication Forwarding Process

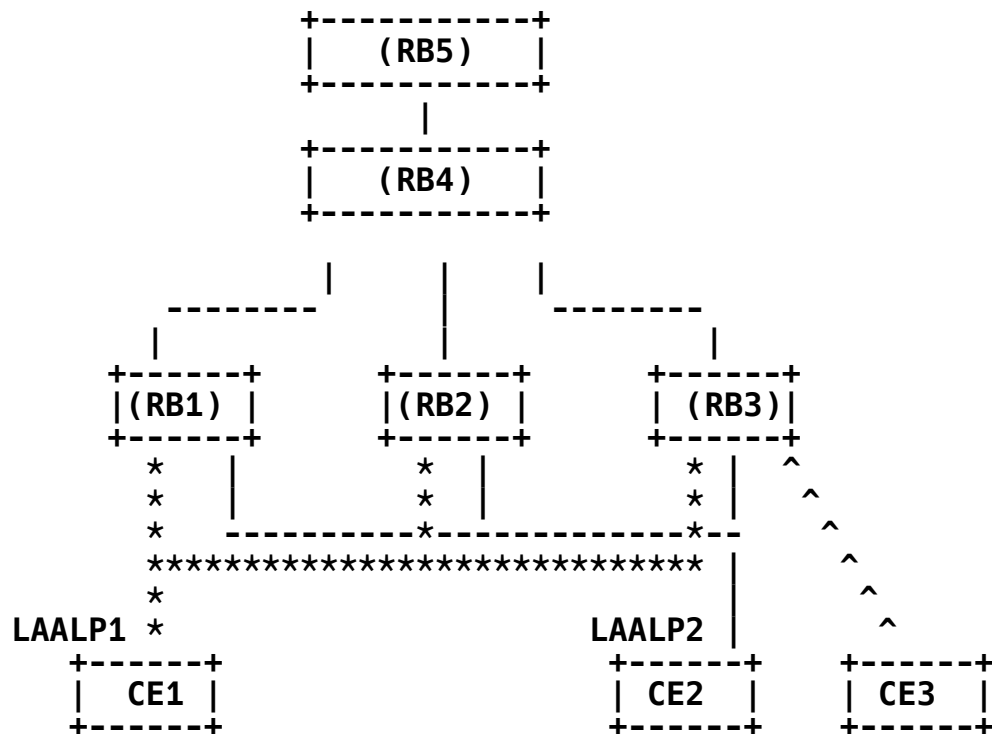


Figure 1: TRILL Active-Active Access

Note: The asterisk line, hyphen & vertical bar line, and circumflex line in this figure indicate the connection of the various CEs to the various RBs.

Assuming the centralized replication solution is used in the example network of above Figure 1: RB5 is the distribution tree root and centralized replication node; CE1 and CE2 are active-active accessed to RB1, RB2, and RB3 through LAALP1 and LAALP2, respectively; and CE3 is single-homed to RB3. The RBridge's own nicknames of RB1 to RB5 are nick1 to nick5, respectively. RB1, RB2, and RB3 use the same pseudo-nickname for LAALP1 and LAALP2; that pseudo-nickname is P-nick. The R-nickname on the centralized replication node of RB5 is S-nick.

The BUM traffic forwarding process from CE1 to CE2 and CE3 is as follows:

1. CE1 sends BUM traffic to RB3.
 2. RB3 replicates and sends the BUM traffic to CE2 locally. RB2 also sends the traffic to RB5 using unicast TRILL encapsulation. In the TRILL Header, the ingress nickname is set as P-nick and the egress nickname is set as S-nick.
 3. RB5 decapsulates the unicast TRILL data packet. Then, it uses a distribution tree for which it is the root to forward the packet as a multi-destination TRILL data packet. The egress nickname in the multi-destination TRILL Header is the nick5 and the ingress nickname is still P-nick. If RB3 had sent the unicast to some nickname that was not an R-nickname, the packet would not be re-encapsulated. If it is sent to an R-nickname that is not a tree root, it either will not be forwarded at all or, if it is re-encapsulated and forwarded, will be subject to incorrect pruning and will not be delivered to all of its intended recipients.
 4. RB4 receives multicast TRILL traffic from RB5. The incoming traffic port is the up port facing the distribution tree root. RB4's RPF check will be correct based on the changed RPF port calculation algorithm in this document. After the RPF check is performed, it forwards the traffic to all other egress RBridges (RB1, RB2, and RB3).
 5. RB3 receives multicast TRILL traffic from RB4. It decapsulates the multi-destination TRILL data packet. Because the ingress nickname of P-nick is equivalent to the nickname of local LAALPs connecting to CE1 and CE2, RB3 doesn't forward the traffic to CE1 and CE2 to avoid a duplicated frame. RB3 only forwards the packet to CE3.
 6. RB1 and RB2 receive multicast TRILL traffic from RB4. The forwarding process is similar to the process on RB3, i.e., because the ingress nickname of P-nick is equivalent to the nickname of the local LAALPs connecting CE1 and CE2, they also don't forward the traffic to local CE1 and CE2.
8. BUM Traffic Load-Balancing among Multiple Centralized Nodes

To support unicast TRILL encapsulation BUM traffic load-balancing, multiple centralized replication nodes can be deployed and the traffic can be spread over these nodes based on data label (VLAN or FGL). Furthermore, if it was desirable for a centralized node to be

sent more of this BUM traffic, it could hold two or more R-nicknames. The share of BUM traffic it would receive would be proportional to the number of R-nicknames it held.

Assuming there are k different R-nicknames held by centralized nodes in a TRILL campus, the VLAN-based (or FGL-based [RFC7172]) load-balancing algorithm used by an ingress active-active access RBridge is as follows:

1. All R-nicknames are ordered and numbered from 0 to $k-1$ in ascending order, treating the nicknames as unsigned 16-bit integers.
2. For data label ID m , choose the R-nickname whose index is given by $(m \bmod k)$ as egress nickname for BUM traffic unicast TRILL encapsulation.

For example, there are three R-Nicknames (RNs). The RNs will be ordered RN0 to RN2. Assuming there are five VLANs from VLAN ID1 to ID5 spreading among edge RBridges, the traffic in VLAN1 will go to RN1, VLAN2 will go to RN2, and so on.

When an ingress RBridge participating in an active-active connection receives BUM traffic from a local CE, the RBridge decides which R-nickname to send the traffic to based on the VLAN-based load-spreading algorithm; thus, data-label-based load-balancing for the BUM traffic can be achieved using multiple centralized nodes/multiple R-nicknames.

9. Coexisting with the CMT Solution (RFC 7783)

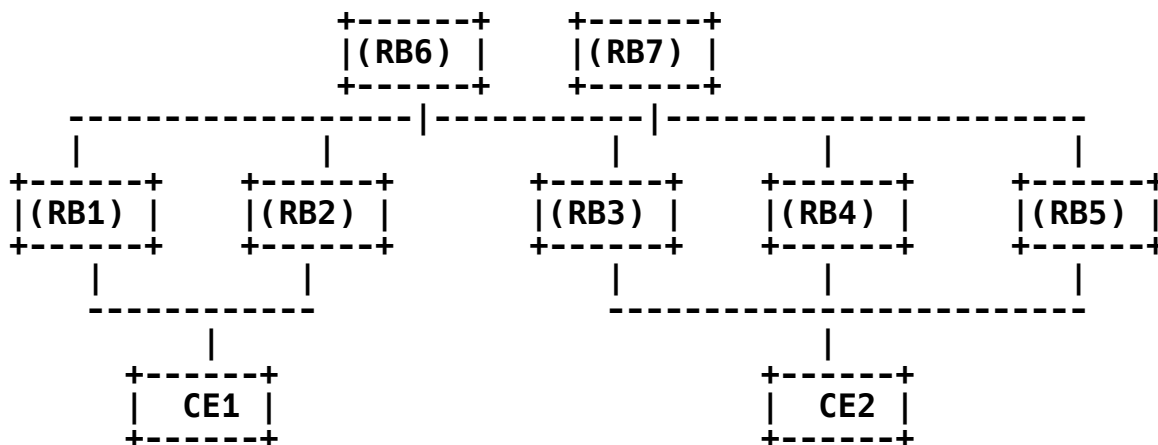


Figure 2: CMT and Centralized Replication Coexisting Scenario

Both the centralized replication solution and the Coordinated Multicast Trees (CMT) solution from [RFC7783] rely on using pseudo-nicknames to avoid MAC flip-flop on remote RBridges. These two solutions can coexist in a single TRILL campus. Each solution can be selected by each active-active edge group of RBridges independently.

As illustrated in Figure 2, RB1 and RB2 use CMT for CE1's active-active access; RB3, RB4, and RB5 use the centralized replication for CE2's active-active access.

For the centralized replication solution, edge group RBridges MUST announce the local pseudo-nickname using the Nickname Flags APPsub-TLV with C flag set. A nickname with the C flag set is called a "C-nickname". A transit RBridge will perform the centralized replication-specific RPF check algorithm if it receives TRILL data packets with a C-nickname as the ingress nickname.

An edge group using CMT [RFC7783] MUST NOT set the C flag on the pseudo-nickname it is using. This is already mandatory behavior because any RBridge originating a Nickname Flags APPsub-TLV is required by [RFC7780] to set any flag bit it does not know about to zero. If an edge RBridge using CMT [RFC7783] nevertheless set the C-bit for an edge group pseudo-nickname, it is very likely that BUM traffic encapsulated with that nickname as ingress would be incorrectly pruned early in its distribution and would, thus, reach few (possibly none) of its intended targets. To avoid confusion, a pseudo-nickname MUST NOT be shared between a centralized replication edge group and a CMT-based edge group.

10. Network Upgrade Analysis

Centralized nodes will typically need software and hardware upgrades to support centralized replication, which stitches together the TRILL unicast traffic decapsulation process and the process of normal TRILL multicast traffic forwarding along the distribution tree.

Active-active connection edge RBridges will typically need software and hardware upgrades to support unicast TRILL encapsulation for BUM traffic; the process is similar to other head-end replication processes.

Transit nodes typically need only a software upgrade to support the changed RPF port calculation algorithm.

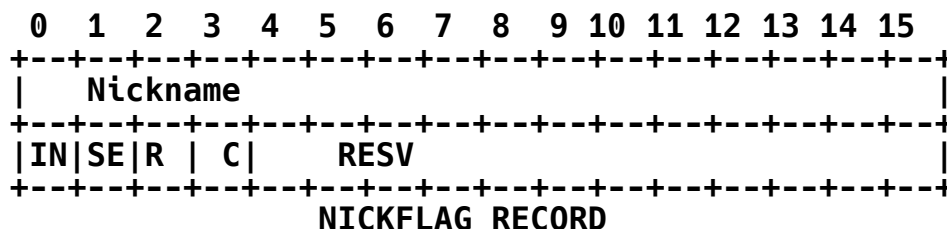
11. TRILL Protocol Extensions

Two new flags, "R" and "C", are specified in the Nickname Flags APPsub-TLV [RFC7780]. A nickname with the R flag set is called an "R-nickname" and a nickname with the C flag set is called a "C-nickname". The R-nickname is a specialized nickname attached to a centralized node to differentiate unicast TRILL-encapsulated BUM traffic from normal unicast TRILL traffic. The C-nickname flag is set on the pseudo-nickname for each edge group that uses the centralized replication. A C-nickname is a specialized pseudo-nickname for which transit RBridges perform a different RPF check algorithm for TRILL data packets with the C-nickname in the ingress nickname field.

When active-active edge RBridges use centralized replication to forward BUM traffic, the R-nickname is used as the egress nickname and the C-nickname is used as ingress nickname in the TRILL header for the unicast TRILL encapsulation of BUM traffic.

11.1. "R" and "C" Flag in the Nickname Flags APPsub-TLV

If this APPsub-TLV is being advertised by an RBridge that does not have the nickname appearing in the Nickname Flags APPsub-TLV, the R and C flag bits in the APPsub-TLV MUST be treated as if they were zero. If an RBridge that is not a distribution tree root advertises an R-nickname, that nickname MUST NOT be treated as an R-nickname but rather as an ordinary nickname; that is, the R-nickname flag is ignored for all purposes if the nickname is held by an RBridge that is not a tree root.



- o R = If the R flag is one, it indicates that the advertising TRILL switch holding Nickname is a centralized replication node, and Nickname is used as egress nickname for edge group RBridges to inject BUM traffic into the TRILL campus when the edge group RBridges use this centralized replication solution for active-active access. If the R flag is zero, that nickname will not be used for that purpose.

- o C = If C flag is one, it indicates that the TRILL traffic with this nickname as an ingress nickname requires the special RPF check algorithm specified in Section 3. If the C flag is zero, that nickname will not be used for that purpose.

Due to errors or due to transient inconsistent LSPs when the link state database is converging after a configuration change or the like, it is possible for there to be inconsistent Nickname Flags APPsub-TLVs for the same nickname. In this case, it is RECOMMENDED that the nickname be treated as if the R / C flag were set if any Nickname Flags APPsub-TLV for that nickname has the R / C flag set.

12. Security Considerations

This document does not introduce any extra security risks. A rogue RBridge that is a tree root can attract traffic by advertising an R-nickname. However, this does not represent a substantial increase in risk as RBridges could cause problems in a number of other ways by advertising low-cost adjacencies or making themselves the highest priority tree root or the like. In general, the protection against an untrusted device acting as an RBridge and wrecking havoc is to use IS-IS authentication [RFC5310] and configure and administer the TRILL campus so that only trusted RBridges have the authentication key.

For general TRILL security considerations, see [RFC6325]. For security considerations related to pseudo-nickname active-active, see [RFC7781].

13. IANA Considerations

IANA has assigned two bits in the Nickname Flags APPsubTLV flags for the R and C bits discussed in Section 11.1 and update the "NickFlags Bits" subregistry of the "Transparent Interconnection of Lots of Links (TRILL) Parameters" registry as follows:

Bit	Mnemonic	Description	Reference
2	R	Replication Nickname	[RFC8361]
3	C	Special RPF Check	[RFC8361]

14. References

14.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [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, <<https://www.rfc-editor.org/info/rfc5310>>.
- [RFC6165] Banerjee, A. and D. Ward, "Extensions to IS-IS for Layer-2 Systems", RFC 6165, DOI 10.17487/RFC6165, April 2011, <<https://www.rfc-editor.org/info/rfc6165>>.
- [RFC6325] Perlman, R., Eastlake 3rd, D., Dutt, D., Gai, S., and A. Ghanwani, "Routing Bridges (R Bridges): Base Protocol Specification", RFC 6325, DOI 10.17487/RFC6325, July 2011, <<https://www.rfc-editor.org/info/rfc6325>>.
- [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, <<https://www.rfc-editor.org/info/rfc7172>>.
- [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, <<https://www.rfc-editor.org/info/rfc7176>>.
- [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, <<https://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>>.

14.2. Informative References

- [RFC7781] Zhai, H., Senevirathne, T., Perlman, R., Zhang, M., and Y. Li, "Transparent Interconnection of Lots of Links (TRILL): Pseudo-Nickname for Active-Active Access", RFC 7781, DOI 10.17487/RFC7781, February 2016, <<https://www.rfc-editor.org/info/rfc7781>>.
- [RFC7379] Li, Y., Hao, W., Perlman, R., Hudson, J., and H. Zhai, "Problem Statement and Goals for Active-Active Connection at the Transparent Interconnection of Lots of Links (TRILL) Edge", RFC 7379, DOI 10.17487/RFC7379, October 2014, <<https://www.rfc-editor.org/info/rfc7379>>.
- [RFC7783] Senevirathne, T., Pathangi, J., and J. Hudson, "Coordinated Multicast Trees (CMT) for Transparent Interconnection of Lots of Links (TRILL)", RFC 7783, DOI 10.17487/RFC7783, February 2016, <<https://www.rfc-editor.org/info/rfc7783>>.
- [IEEE802.1AX] IEEE, "IEEE Standard for Local and metropolitan area networks -- Link Aggregation", IEEE 802.1AX, DOI 10.1109/IEEESTD.2017.7888436, March 2017, <<http://ieeexplore.ieee.org/document/7888436/>>.

Acknowledgments

The authors wish to acknowledge the important contributions of Donald Eastlake, Hongjun Zhai, Xiaomin Wu, Liang Xia, and Francis Dupont.

Authors' Addresses

Weiguo Hao
Huawei Technologies
101 Software Avenue,
Nanjing 210012
China

Email: haoweiguo@huawei.com

Yizhou Li
Huawei Technologies
101 Software Avenue,
Nanjing 210012
China

Email: liyizhou@huawei.com

Muhammad Durrani
Equinix

Email: mdurrani@equinix.com

Sujay Gupta
IP Infusion
RMZ Centennial
Mahadevapura Post
Bangalore - 560048
India

Email: sujay.gupta@ipinfusion.com

Andrew Qu
MediaTec

Email: laodulaodu@gmail.com