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Experience with the LOADng routing protocol for LLNs draft-lavenu-lln-loadng-interoperability-report-01

Abstract

This document reports experience with the LOADng routing protocol for LLNs which is specified in the draft-clausen-lln-loadng internet draft. This report is providing information resulting from interoperability testing performed at Hitachi YRL facilities in Yokohama, Japan, from october 17th to october 19th 2011.

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1. Introduction

This document reports about the interoperability tests carried out at Hitachi YRL facilities in Yokohama, Japan, from october 17th to october 19th 2011 for different implementations of the LOADng (LLN On-demand Ad hoc Distance-vector - Next Generation) routing protocol.

Interoperability tests between LOADng Routers implemented on the basis of the draft-clausen-lln-loadng internet draft have been run mainly for the following purposes :

- Show evidence that interoperable LOADng implementations do exist.
- Clarify and improve the overall quality of the LOADng specification.
- Demonstrate that the final LOADng internet draft can be considered as a standalone specification allowing the development of interoperable implementations of LOADng.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

Additionally, this document uses the following terminology:

LOADng Router - A router which implements this routing protocol.

Destination - The address of a router or host, to which a route is sought discovered and maintained.

Originator - The address of a router, which seeks to discover and maintain a route to a Destination.

Forward Route - A route set up so as to send data packets from the Originator to the Destination. The Forward Route is set up when a LOADng Router forwards Route Reply (RREP) messages.

Reverse Route - A route set up so as to send data packets from the Destination to the Originator. The Reverse Route is set up when a LOADng Router forwards Route Request (RREQ) messages. It is used for forwarding RREP messages, as well as for forwarding data packets.

Route Cost - The sum of the Link Costs for the links that a RREQ or RREP has crossed.

Weak Link - A link which is marginally usable, i.e., MAY be used if no other links are available, but SHOULD be avoided if at all possible - even if it entails an ultimately longer path. As an example, a Weak Link might be defined as a link with a significant loss-rate.

This document employs the same notational conventions as in [RFC5444].

3. Implementations

Several LOADng implementations are currently available. This section

is listing the implementations that have been used to perform the interoperability tests this document is reporting about (listed in alphabetical order) :

Ecole Polytechnique : "LIX" - This implementation was jointly developed by Axel Colin de Verdiere, Jiazi Yi, Ulrich Herberg and Thomas Clausen of Ecole Ploytechnique's networking team. It consists of approximately 6000 lines of JAVA code running in a Mac OS environment. It supports RREQ, RREP, RREP-ACK and RERR generation, processing, forwarding and transmission.

Hitachi YRL 1 : "Hitachi 1" - This implementation was fully developed by Yuichi Igarashi of Hitachi YRL. It consists of 1589 lines of C code running in the Hitachi proprietary micro OS environment embedded in a 16MHz H8 micro processor. It supports RREQ, RREP, RREP-ACK and RERR generation, processing, forwarding and transmission.

Hitachi YRL 2 : "Hitachi 2" - This implementation was jointly developed by Nobukatsu Inomata of Hitachi ULSI Systems and Yoko Morii of Hitachi YRL. It consists of 1987 lines of C++ code running in a Mac OS environment. It supports RREQ, RREP, RREP-ACK generation, processing, forwarding and transmission, and RERR processing.

4. Interoperability Testing

This section is describing all the tests carried out between the implementations that are previously considered in this document.

4.1. Testbed configuration

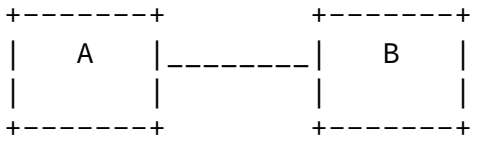
The testbed was composed of up to five LOADng Routers put together according to the different topologies described hereunder. The LOADng routing protocol were run over UDP, IPv4 and Ethernet. Wireshark packet sniffers, that have been modified to interpret LOADng control traffic, were used to monitor each single underlying link.

For each test, the initiation of the communication resulting in the generation of the first LOADng control traffic message is always triggered manually. In addition, RREP-ACK LOADng control messages were systematically expected from each LOADng Router upon reception of a RREP LOADng control message in order to allow the detection of unidirectional links.

4.2. 1-hop bidirectional route establishment

4.2.1. Topology

The testbed is composed of two LOADng Routers :



Routers A and B are embedding a different implementation of LOADng. This test was performed between all previously considered implementations.

This test suite consists in establishing a bidirectional route between LOADng Router A and LOADng Router B.

4.2.2. Forward Route and Reverse Route initial installation

For each implementation, this test aims to verifiy the initial installation of a bidirectional route (Forward Route and Reverse Route from A to B) within the LOADng Router routing tables (Routing Sets) through the effective generation and processing of LOADng control messages (RREQ, RREP, RREP-ACK).

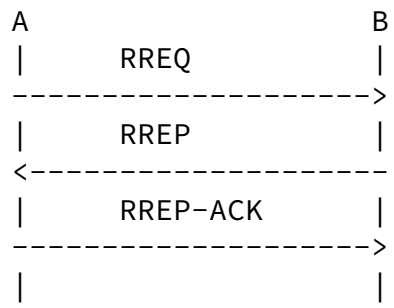
The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router B.

- Upon receiving the RREQ, LOADng Router B installs a new entry in

its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and sends an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREP, LOADng Router A installs a new entry in its Routing Set towards LOADng Router B (Forward Route from LOADng Router A to LOADng Router B) and sends an unicast RREP-ACK message to LOADng Router B.



4.2.3. Forward Route and Reverse Route updating

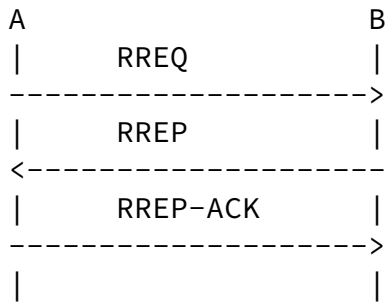
For each implementation, this test aims to verifiy the refreshment of a bidirectional route (Forward Route and Reverse Route from A to B) already installed within the LOADng Router routing tables (Routing Sets) through the effective generation and processing of LOADng control messages (RREQ, RREP, RREP-ACK).

The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router B.

- Upon receiving the RREQ, LOADng Router B updates the corresponding route (Reverse Route from LOADng Router B to LOADng Router A) already installed within its Routing Set and sends an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREP, LOADng Router A updates the corresponding route (Forward Route from LOADng Router A to LOADng Router B) already installed within its Routing Set and sends an unicast RREP-ACK message to LOADng Router B.



4.2.4. Obtained results

The following table is summarizing the results obtained for the different combinations for which test 1 (Forward Route and Reverse Route initial installation) was performed :

	LIX	Hitachi 1	Hitachi 2
LIX	N/R	Pass	Pass
Hitachi 1	Pass	N/R	Pass
Hitachi 2	Pass	Pass	N/R

Table 1

The following table is summarizing the results obtained for the different combinations for which test 2 (Forward Route and Reverse Route updating) was performed :

	LIX	Hitachi 1	Hitachi 2
LIX	N/R	Pass	Pass
Hitachi 1	Pass	N/R	Pass
Hitachi 2	Pass	Pass	N/R

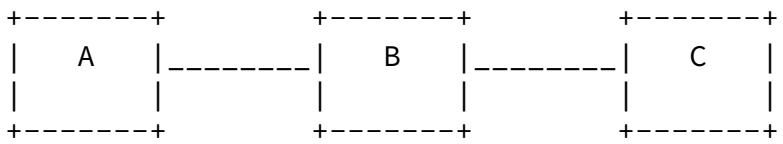
Table 2

4.3. 2-hop bidirectional route establishment

4.3.1. Topology

The testbed is composed of three LOADng Routers. Control traffic generated by either LOADng Router A towards LOADng Router C or LOADng Router C towards LOADng Router A has to be forwarded by LOADng Router

B :



This test suite consists in establishing a bidirectional route between LOADng Router A and LOADng Router C.

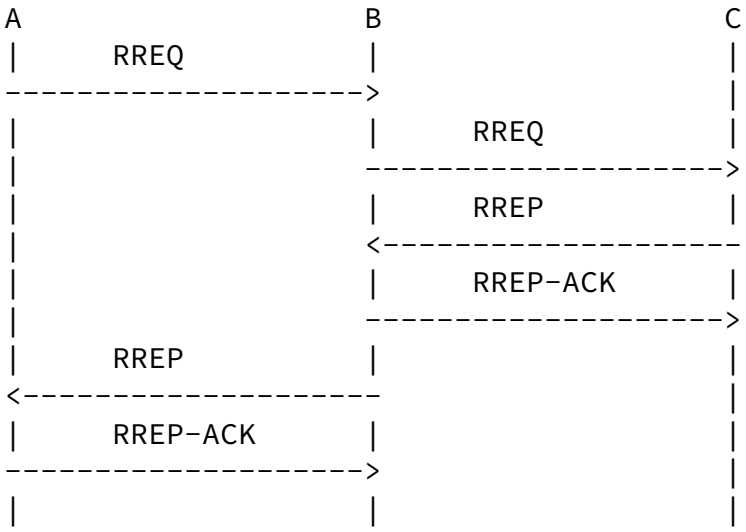
4.3.2. Forward Route and Reverse Route initial installation

This test aims to verify the initial installation of a bidirectional route (Forward Route and Reverse Route from A to C) within the LOADng Router routing tables (Routing Sets) through the effective forwarding of LOADng control traffic by LOADng Router B which is located between LOADng Router A and LOADng Router C. It is also verified that RREP-ACK messages are not forwarded by the LOADng Routers these messages are intended for.

The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router C.
- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.
- Upon receiving the RREQ, LOADng Router C installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router C to LOADng Router A) and a new entry towards LOADng Router B (Reverse route from LOADng Router C to LOADng Router B). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".
- Upon receiving the RREP, LOADng Router B installs a new entry in its Routing Set towards LOADng Router C (Forward Route from LOADng Router B to LOADng Router C), sends an unicast RREP-ACK message to LOADng Router C and forwards the RREP received previously.

- Upon receiving the RREP, LOADng Router A installs a new entry in its Routing Set towards LOADng Router B (Forward Route from LOADng Router A to LOADng Router B) and a new entry towards LOADng Router C (Forward Route from LOADng Router A to LOADng Router C). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.



4.3.3. Forward Route and Reverse Route updating

This test aims to verify the refreshment of a bidirectional route (Forward Route and Reverse Route from A to C) already installed within the LOADng Router routing tables (Routing Sets) through the effective forwarding of LOADng control traffic by LOADng Router B which is located between LOADng Router A and LOADng Router C.

The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router C.

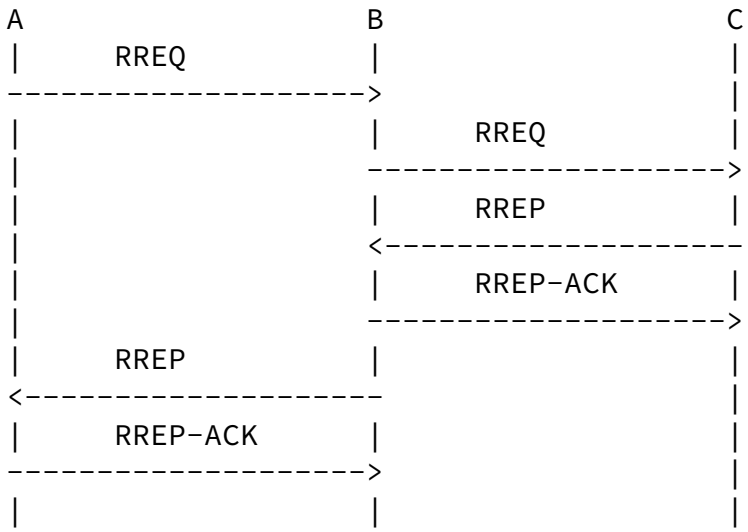
- Upon receiving the RREQ, LOADng Router B updates the corresponding route (Reverse Route from LOADng Router B to LOADng Router A) already installed within its Routing Set and forwards the received RREQ.

- Upon receiving the RREQ, LOADng Router C updates the corresponding routes (Reverse Routes from LOADng Router C to LOADng Router A and from LOADng Router C to LOADng Router B). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREP, LOADng Router B updates the corresponding route (Forward route from LOADng Router B to LOADng Router C), sends an unicast RREP-ACK message to LOADng Router C and forwards the RREP received previously.

- Upon receiving the RREP, LOADng Router A updates the corresponding routes (Forward routes from LOADng Router A to LOADng Router B and from LOADng Router A to LOADng Router C). The reception of the

RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.



4.3.4. Link breakage handling

This test aims to verify the proper generation and processing of a RERR message after an artificially created link breakage on an previously established bidirectional route.

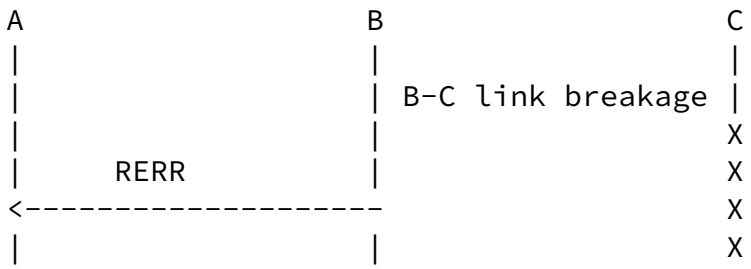
The expected message sequencing is as follows :

- A bidirectional route is already established between LOADng Routers A and C.

- At some time, link breakage is detected by LOADng Router B. Consequently, an unicast RERR message intended for LOADng Router A (here the assumption is made that the unsuccessful delivered data traffic would have been generated by LOADng Router A) is transmitted.

  Note : link breakage is provoked artificially and its detection by LOADng Router B is triggered manually (normally, this would be triggered by failure in sending data traffic intended for LOADng Router C).

- Upon receiving the RERR, LOADng Router A updates its Routing Set by invalidating the existing Forward Route from LOADng Router A to LOADng Router C.



4.3.5. Obtained results

The following table is summarizing the results obtained for the different combinations for which these test 1 (Forward Route and Reverse Route initial installation) and test 2 (Forward Route and Reverse Route updating) were performed :

A	B	C	Test 1	Test 2

Hitahci 1	LIX	Hitachi 2	Pass	Pass
Hitachi 2	LIX	Hitachi 1	Pass	Pass
LIX	Hitachi 1	Hitachi 2	Pass	Pass
Hitachi 2	Hitachi 1	LIX	Pass	Pass
LIX	Hitachi 2	Hitachi 1	Pass	Pass
Hitachi 1	Hitachi 2	LIX	Pass	Pass

Table 3

The following table is summarizing the results obtained for the different combinations for which these test 3 (Link breakage handling) was performed :

A	B	C	Test 3
Hitachi 1	LIX	LIX	Pass
LIX	Hitachi 1	LIX	Pass

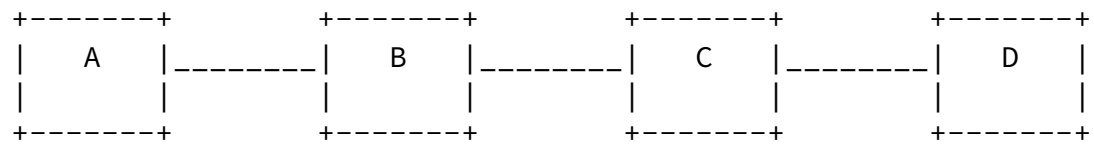
Table 4

4.4. 4-hop bidirectional route establishment

4.4.1. Topology

The testbed is composed of four LOADng Routers. Control traffic generated by either LOADng Router A towards LOADng Router D or LOADng

Router D towards LOADng Router A has to be forwarded by LOADng Routers B and C :



This test suite consists in establishing a bidirectional route between LOADng Router A and LOADng Router D.

4.4.2. Forward Route and Reverse Route initial installation

This test aims to verify the initial installation of a bidirectional route (Forward Route and Reverse Route from A to D) within the LOADng Router routing tables (Routing Sets) through the effective forwarding of LOADng control traffic by LOADng Routers B and C, which are located between LOADng Router A and LOADng Router D. It is also verified that RREP-ACK messages are not forwarded by the LOADng Routers these messages are intended for.

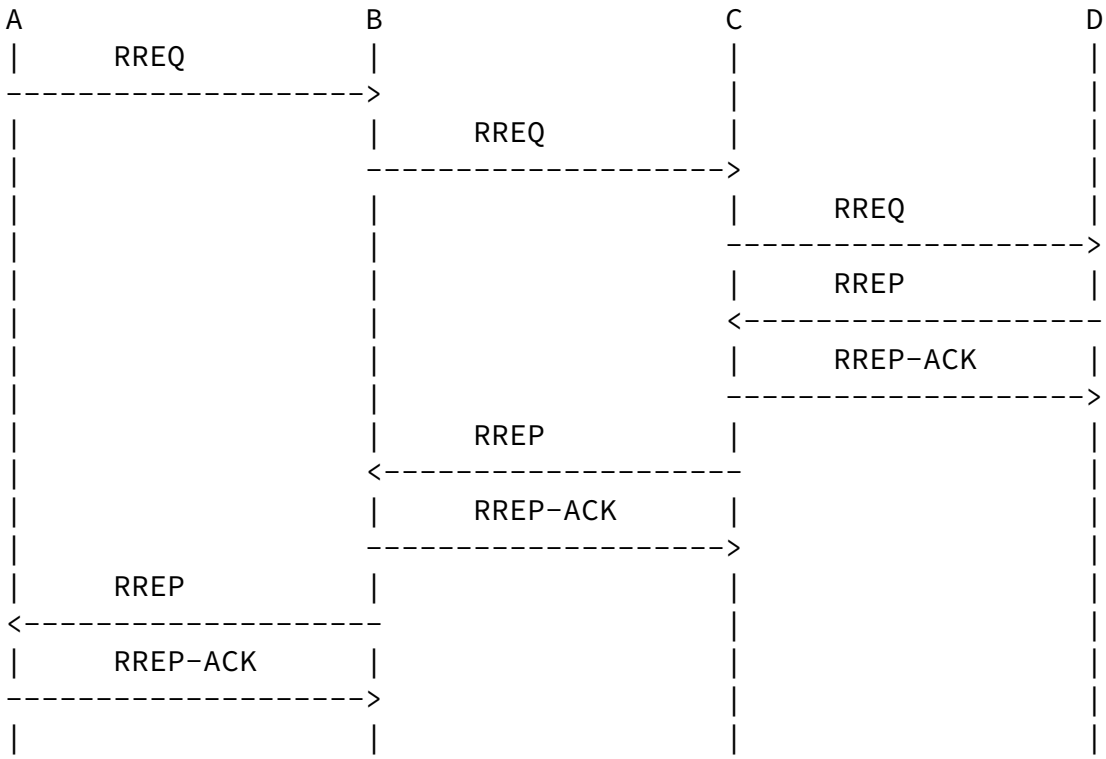
The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router D.
- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.
- Upon receiving the RREQ, LOADng Router C installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router C to LOADng Router A) and a new entry towards LOADng Router B (Reverse route from LOADng Router C to LOADng Router B) and forwards the received RREQ.
- Upon receiving the RREQ, LOADng Router D installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router D to LOADng Router A) and a new entry towards LOADng Router C (Reverse route from LOADng Router D to LOADng Router C). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".
- Upon receiving the RREP, LOADng Router C installs a new entry in its Routing Set towards LOADng Router D (Forward Route from LOADng Router C to LOADng Router D), sends an unicast RREP-ACK message to LOADng Router D and forwards the RREP received previously.

- Upon receiving the RREP, LOADng Router B installs a new entry in its Routing Set towards LOADng Router D (Forward Route from LOADng Router B to LOADng Router D) and a new entry towards LOADng Router C (Forward Route from LOADng Router B to LOADng Router C). An

unicast RREP-ACK message is also sent to LOADng Router C and the RREP received previously is forwarded.

- Upon receiving the RREP, LOADng Router A installs a new entry in its Routing Set towards LOADng Router B (Forward Route from LOADng Router A to LOADng Router B) and a new entry towards LOADng Router D (Forward Route from LOADng Router A to LOADng Router D). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.



4.4.3. Forward Route and Reverse Route updating

This test aims to verify the refreshment of a bidirectional route (Forward Route and Reverse Route from A to D) already installed within the LOADng Router routing tables (Routing Sets) through the effective forwarding of LOADng control traffic by LOADng Routers B and C which are located between LOADng Router A and LOADng Router D.

The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router D.

- Upon receiving the RREQ, LOADng Router B updates the corresponding route (Reverse Route from LOADng Router B to LOADng Router A) already installed within its Routing Set and forwards the received RREQ.

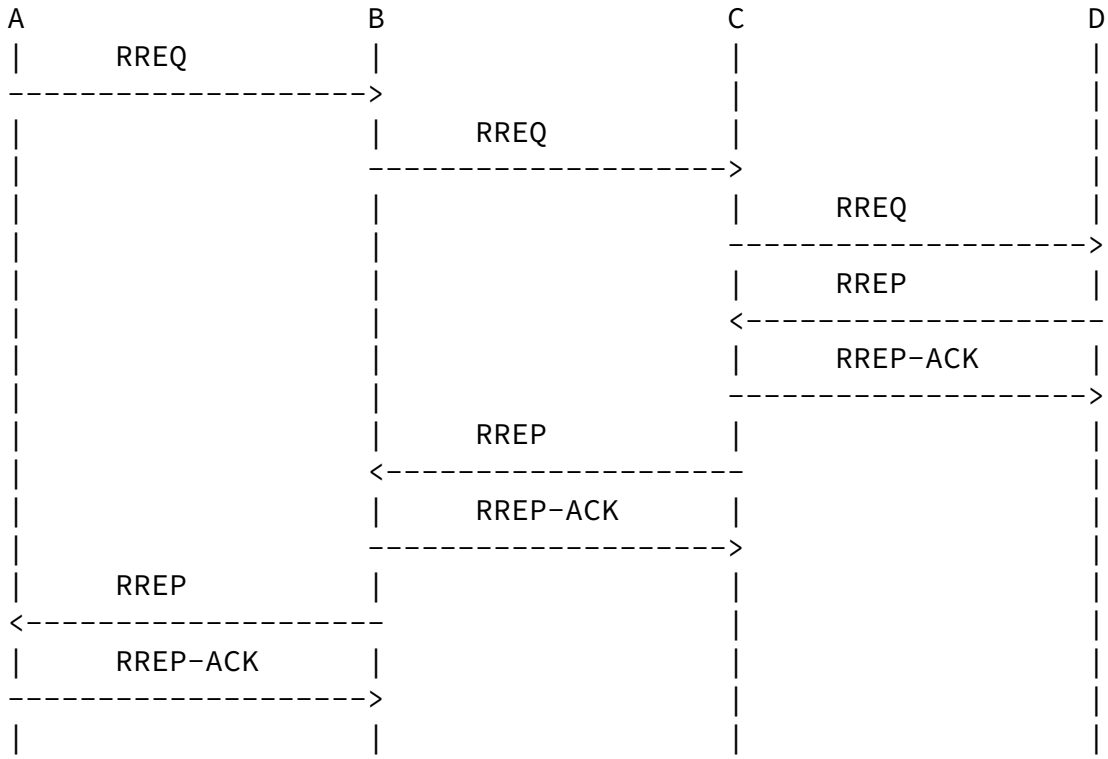
- Upon receiving the RREQ, LOADng Router C updates the corresponding routes (Reverse Routes from LOADng Router C to LOADng Router A and from LOADng Router C to LOADng Router B) already installed within its Routing Set and forwards the received RREQ.

- Upon receiving the RREQ, LOADng Router D updates the corresponding routes (Reverse Routes from LOADng Router D to LOADng Router A and from LOADng Router D to LOADng Router C) already installed within its Routing Set. The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREP, LOADng Router C updates the corresponding route (Forward Route from LOADng Router C to LOADng Router D), sends an unicast RREP-ACK message to LOADng Router D and forwards the RREP received previously.

- Upon receiving the RREP, LOADng Router B updates the corresponding routes (Forward Route from LOADng Router B to LOADng Router D and from LOADng Router B to LOADng Router C). An unicast RREP-ACK message is also sent to LOADng Router C and the RREP received previously is forwarded.

- Upon receiving the RREP, LOADng Router A updates the corresponding routes (Forward Route from LOADng Router A to LOADng Router B and from LOADng Router A to LOADng Router D). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.



4.4.4. Link breakage handling

This test aims to verify the proper generation, processing and forwarding of a RERR message after an artificially created link breakage on an previously established bidirectional route.

The expected message sequencing is as follows :

- A bidirectional route is already established between LOADng Routers A and D.

- At some time, link breakage is detected by LOADng Router C. Consequently, an unicast RERR message intended for LOADng Router A (here the assumption is made that the unsuccessful delivered data traffic would have been generated by LOADng Router A) is transmitted to LOADng Router B according to the Reverse Route from LOADng Router C to LOADng Router A computed previously.

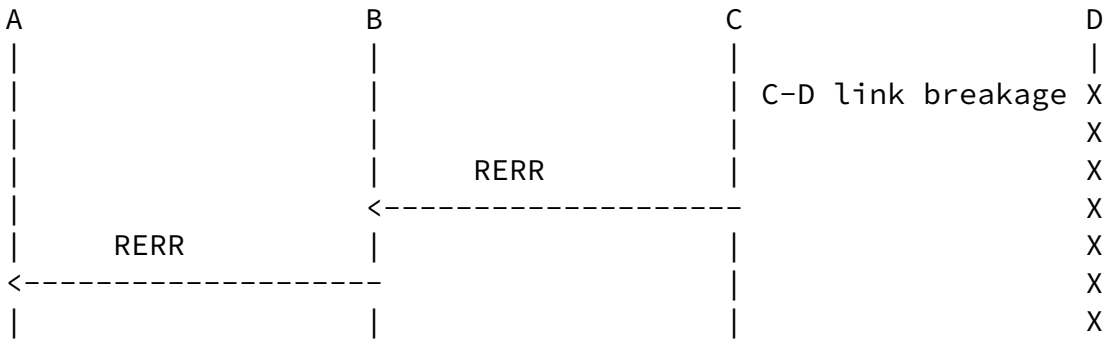
  Note : link breakage is provoked artificially and its detection by

LOADng Router C is triggered manually (normally, this would be triggered by failure in sending data traffic intended for LOADng Router D).

- Upon receiving the RERR, LOADng Router B updates its Routing Set by invalidating the existing Forward Route from LOADng Router B to LOADng Router D. Afterwards, the RERR message is forwarded according to the existing Reverse Route from LOADng Router B to

LOADng Router A.

- Upon receiving the RERR, LOADng Router A updates its Routing Set by invalidating the existing Forward Route from LOADng Router A to LOADng Router D.



4.4.5. Obtained results

The following table is summarizing the results obtained for the different combinations for which these test 1 (Forward Route and Reverse Route initial installation) and test 2 (Forward Route and Reverse Route updating) were performed :

A	B	C	D	Test 1	Test 2
Hitachi 1	LIX	LIX	Hitachi 2	Pass	Pass
Hitachi 1	LIX	Hitachi 2	LIX	Pass	Pass
LIX	Hitachi 2	Hitachi 1	LIX	Pass	Pass

Table 5

The following table is summarizing the results obtained for the different combinations for which these test 3 (Link breakage handling) was performed :

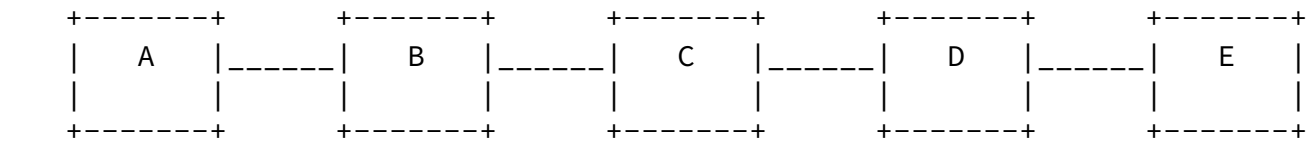
A	B	C	D	Test 3
Hitachi 1	LIX	LIX	Hitachi 2	Pass
LIX	Hitachi 1	LIX	Hitachi 2	Pass

Table 6

4.5. 4-hop bidirectional route establishment

4.5.1. Topology

The testbed is composed of five LOADng Routers. Control traffic generated by either LOADng Router A towards LOADng Router E or LOADng Router E towards LOADng Router A has to be forwarded by LOADng Routers B, C and D :



This test suite consists in establishing a bidirectional route between LOADng Router A and LOADng Router E.

4.5.2. Forward Route and Reverse Route initial installation

This test aims to verify the initial installation of a bidirectional route (Forward Route and Reverse Route from A to E) within the LOADng Router routing tables (Routing Sets) through the effective forwarding of LOADng control traffic by LOADng Routers B, C and D, which are located between LOADng Router A and LOADng Router E. It is also verified that RREP-ACK messages are not forwarded by the LOADng Routers these messages are intended for.

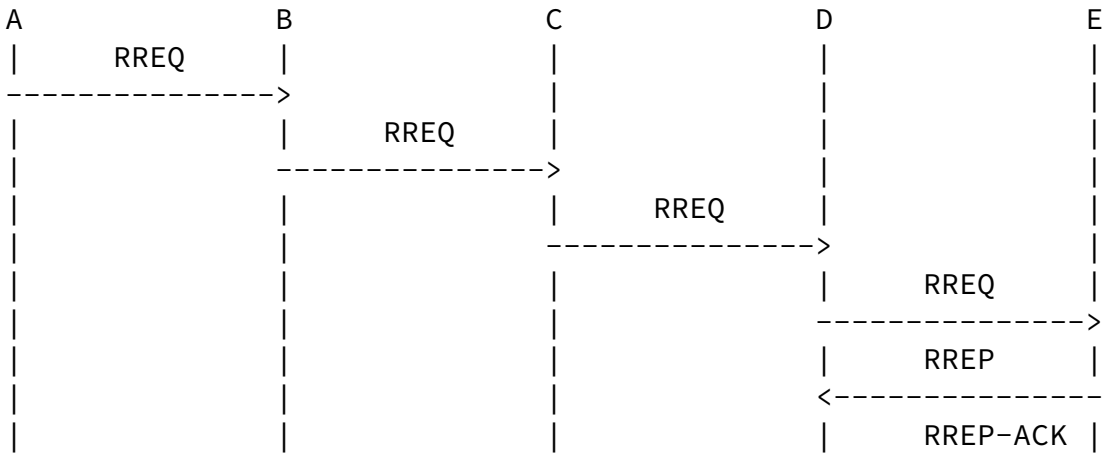
The expected message sequencing is as follows :

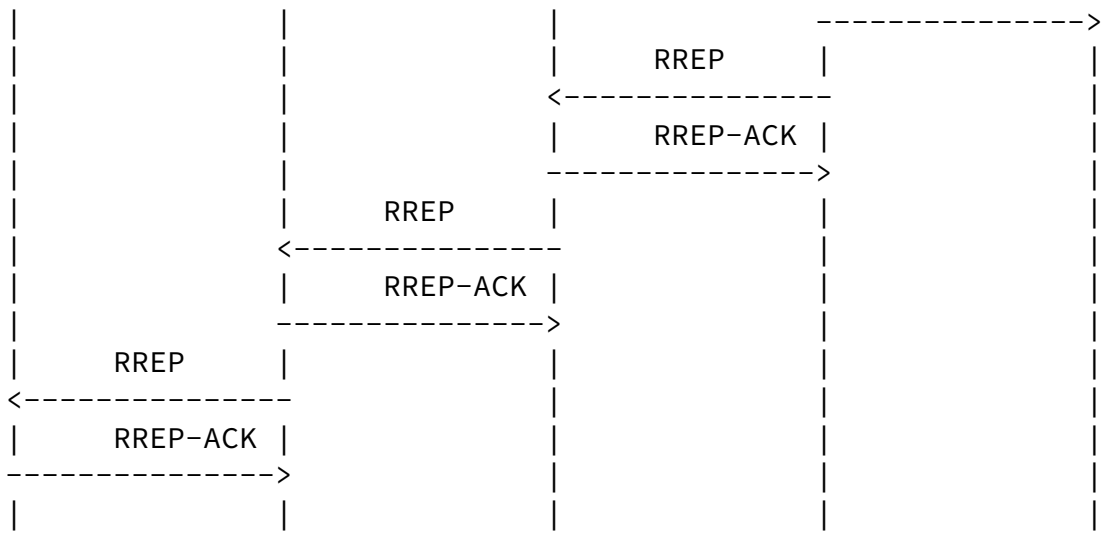
- LOADng Router A generates a RREQ message intended for LOADng Router E.
- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.
- Upon receiving the RREQ, LOADng Router C installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router C to LOADng Router A) and a new entry towards LOADng Router B (Reverse route from LOADng Router C to LOADng Router B) and forwards the received RREQ.
- Upon receiving the RREQ, LOADng Router D installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router D to LOADng Router A) and a new entry towards LOADng Router C (Reverse route from LOADng Router D to LOADng Router C) and forwards the received RREQ.

- Upon receiving the RREQ, LOADng Router E installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router E to LOADng Router A) and a new entry towards LOADng Router D (Reverse route from LOADng Router E to LOADng Router D). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".
- Upon receiving the RREP, LOADng Router D installs a new entry in its Routing Set towards LOADng Router E (Forward Route from LOADng Router D to LOADng Router E), sends an unicast RREP-ACK message to LOADng Router E and forwards the RREP received previously.
- Upon receiving the RREP, LOADng Router C installs a new entry in its Routing Set towards LOADng Router E (Forward Route from LOADng Router C to LOADng Router E) and a new entry towards LOADng Router D (Forward Route from LOADng Router C to LOADng Router D). An unicast RREP-ACK message is also sent to LOADng Router D and the RREP received previously is forwarded.

- Upon receiving the RREP, LOADng Router B installs a new entry in its Routing Set towards LOADng Router E (Forward Route from LOADng Router B to LOADng Router E) and a new entry towards LOADng Router C (Forward Route from LOADng Router B to LOADng Router C). An unicast RREP-ACK message is also sent to LOADng Router C and the RREP received previously is forwarded.

- Upon receiving the RREP, LOADng Router A installs a new entry in its Routing Set towards LOADng Router B (Forward Route from LOADng Router A to LOADng Router B) and a new entry towards LOADng Router E (Forward Route from LOADng Router A to LOADng Router E). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.





4.5.3. Link breakage handling

This test aims to verify the proper generation, processing and forwarding of a RERR message after an artificially created link breakage on an previously established bidirectional route.

The expected message sequencing is as follows :

- A bidirectional route is already established between LOADng Routers A and E.
- At some time, link breakage is detected by LOADng Router D. Consequently, an unicast RERR message intended for LOADng Router A (here the assumption is made that the unsuccessful delivered data traffic would have been generated by LOADng Router A) is transmitted to LOADng Router C according to the Reverse Route from LOADng Router C to LOADng Router A computed previously.

  Note : link breakage is provoked artificially and its detection by LOADng Router D is triggered manually (normally, this would be triggered by failure in sending data traffic intended for LOADng

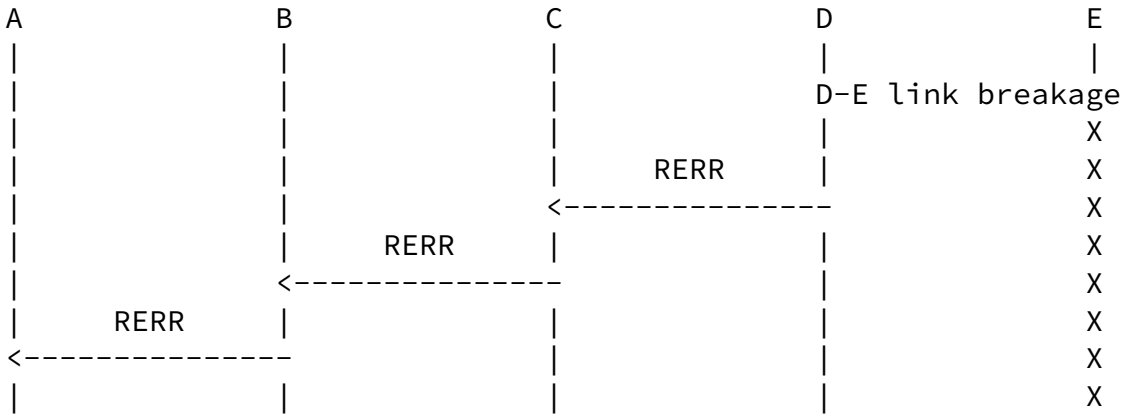
Router E).

- Upon receiving the RERR, LOADng Router C updates its Routing Set by invalidating the existing Forward Route from LOADng Router C to LOADng Router E. Afterwards, the RERR message is forwarded

according to the existing Reverse Route from LOADng Router C to LOADng Router A.

- Upon receiving the RERR, LOADng Router B updates its Routing Set by invalidating the existing Forward Route from LOADng Router B to LOADng Router E. Afterwards, the RERR message is forwarded according to the existing Reverse Route from LOADng Router B to LOADng Router A.

- Upon receiving the RERR, LOADng Router A updates its Routing Set by invalidating the existing Forward Route from LOADng Router A to LOADng Router E.



4.5.4. Obtained results

The following table is summarizing the results obtained for the different combinations for which test 1 (Forward Route and Reverse Route initial installation) and test 2 (Link breakage handling) were performed :

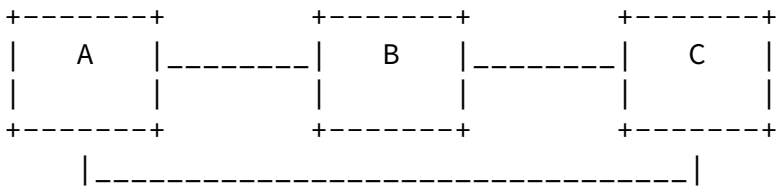
A	B	C	D	E	Test 1	Test 2
Hitachi 2	Hitachi 1	LIX	Hitachi 1	LIX	Pass	Pass

Table 7

4.6. Establishment of the best bidirectional route

4.6.1. Topology

The testbed is composed of three LOADng Routers. Control traffic generated by either LOADng Router A towards LOADng Router C or LOADng Router C towards LOADng Router A can be forwarded by LOADng Router B or transmitted via the direct link between LOADng Routers A and C :



This test consists in establishing a bidirectional route between LOADng Router A and LOADng Router C.

4.6.2. Description

This test aims to verify the processing of multiple RREQs when installing a bidirectional route (Forward Route and Reverse Route from A to C) within the LOADng Router routing tables (Routing Sets).

The expected message sequencing is as follows :

- LOADng Router A generates a RREQ message intended for LOADng Router C. According to RREQ transmission rules, the generated RREQ message is transmitted to all neighbor LOADng Routers.

- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.

  At the same time, upon receiving the same RREQ via its direct link with LOADng Router A, LOADng Router C installs a new entry in its Routing Set (Reverse Route from LOADng Router C to LOADng Router A). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the same RREQ via LOADng Router B, LOADng Router C compares the Route Cost and Weak Link information carried by the RREQ with the already existing entry within its Routing Set (Reverse Route from LOADng Router C to LOADng Router A) according to the comparison operator specified by the metric used (the "hop count while avoiding Weak Links" metric was used). No Weak Links are emulated. Thus, the best route is chosen considering the

Route Cost information only :

Already existing entry :

<R_dist> = (Weak Link, Route Cost) = (0, 1)

Tuple corresponding to the newly received RREQ :

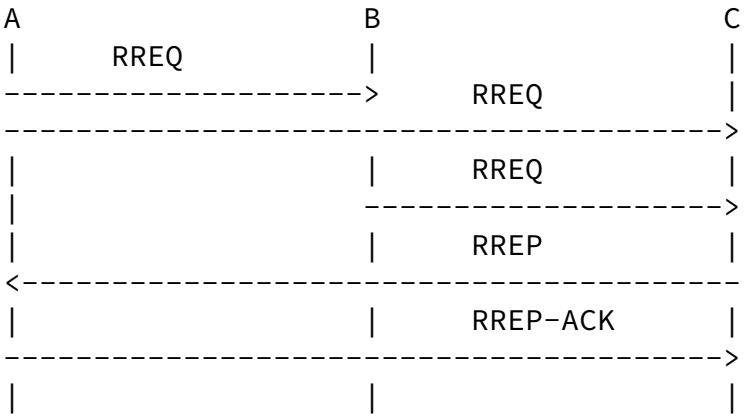
<R_dist> = (Weak Link, Route Cost) = (0, 2)

According to the comparison operator specified by the metric used :

(0, 1) < (0,2)

Consequently, the newly received RREQ message is discarded without affecting the Routing Set or triggering the generation of any RREP message.

o Upon receiving the RREP via its direct link with LOADng Router C, LOADng Router A installs a new entry in its Routing Set (Forward Route from LOADng Router A to LOADng Router C). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router C.



Note : the RREQ forwarded by LOADng Router B towards C is not necessarily received before LOADng Router C generates the RREP message intended for LOADng Router A. Indeed, the order in which those messages are transmitted is dependent on the transmission delays of each single link between LOADng Routers A, B and C.

4.6.3. Obtained results

The following table is summarizing the results obtained for the different combinations for which this test was performed :

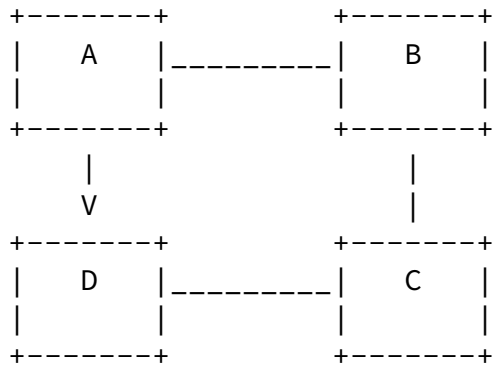
A	B	C	Result
LIX	Hitachi 1	Hitachi 2	Pass
LIX	Hitachi 2	Hitachi 1	Pass
Hitachi 2	Hitachi 1	LIX	Pass
Hitachi 1	LIX	Hitachi 2	Pass

Table 8

4.7. Blacklisting

4.7.1. Topology

The testbed is composed of four LOADng Routers with a unidirectional link between LOADng Routers A and D (direct communication from D towards A is impossible).



This test consists in establishing a bidirectional route between LOADng Router A and LOADng Router D.

4.7.2. Description

This test aims to verify the effectiveness of avoiding unidirectional links using blacklisting.

First attempt to establish a bidirectional route between LOADng Routers A and D :

- LOADng Router A generates a RREQ message (<seq-num> = 0, <originator> = A) intended for LOADng Router D.

- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.

At the same time, upon receiving the same RREQ via its direct (unidirectional) link with LOADng Router A, LOADng Router D installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router D to LOADng Router A). The reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREQ, LOADng Router C installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router C to LOADng Router A) and a new entry towards LOADng Router B (Reverse route from LOADng Router C to LOADng Router B) and forwards the received RREQ.

- Upon receiving the same RREQ (<seq-num> = 0, <originator> = A) again via LOADng Router C, LOADng Router D compares the Route Cost and Weak Link information carried by the RREQ with the already existing entry within its Routing Set (Reverse Route from LOADng Router D to LOADng Router A) according to the comparison operator specified by the metric used (the "hop count while avoiding Weak Links" metric was used). No Weak Links are emulated. Thus, the best route is chosen considering the Route Cost information only :

Already existing entry :

<R_dist> = (Weak Link, Route Cost) = (0, 1)

Tuple corresponding to the newly received RREQ :

<R_dist> = (Weak Link, Route Cost) = (0, 2)

According to the comparison operator specified by the metric used :

(0, 1) < (0,2)

Consequently, the newly received RREQ message is discarded without affecting the Routing Set or triggering the generation of any RREP message.

- Due to the unidirectional nature of the existing link between LOADng Routers A and D, the RREP message previously sent by LOADng Router D intended for LOADng Router A did not reach its destination. After an elapsed time equaling ack_timeout, LOADng Router D is not expecting an RREP-ACK message anymore. This results in recording LOADng Router A neighbor in LOADng Router D's Blacklist.

Second attempt to establish a bidirectional route between LOADng

Routers A and D :

- LOADng Router A generates a RREQ message (<seq-num> = 1, <originator> = A) intended for LOADng Router D.

- Upon receiving the RREQ, LOADng Router B installs a new entry in its Routing Set towards LOADng Router A (Reverse Route from LOADng Router B to LOADng Router A) and forwards the received RREQ.

  At the same time, upon receiving the same RREQ via its blacklisted neighbor LOADng Router A, LOADng Router D discards the message.

- Upon receiving the RREQ, LOADng Router C updates the corresponding routes (Reverse Routes from LOADng Router C to LOADng Router A and from LOADng Router C to LOADng Router B) and forwards the received RREQ.

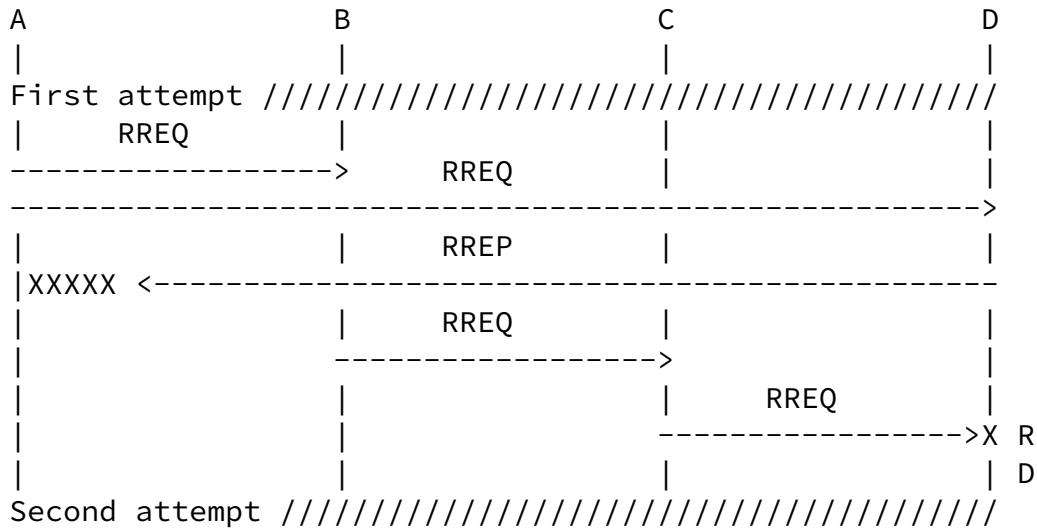
- Upon receiving the RREQ, LOADng Router D updates the already installed route (Reverse Route from LOADng Router C to LOADng Router A) and installs a new entry towards LOADng Router C (Reverse route from LOADng Router D to LOADng Router C). The

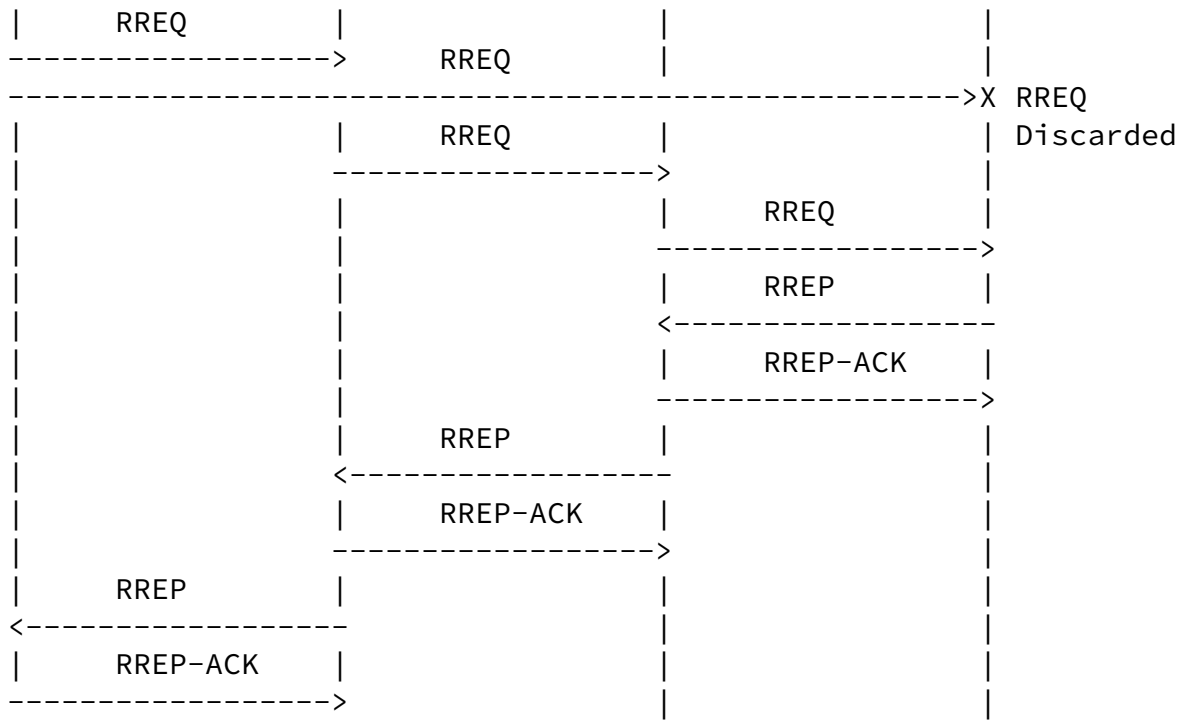
reception of the RREQ also triggers the generation of an unicast RREP message intended for LOADng Router A. The <flags> field of the sent RREP message is set to "ACK-REQUIRED".

- Upon receiving the RREP, LOADng Router C installs a new entry in its Routing Set towards LOADng Router D (Forward Route from LOADng Router C to LOADng Router D), sends an unicast RREP-ACK message to LOADng Router D and forwards the RREP received previously.

- Upon receiving the RREP, LOADng Router B installs a new entry in its Routing Set towards LOADng Router D (Forward Route from LOADng Router B to LOADng Router D) and a new entry towards LOADng Router C (Forward Route from LOADng Router B to LOADng Router C). An unicast RREP-ACK message is also sent to LOADng Router C and the RREP received previously is forwarded.

- Upon receiving the RREP, LOADng Router A installs a new entry in its Routing Set towards LOADng Router D (Forward Route from LOADng Router A to LOADng Router D) and a new entry towards LOADng Router B (Forward Route from LOADng Router A to LOADng Router B). The reception of the RREP also triggers an unicast RREP-ACK message intended for LOADng Router B.





4.7.3. Obtained results

The following table is summarizing the results obtained for the different combinations for which this test was performed :

A	B	C	D	Result
Hitachi 2	LIX	Hitachi 1	LIX	Pass
LIX	LIX	Hitachi 1	Hitachi 2	Pass
Hitachi 2	LIX	LIX	Hitachi 1	Pass

Table 9

4.8. Conclusions

The different test scenarios carried that were carried out for different interoperable and independent implementations allowed to completely cover the LOADng specification by checking each technical feature one by one. In addition, the completion of this process permitted the improvement of the overall quality and accuracy of the

LOADng specification (draft-clausen-lln-loadng).

Chap.	Item	Technical feature		Scenario 1	2	3	4	5	6
6.1	Information Base	Routing Set	Originator	X	X	X		X	X
6.1			Previous		X	X	X		X
6.2		Blacklist Neighbor set							X
8.1	Packet Format	TLV		X	X	X	X	X	X
8.2.1		Route Request Message		X	X	X	X	X	X
8.2.1		Route Reply Message		X	X	X	X	X	X
8.2.2		Route Reply Ack Message		X	X	X	X	X	X
8.2.3		Route Error Message			X	X	X		
10.1	Unidirectional link handling	Blacklist							X
11.1	Common rules for RREQ, RREP Message	Invalid RREQ, RREP		X	X	X	X	X	X
11.2		RREQ, RREP Processing		X	X	X	X	X	X
11.3		Updating RREQ, RREP		X	X	X	X	X	X
12.1	Route Requests (RREQs)	RREQ Generation		X	X	X	X	X	X
12.2		RREQ Processing		X	X	X	X	X	X
12.3		RREQ Forwarding			X	X	X	X	X
12.4		RREQ Transmission		X	X	X	X	X	X
13.1		RREP Generation		X	X	X	X	X	X

13.2	Route Replies (RREPs)	RREP Processing	X	X	X	X	X	X
13.3		RREP Forwarding		X	X	X	X	X
13.4		RREP Transmission	X	X	X	X	X	X
14.1	Route Errors (RERRs)	RERR Generation		X	X	X		
14.2		RERR Processing		X	X	X		
14.3		RERR Forwarding			X	X		
14.4		RERR Transmission		X	X	X		
15.1	Route Reply Acknowledgement (RREP-ACKs)	RREP-ACK Generation	X	X	X	X	X	X
15.2		RREQ-ACK Processing	X	X	X	X	X	X
15.3		RREQ-ACK Forwarding	X	X	X	X	X	X
15.4		RREQ-ACK Transmission	X	X	X	X	X	X
16	Metrics	Hop Count While Avoiding Weak Links	X	X	X	X	X	X

Scenario 1: 1-hop bidirectional route establishment

Scenario 2: 2-hop bidirectional route establishment

Scenario 3: 3-hop bidirectional route establishment

Scenario 4: 4-hop bidirectional route establishment

Scenario 5: Establishment of the best bidirectional route

Scenario 6: Blacklisting

5. Security Considerations

This document does currently not specify any security considerations.

6. IANA Considerations

This document has no actions for IANA.

7. Contributors

This specification is the result of the joint efforts of the following contributors -- listed alphabetically.

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8. Acknowledgments

TBD

9. References

9.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", RFC 2119, BCP 14, March 1997.

9.2. Informative References

[RFC5444] Clausen, T., Dearlove, C., Dean, J., and C. Adjih, "Generalized MANET Packet/Message Format", RFC 5444, February 2009.

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