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ASON routing architecture and requirements for remote route query

ITU-T Recommendation G.7715.2/Y.1706.2

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ITU-T Recommendation G.7715.2/Y.1706.2

ASON routing architecture and requirements for remote route query

Summary

ITU-T Recommendation G.7715.2/Y.1706.2 describes the ASON routing architecture and requirements for remote route query.

Source

ITU-T Recommendation G.7715.2/Y.1706.2 was approved on 6 February 2007 by ITU-T Study Group 15 (2005-2008) under the ITU-T Recommendation A.8 procedure.

Keywords

ASON, connection controller, control plane, hierarchical routing, remote route query, route query requester, route query responder, routing controller.

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CONTENTS

ITU-T Recommendation G.7715.2/Y.1706.2

ASON routing architecture and requirements for remote route query

1 Scope

This Recommendation specifies the requirements and architecture for the functions performed by routing controllers (RC) during the operation of remote route query. The purpose of the remote route query is to compute one or more routing paths for a switched connection (SC) or a soft permanent connection (SPC) within the framework of the automatically switched optical network (ASON).

During the operation of remote route query, a RC (route query requester) sends a RI_QUERY message to another RC (route query responder) not associated with the same set of layer resources, and if a routing path (or more) is found after computation, the route query responder would send back a RI_UPDATE message to the route query requester. A routing path for a SC or SPC may be computed collaboratively by a group of RCs in this manner.

The route query interface as defined by [ITU-T G.8080] is used by routing controllers when they communicate with each other during the remote route query operation. Note that the route query interface is used in two different cases. First, a connection controller (CC) might request its routing controller for a routing path, and secondly, a routing controller (RC-X) might send a request to another routing controller (RC-Y) for a routing path, either because it (RC-X) needs to respond to a connection controller (CC-X) or a remote routing controller (RC-A), for a route query. The second case, i.e., the RC-to-RC communication for path computation, is the main focus of this Recommendation.

The messages exchanged between routing controllers during the remote route query operation fall into the same category of the routing messages as defined in [ITU-T G.7715], and they are transported over a data communication network (DCN). This Recommendation takes a protocol neutral approach, i.e., it does not specify any protocol solution for the communication between routing controllers during remote route query operation.

The routing algorithm used by a route query responder during the path computation is beyond the scope of this Recommendation.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.7712] ITU-T Recommendation G.7712/Y.1703 (2003), *Architecture and specification of data communication network*.

[ITU-T G.7713] ITU-T Recommendation G.7713/Y.1704 (2006), *Distributed call and connection management (DCM)*.

[ITU-T G.7713.1] ITU-T Recommendation G.7713.1/Y.1704.1 (2003), *Distributed call and connection management (DCM) based on PNNI*.

[ITU-T G.7713.2] ITU-T Recommendation G.7713.2/Y.1704.2 (2003), *Distributed call and connection management: Signalling mechanism using GMPLS RSVP-TE*.

[ITU-T G.7713.3] ITU-T Recommendation G.7713.3/Y.1704.3 (2003), *Distributed call and connection management: Signalling mechanism using GMPLS CR-LDP*.

[ITU-T G.7715] ITU-T Recommendation G.7715/Y.1706 (2002), *Architecture and requirements for routing in the automatically switched optical networks* plus Amendment 1 (2007).

[ITU-T G.7715.1] ITU-T Recommendation G.7715.1/Y.1706.1 (2004), *ASON routing architecture and requirements for link state protocols*.

[ITU-T G.8080] ITU-T Recommendation G.8080/Y.1304 (2006), *Architecture for the automatically switched optical network (ASON)*.

[ITU-T G.8081] ITU-T Recommendation G.8081/Y.1353 (2004), *Terms and definitions for automatically switched optical networks (ASON)*.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 data communication network (DCN): [ITU-T G.7712]

3.1.2 connection controller (CC): [ITU-T G.8080]

3.1.3 federation: [ITU-T G.8080]

3.1.4 protocol controller (PC): [ITU-T G.8080]

3.1.5 routing area (RA): [ITU-T G.8080]

3.1.6 routing controller (RC): [ITU-T G.8080]

3.1.7 routing information database (RDB): [ITU-T G.8081]

3.1.8 soft permanent connection (SPC): [ITU-T G.8080]

3.1.9 switched connection (SC): [ITU-T G.8080]

3.1.10 routing adjacency (RAdj): [ITU-T G.7715]

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 remote route query: An operation where a routing controller communicates with another routing controller, which does not have the same set of layer resources, in order to compute a routing path in a collaborative manner.

3.2.2 route query requester: A connection controller or routing controller that sends a route query message to a routing controller requesting for one or more routing path that satisfies a set of routing constraints.

3.2.3 route query responder: A routing controller that performs path computation upon reception of a route query message from a routing controller or connection controller, sending a response back at the end of computation.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ASON	Automatically Switched Optical Network
CC	Connection Controller
DCN	Data Communication Network
E-NNI	External Network-Network Interface
NE	Network Element
NNI	Network-to-Network Interface
RC	Routing Controller
SC	Switched Connection
SPC	Switched Permanent Connection

5 Conventions

None

6 General architecture

The remote route query operation is part of ASON routing paradigms as defined in [ITU-T G.8080], where when one routing controller does not have sufficient routing information in a local RDB to compute a routing path for a connection request, it may communicate with another routing controller at a remote site for assistance.

6.1 Route query as used by RC federations

As described in [ITU-T G.8080], a routing controller can be implemented as a distributed set of entities that make up a cooperative federation, i.e., RC federations. There are two aspects of the use of the RC federations, as follows:

1) Routing topology information may be exchanged between RC federations and also among RCs within a single federation. This aspect is described in [ITU-T G.7715] and [ITU-T G.7715.1].
2) Route query messages may be exchanged between RC federations and also among RCs within a single federation. This aspect is described in this Recommendation.

Note that these two aspects are associated with different functions performed by routing controllers.

There are different styles that are used by RC federations during remote route query operation including the following:

1) step-by-step remote path computation;
2) hierarchical remote path computation;
3) combination of the above two.

The step-by-step case is illustrated in Figure 1, where the dotted lines show the RC federation boundaries. Each RC is responsible to compute a portion of the end-to-end routing path, usually within its own routing area; for the portion of the routing path that is outside of its routing area, the RC would first decide the next RC in the chain that belongs to another routing area. This presumes that the RC has enough knowledge to determine the appropriate next RC or, if not, it has to communicate (simultaneously or successively) to all neighbouring RCs belonging to another routing area to find out the appropriate one. The RC communicates with that RC belonging to another routing area for assistance in order to compute the remaining routing path. The complete routing path for an end-to-end connection is therefore collaboratively computed by a series of RCs in a step-by-step fashion.

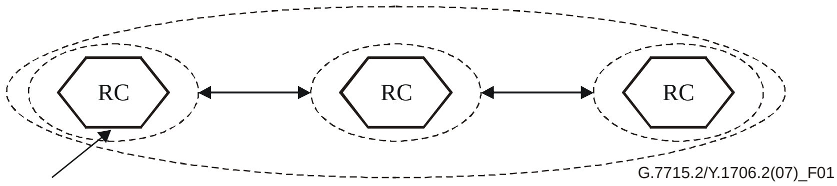


Figure 1 – Step-by-step remote path computation

The hierarchical case is illustrated in Figure 2, where the dotted lines show the RC federation boundaries. Each child RC computes routing paths that are within its own routing area. For routing paths that cross routing area boundaries, a child RC invokes remote route query function by communicating with one or more of its parent RC, which resides at the next higher level of the ASON routing hierarchy. In this case, the child RC and a parent RC function as a route query requester and a route query responder, respectively. A parent RC may further communicate with other child RCs that belong to other child routing areas at the next lower hierarchical level, functioning as pairs of route query requester and route query responder, respectively. Note this interaction between child RCs and parent RCs may be recursively performed allowing a routing path to be computed across multiple routing areas.

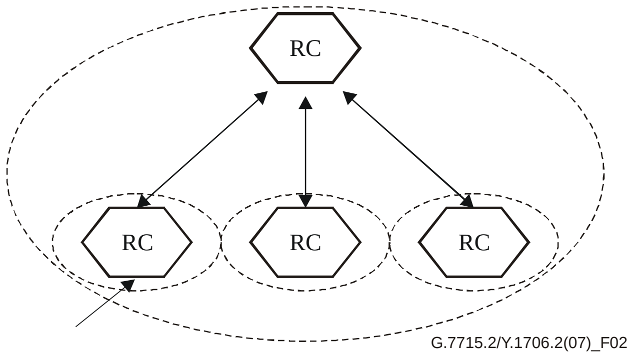


Figure 2 – Hierarchical remote path computation

The combined case is illustrated in Figure 3, where the dotted lines show the RC federation boundaries. Each RC computes routing paths that are within its own routing area. For routing paths that cross routing area boundaries, remote path computation may be conducted using either step-by-step or hierarchical style. In RC federation F1 and F3, the hierarchical computation style is used, respectively, whereas in RC federation F2, the step-by-step computation style is used. In RC federation F4, where the routing area is at a higher hierarchical level, the RCs perform remote path computation using step-by-step style.

The choice of style when performing remote path computation by a RC federation depends on circumstances, including how the routing information is disseminated, the network topology, the routing constraints that are associated with a given connection requested, requirement for path optimization, administrative policies, etc., where the detail is out of the scope of this Recommendation.

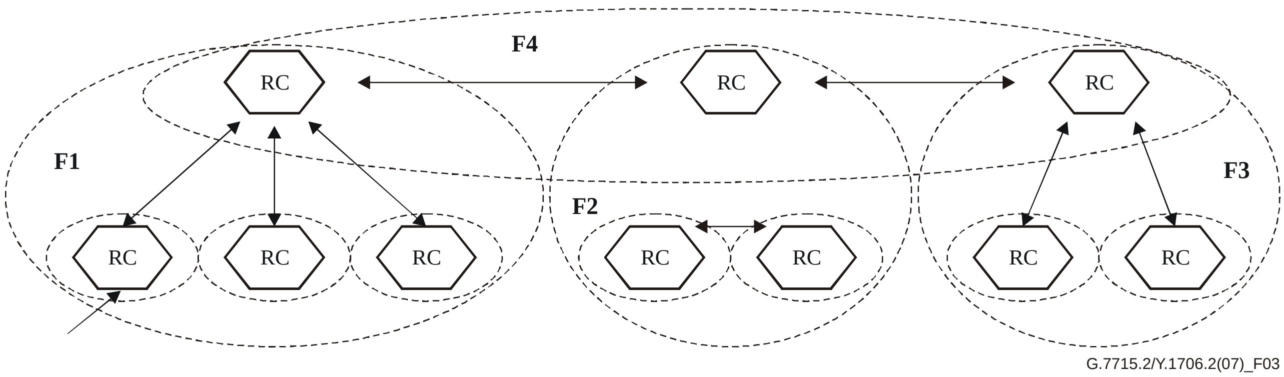


Figure 3 – Combined use of step-by-step and hierarchical RC federations

6.2 Route query interface

[ITU-T G.8080] defines a route query interface that is attached to a routing controller (RC), which can be used in either of the two following cases:

- route queries from the connection controller (CC);
- route queries from another RC.

In the first case, a connection controller (CC) uses the RC's route query interface to ask an RC for providing a route upon receiving a connection request; and the RC, upon receiving the request, would calculate a route based on its associated routing information database (RDB). If the RC finds a route, it will respond back to the CC and the CC will then continue with setting up the connection along the provided route. If the CC and the RC are not collocated, the CC-to-RC route query interface becomes an exposed interface, and following [ITU-T G.8080], a protocol controller (PC) has to be used on either side to allow the CC and the RC to communicate, which is shown in Figure 4 between the CC and RC1.

In the second case, when a RC (RC1) is not able to find a route to the given destination based on its associated RDB (RDB1), it can use the route query interface to communicate with another RC (RC2) that may assist RC1 in calculating a route based on its associated RDB (RDB2) to the given destination. RC2 will return its part of the route to RC1, which in turn, will return the entire route back to the CC. In this second case, the route query interface between RC1 and RC2 may again be an exposed interface and PCs are involved allowing the RCs to communicate. This is also shown in Figure 4 between RC1 and RC2. The RC-to-RC communication for path computation is the main focus of this Recommendation.

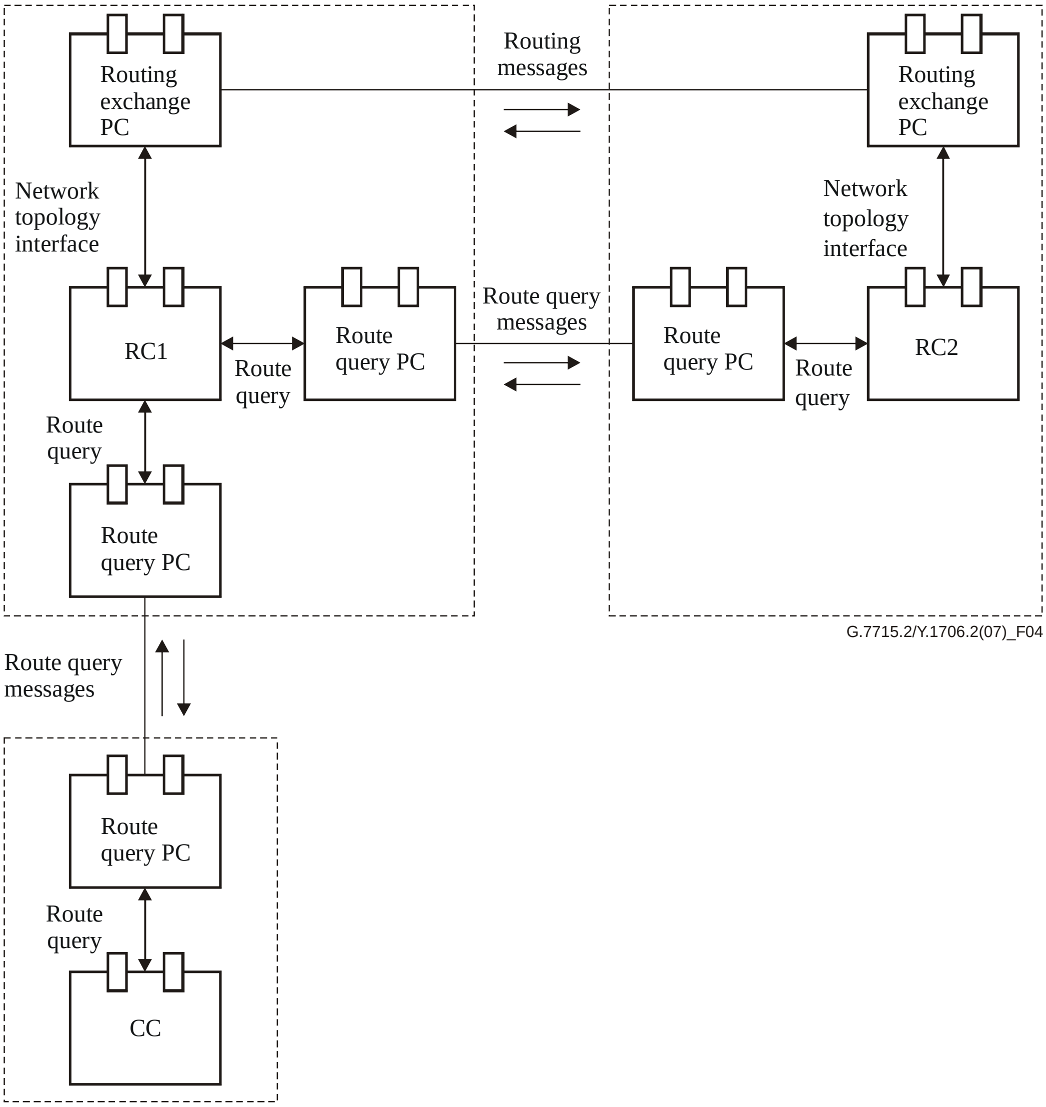


Figure 4 – Exposed CC-to-RC and RC-to-RC route query interfaces

Note in the first case, the CC is not privy to the structure of the RC federation, and as such, the behaviour it exhibits and the primitives it uses are a subset of those by an RC on the RC-RC route query interface.

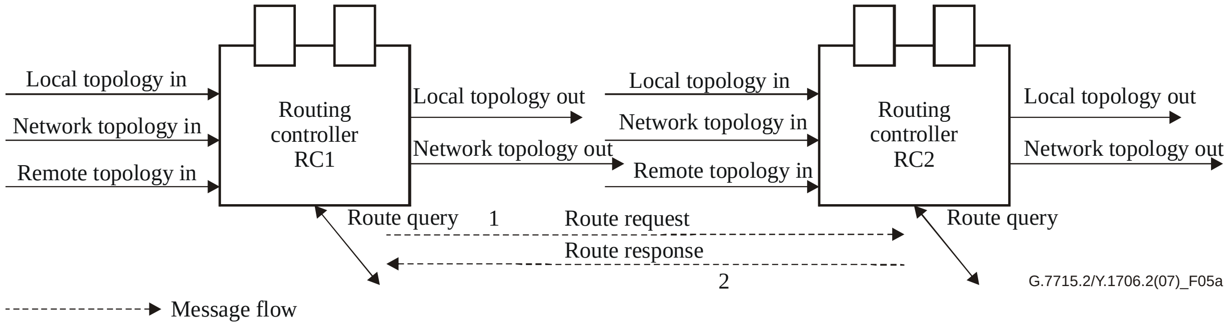
6.3 Path computation by a single or multiple RCs

For an end-to-end connection, the routing path may be computed by a single RC or multiple RCs in a collaborative manner, and the two scenarios are termed as centralized remote route query model and distributed remote route query model, respectively. Note that centralized or distributed model reflects a different aspect in the context of remote route query performed by a RC federation, in addition to the step-by-step or hierarchical styles as described in clause 6.1.

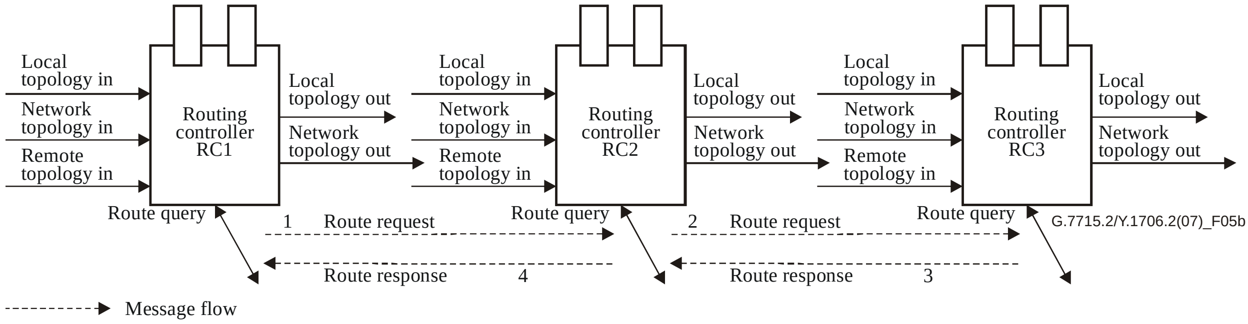
In Figure 5-a, RC1 sends a route query message to RC2, which in turn, sends a route response message back to RC1. The routing path for an end-to-end connection is thus computed by a single RC (RC2) and this scenario is called centralized remote route query.

Further, if RC2 has some but not a complete set of routing information that satisfies the set of routing constraints associated with the original connection request, RC2 may go on to communicate with yet another routing controller, say RC3, as illustrated in Figure 5-b. If RC3 could fulfil the remaining route search task, it can then send a response back to RC2, which then appends its own input (if any) to the final response before sending that information back to RC1. In other words, the route query model should allow a route search for any given connection being computed by a single or multiple RCs, and in the latter case, collaboratively.

When a route search accomplished collaboratively by multiple RCs, the messages exchanged between each communicating pair of RCs are private, and in fact, their communication is totally transparent to all the other involved RCs, if any. In Figure 5-b, the initiating RC (RC1) only knows that there is a RC2 that will receive route query message and help perform a route search, without knowing that RC2 might communicate with other RCs; when RC3 receives a route query message from RC2, it returns a route search result back to RC2 without knowing the original request coming from RC1.



a) Single RCs



b) Multiple RCs

Figure 5 – Path computation

6.4 Hierarchical relationship between communicating RCs

ASON routing adopts a hierarchical architecture as described in [ITU-T G.8080], and as a result, there is an association between a pair of routing controllers in the context of hierarchical relationship. For practical reasons, a routing controller as a route query responder is always at either a higher level or lower level of hierarchy, compared to the routing controller as an associated route query requester. A routing controller at a higher level of hierarchy would possibly be contacted to perform functions as a route query responder because a routing controller at a higher hierarchy usually has a wider topological view of the network or subnetwork, and it may be able to compute and provide a routing path that traverses a larger portion of the network or subnetwork. A routing controller at a lower level of hierarchy would possibly be contacted to perform functions as a route query responder because a routing controller at lower hierarchy usually has more details of topological view within its own network or subnetwork, and it may be able to compute and provide a routing path that is the exact physical path in the associated network or subnetwork or close to such a path.

6.5 Discovery of a route query responder

Before a route query requester communicates with a route query responder, it must know the location (address or name) of the latter, and the process is called the "discovery" of the route query responder.

If a routing controller (RC) is capable of performing path computation for other RCs, its location may be statically provisioned on other RCs, and alternatively, learnt dynamically by others through protocol mechanisms. The two discovery methods may coexist in the same network or subnetwork. The discovery of one or more routing controllers as route query responder is part of control plane initialization.

6.6 Capability of a route query responder

A routing controller may or may not be capable of, or provisioned for, performing routing path computation to assist other routing controllers. When a routing controller is capable of performing such a task, there is a set of attributes that are associated with the capability of the path computation function, which any potential route query requester might like to understand before sending any route query request message.

There are two types of capabilities that might be associated with any specific route query responder as follows:

1) *Constraints-based path computation*

   The routing constraints are normally associated with routing attributes including node attributes, link attributes, etc., as defined in [ITU-T G.7715] and [ITU-T G.7715.1].

2) *Policy-based path computation*

   Examples of policies that might be used during path computation include:

   - compute load-balanced paths;
   - compute routing paths across E-NNI;
   - compute alternate path;
   - compute and return a routing path to route query requesters with confidentiality.

The capability that is associated with a route query responder may be made known to a potential route query requester, as part of control plane initialization. Knowing the capability of a route query responder, a route query requester would be able to determine whether to communicate with it for computing a given routing path, based on the capability of the route query responder along with the associated routing constraints.

6.7 Route request and response messages

The route request and response messages that are exchanged between a route query requester and a route query responder are part of the routing information messages over NNI reference points, as described by the abstract representation defined in clause 8.2 of [ITU-T G.7715].

In particular, the following two abstract messages are used for this purpose:

- RI_QUERY: This message, as defined in clause 8.2 of [ITU-T G.7715], is used when a route query requester sends a route query message to a route query responder.
- RI_UPDATE: This message, as defined in clause 8.2 of [ITU-T G.7715], is used when a route query responder sends a route query response message back to a route query requester.

The message exchange for route query is always initiated by a route query requester. The information carried by route query messages is dependent on the actual protocol that is being used for this purpose and is out of scope of this Recommendation.

6.8 Routing controllers and their adjacency

When two routing controllers take the roles of a route query requester and a route query responder, respectively, they form a routing adjacency, which represents a logical association between the two routing controllers. The purpose of forming a routing adjacency between a pair of route query requester and route query responder is to assure that they communicate reliably and properly. Note the duration of an adjacency between two routing controllers in the context of remote route query may vary.

The nature of the adjacency between two routing controllers in the context of remote route query is the same as that when two routing controllers exchange routing topology information, and for that matter, the two routing controllers may also exchange routing adjacency maintenance messages, as documented in clause 8.1 of [ITU-T G.7715], in order to maintain their adjacency. Details of routing maintenance messages between two adjacent RCs are outside the scope of this Recommendation.

6.9 Communication channels for route query messages

Messages exchanged between route query requesters and route query responders, including route query and response, as well as adjacency maintenance messages, are transported over a data communication network (DCN).

7 Requirements

There are requirements for remote route query in the context of architecture, protocol, route query responder discovery as recommended in the following.

7.1 Architectural requirements

Architectural requirements for remote route query function include the following:

- Within the ASON framework, a routing path for a SC or SPC may be computed by using the remote route query function, which is however not the only method. Other routing methods as described in clause 10 of [ITU-T G.7715] may also be used.
- The remote route query function may be used for computing routing path that is within a routing area or across E-NNI within the framework of ASON.
- The role of a RC in the remote route query operation, i.e., a route query requester or route query responder, is dependent on the actual activity it performs for any given path computation. When a RC communicates with another RC for assistance on any given path computation, it is a route query requester; when a RC receives a request from another RC for any given path computation, it is a route query responder. Note that a RC can be a route query requester and route query responder for a given path computation but in the context of different peers.
- If the remote route query function is invoked, a routing path may be collaboratively computed by one or multiple routing controllers.
- It should allow policy to be included during remote route query operation. Policy would play a role such as selection of a route query responder, selection of routing path across E-NNI, etc. Policy is obtained from the management plane.

7.2 Discovery requirements

The discovery in this context is about a routing controller learning the location of another routing controller (not within the same NE) that is capable of performing path computation for others. After discovery, messages for route query can be exchanged between a route query requester and a route query responder. Requirements for the discovery include the following:

- The discovery of any route query responder can be accomplished either dynamically through protocol mechanism, or statically via provisioning.
- A routing controller is allowed to discover one or more route query responders.
- Upon discovering the location of a route query responder, there may be associated with it a set of capabilities that might be useful for a routing controller before sending RI_QUERY message to it. However, learning these capabilities is not mandatory for the discovery.

7.3 Protocol requirements

During remote route query, a route query requester and a route query responder exchange routing messages as defined in [ITU-T G.7715] where a communication protocol is used. Details of the communication protocol is beyond the scope of this Recommendation, but with some requirements as follows:

- The protocol shall support routing adjacency maintenance as well as routing information exchange as defined in clauses 8.1 and 8.2, respectively, of [ITU-T G.7715], in the context of remote route query.
- The protocol shall be capable of carrying routing information messages that is consistent with the ASON framework, including routing and signalling architecture.
- The routing information carried by the protocol returned by a route query responder may be used by any signalling protocol as specified by [ITU-T G.7713.1], [ITU-T G.7713.2], or [ITU-T G.7713.3], without bias.
- When a route query responder sends RI_UPDATE message back to the route query requester, it shall be capable of protecting the privacy of the network or subnetwork where the computed path is associated with by using techniques such as indirect reference, encryption, etc.

Appendix I

Remote route query examples

(This appendix does not form an integral part of this Recommendation)

The architecture of remote route query allows flexibility in both implementation and practice by network operators. For example, the routing path for an end-to-end connection can be computed in a centralized or distributed fashion; and also, a routing path can be computed by remote route query function using either step-by-step or hierarchical style, or a mixture of the two.

Associated with the architecture of remote route query, there are a number of components and interfaces including route query interface, route query requester, route query responder, routing controllers and their federations, connection controllers, etc. During the operation of remote route query, there are interactions between these components in varies ways depending on implementation and network applications.

This appendix provides several examples as how remote route query functions may be used, including interactions between RCs and their federations, between CC and RC, etc., along with different operating styles. These examples demonstrate various architectural aspects and the flexibility that are associated with remote route query within the ASON framework. Note that these examples are not exhaustive.

I.1 Step by step remote route query

In Figure I.1, an end-to-end connection crosses three routing areas. RC(s) within each RA is responsible for computing one portion of the routing path in that area, and RCs in different RAs communicate with each other in order to compute other path segments across routing area boundaries. In this example, the step-by-step remote route query style is used.

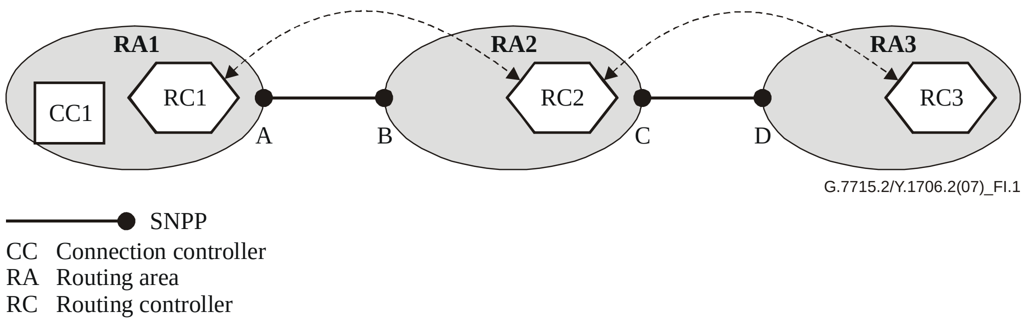


Figure I.1 – Step-by-step route query example topology

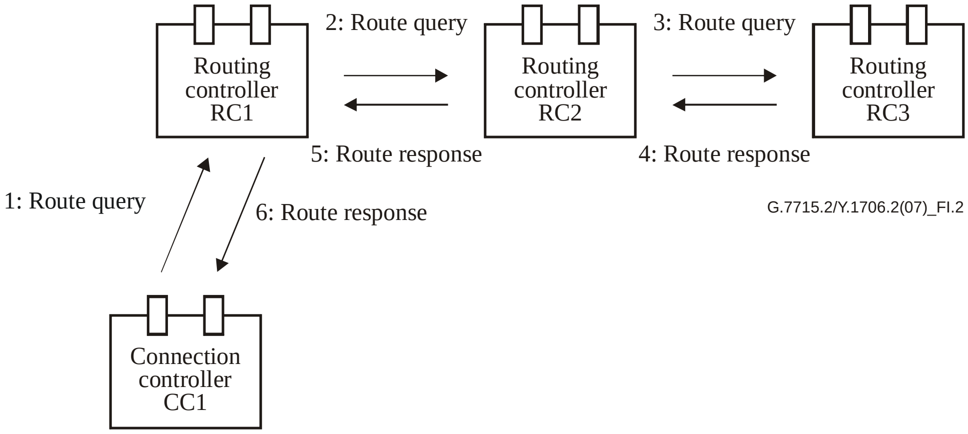


Figure I.2 – Step-by-step route query component interactions

Component interaction during step-by-step remote route query in this example is illustrated in Figure I.2 with the following procedure:

1) CC1 sends a route query message to RC1, optionally including constraints.

2) RC1 finds that the destination SNPP is not within its responsible routing area. A route query message is sent to RC2, requesting a path starting with SNPP B.

3) RC2 finds that the destination SNPP is not within its responsible routing area. A route query message is sent to RC3, requesting a path starting with SNPP D.

4) Upon receiving the route query message, RC3 finds that the destination SNPP is within its routing area. RC3 determines the path to the destination SNPP, which is sent back to RC2 as a response. The path starts with SNPP D.

5) RC2 knows that SNPP D in RA3 is connected to SNPP C in RA2. It therefore computes a path to SNPP C, and appends it to the route provided by RC3. This compound path, which starts from SNPP B, is returned to RC1 as a response.

6) RC1 knows that SNPP B in RA2 is connected to SNPP A in RA1. It therefore computes a path to SNPP A, and appends it to the route provided by RC2 (which includes the route provided by RC3). This end-to-end path is returned to CC1. CC1 can then initiate the connection setup process.

The procedure of step-by-step remote route query shall be visualized in the sequence diagram in Figure I.3:

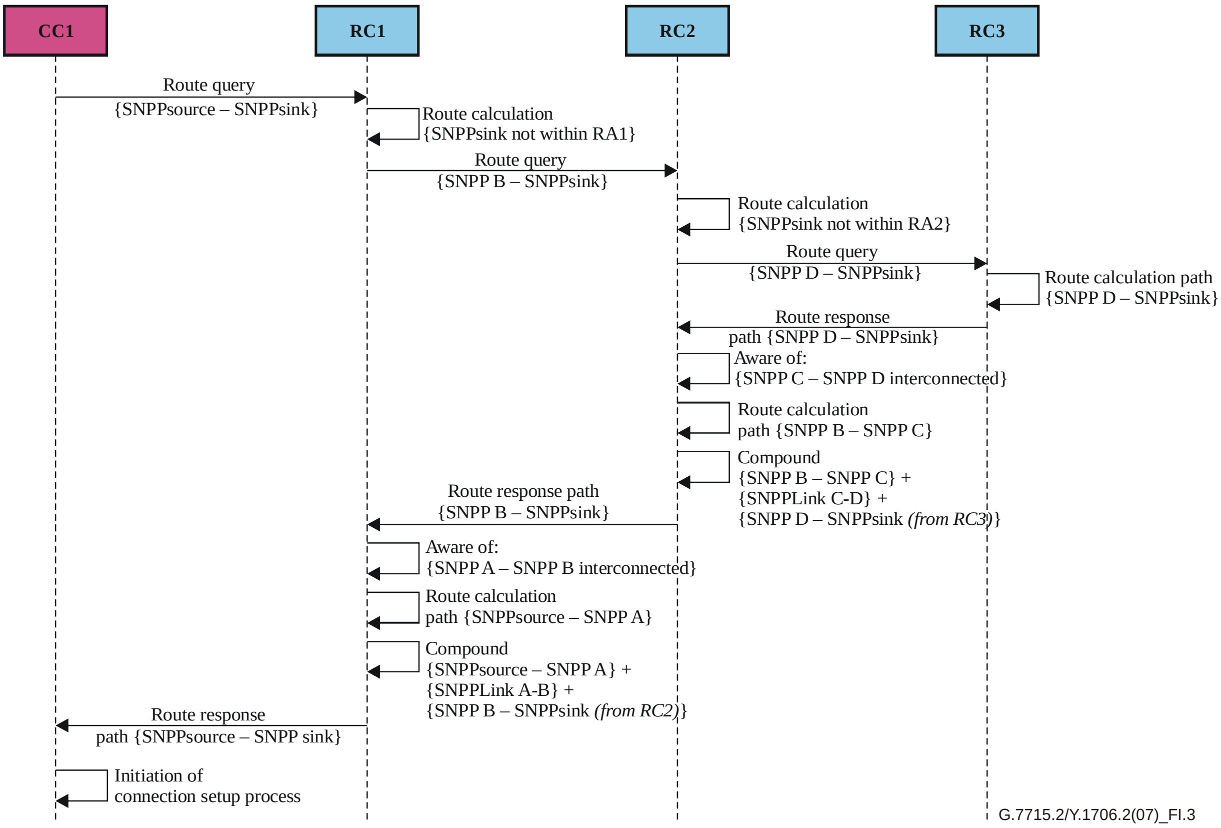


Figure I.3 – Step-by-step route query sequence diagram

I.2 Simultaneous remote route query

In Figure I.4, an end-to-end connection is requested and the source and destination SNPP is in RA1 and RA3, respectively. Assuming the RC in RA1 does not know which routing area the destination SNPP is in, it communicates with RCs in both RA2 and RA3 for path computation simultaneously.

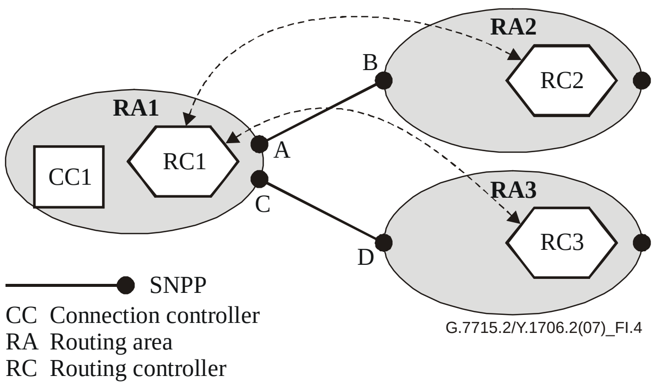


Figure I.4 – Simultaneous route query example topology

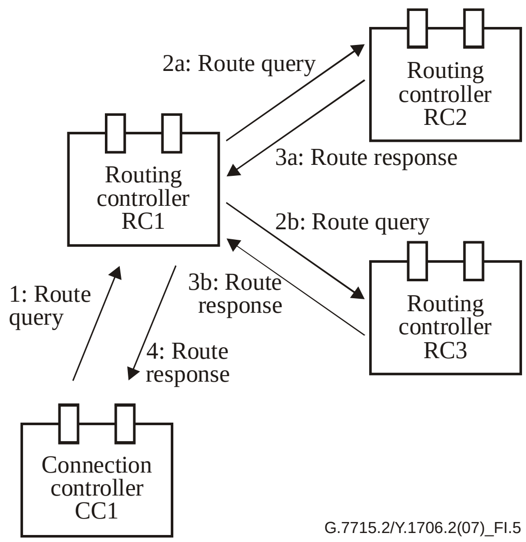


Figure I.5 – Simultaneous route query component interactions

Component interaction in this example is illustrated in Figure I.5 with the following procedure:

1) CC1 sends a route query message to RC1, optionally including constraints.

2) RC1 finds that the destination SNPP is not within its responsible routing area. Not knowing if the destination SNPP is in RA2 or RA3, a separate route query message is sent simultaneously to RC2 and RC3, requesting a path starting at SNPP B and SNPP D, respectively.

   RC1 needs to review the responses sent back by RC2 and RC3 and chooses an optimal routing path only, if any. The following is one possible scenario.

3) RC2 receives the route query message, and determines the destination SNPP is not within its routing area, nor reachable, and so responds to RC1 with an indication that no route was found.

4) RC1 receives the indication from RC2. No further action is taken.

5) Upon receiving the route query message by RC3, it finds the destination SNPP is within its routing area. RC3 determines the path to the destination SNPP, which is sent back to RC1 as a response. The path starts with SNPP D.

6) RC1 knows that SNPP D in RA3 is connected to SNPP C in RA1. It therefore computes a path to SNPP C, and appends it to the route provided by RC3. The end-to-end path is returned to CC1.

7) CC1 initiates the connection setup process.

The procedure of simultaneous remote route query shall be visualized in the sequence diagram in Figure I.6:

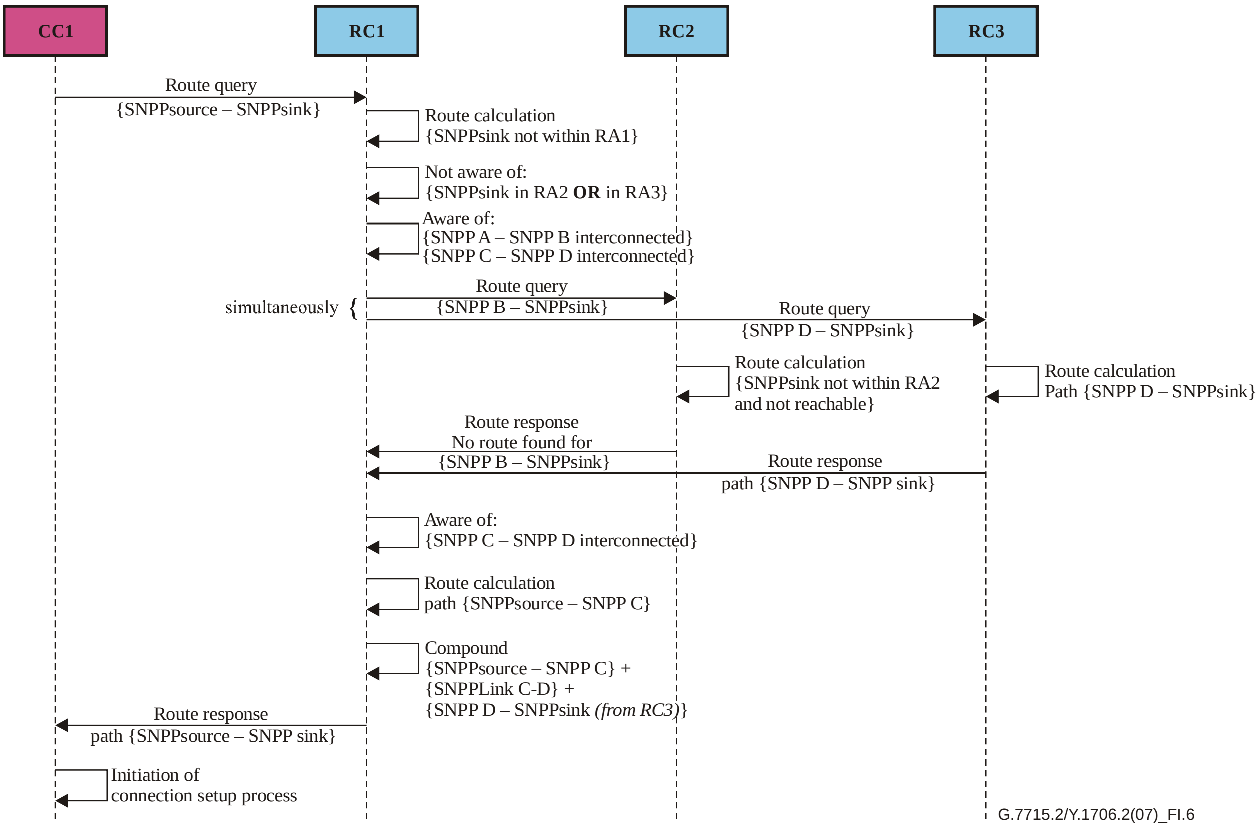


Figure I.6 – Simultaneous route query sequence diagram

I.3 Hierarchical remote route query

In Figure I.7, an end-to-end connection is requested, where the source and destination SNPP is in RA1 and RA3, respectively, and the connection also passes through RA2. There is a parent routing RA (RA11) in the next higher routing hierarchy and the parent RC there (RC11) performing remote route query function along with RC1, RC2 and RC3 in the child RAs in a collaborative manner in order to compute routing paths across routing area boundaries.

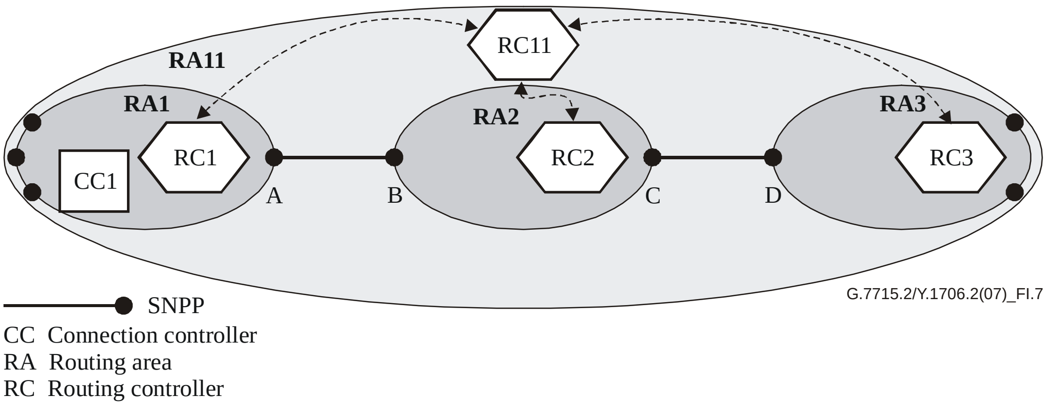


Figure I.7 – Hierarchical route query example topology

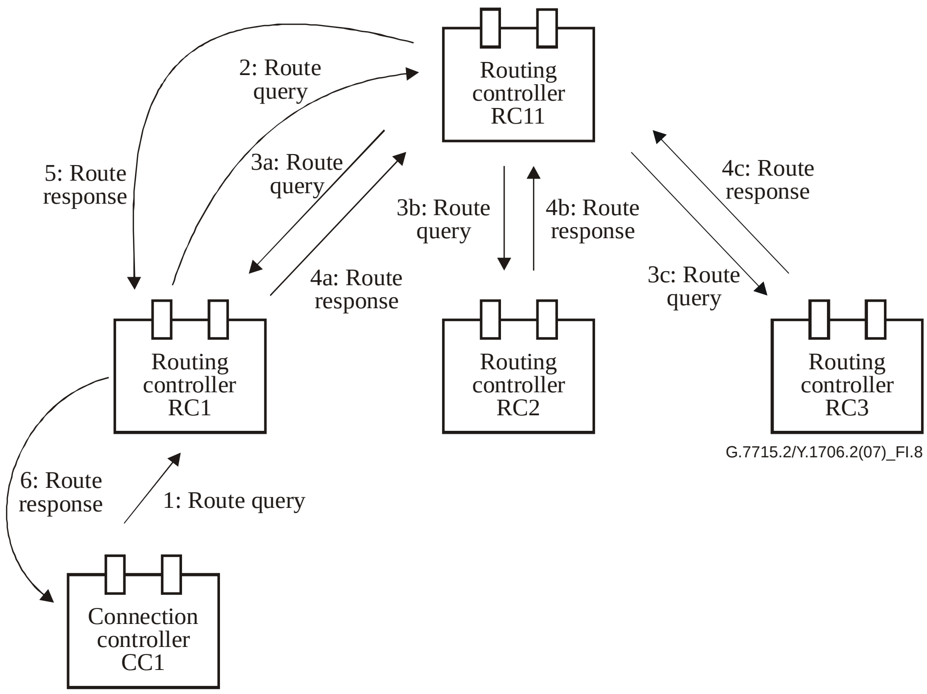


Figure I.8 – Hierarchical route query component interactions

Component interaction in this example is illustrated in Figure I.8 with the following procedure:

1) CC1 sends a route query message to RC1 which belongs to the same routing area with CC1.

2) RC1 does not have the sufficient information to satisfy the path computation query, it sends a route query message to its parent route controller RC11, which is assumed to be having the capability to determine the required path.

3) RC11 looks up the associated routing information database, and finds the destination SNPP belongs to RA3, which can be reached via SNPP link A-B between RA1 and RA2, followed by SNPP link C-D between RA2 and RA3. RC11 sends a route query message to RC1 to compute from the source to SNPP A, RC2 to compute from SNPP B to SNPP C and RC3 to compute from SNPP D to the destination SNPP, respectively.

4) RC1, RC2 and RC3 return the corresponding path computation results to RC11.

5) RC11 collects all the responses and assembles them into a complete end-to-end route which is finally sent back to RC1. RC1 in turn returns the path to CC1.

6) The end-to-end route is received by CC1, and CC1 initiates the connection setup process.

The procedure of hierarchical remote route query shall be visualized in the sequence diagram in Figure I.9:

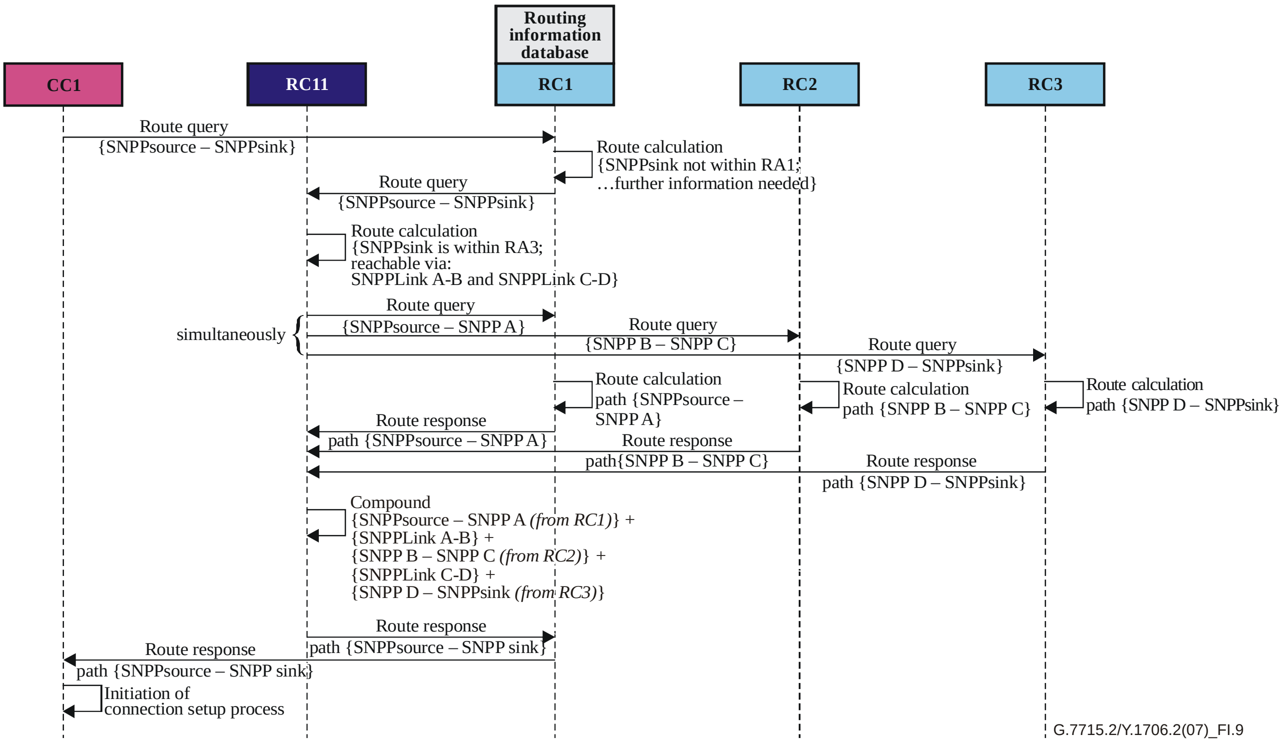


Figure I.9 – Hierarchical route query sequence diagram

I.4 Hierarchical source routing using route query interface

In Figure I.10, an end-to-end connection is requested, where the source and destination SNPP is attached with Node A in RA1 and Node I in RA3, respectively, and the connection also passes through RA2. There is also a parent routing RA (RA0) in the next higher routing hierarchy, where there are three parent RCs that are on the same nodes as their child RCs, and they are C, D and H, respectively.

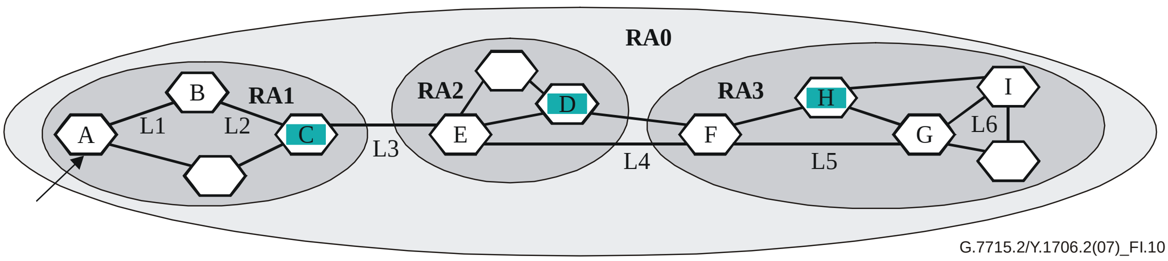


Figure I.10 – Hierarchical source routing using route query interface

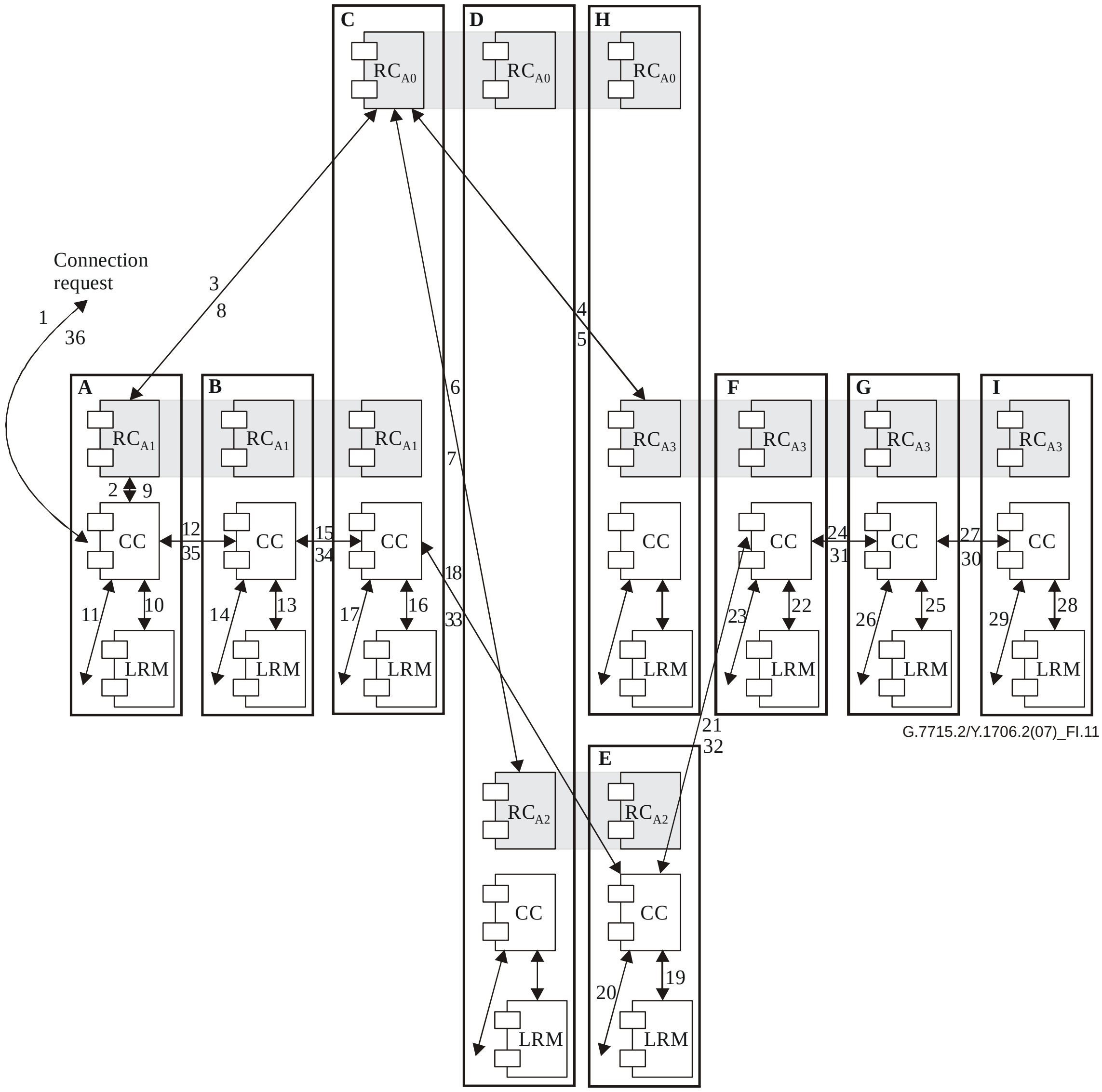


Figure I.11 – Hierarchical source routing component interactions

Figure I.11 illustrates the detailed sequence of operations involved in setting up a connection using source routing assisted by RC-RC route query. The notation $RC_{A1,}$ $RC_{A2,}$ etc., represent routing controller in Area A1, A2, etc. The actual communication components may be facilitated by other intermediate components – for example, the communication from RC_{A0} on Node C to RC_{A2} on Node D may be performed by transferring the message through RC_{A0} on Node D.

The procedure of hierarchical source routing shall be visualized in the sequence diagram in Figure I.12:

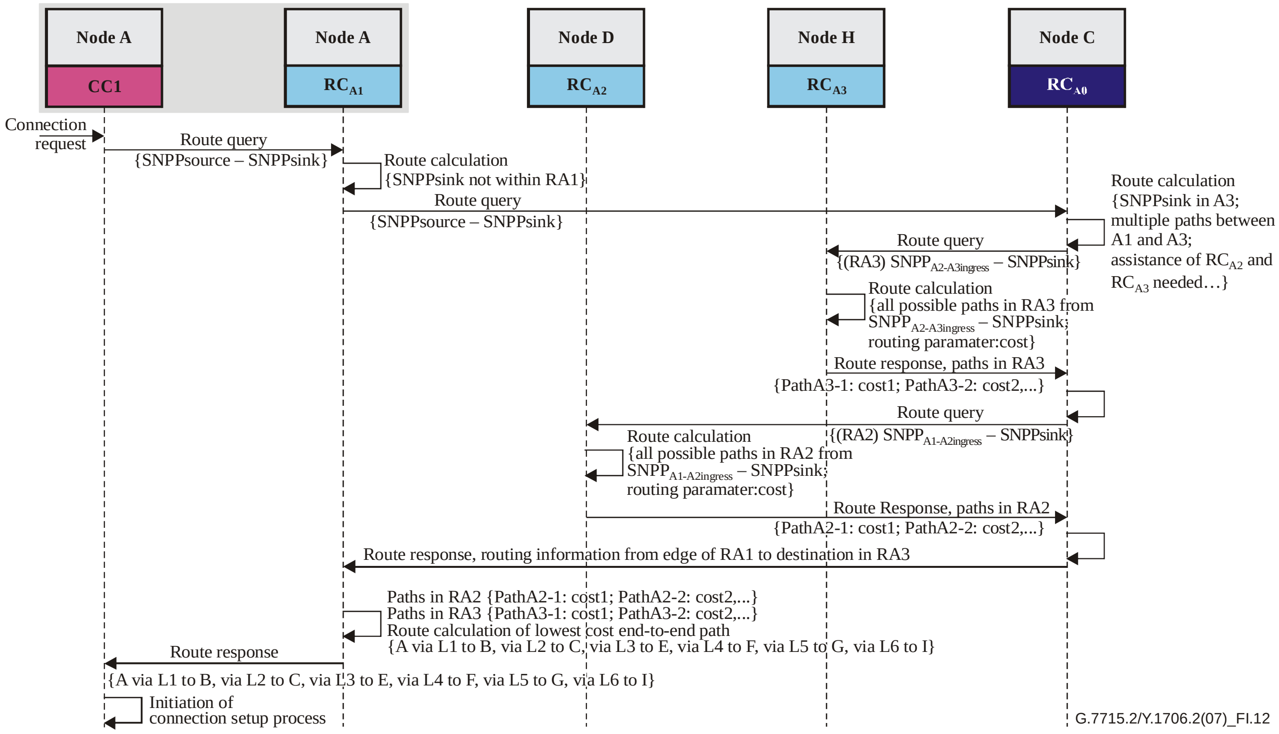


Figure I.12 – Hierarchical source routing sequence diagram

The steps involved are listed below.

1) A connection request arrives at the connection controller (CC_A) from the connection_request_in interface, specified as a pair of names (A and Z) at the edge of the subnetwork.

2) The routing controller RC_{A1} on Node A is queried (using the Z end SNP over the route query interface).

3) The routing controller RC_{A1} on Node A recognizes that the destination address is not visible within Area A1 so it sends a route query to RC_{A0} on Node C for assistance over the route query interface. While RC_{A1} on Node C has the same routing information as RC_{A1} on Node A as they are in a common routing area, RC_{A0} on Node C has visibility to the destination making the computation of a path possible.

4) In the process of computing a path to the destination, RC_{A0} on Node C recognizes that to reach the destination it needs to reach Area A3. However, since there are multiple paths between Area A1 and Area A3, it needs the assistance of RC_{A2} and RC_{A3} to determine the best path. Thus a query is sent by RC_{A0} on Node C to RC_{A3} on Node H to determine which link from A2 to A3 should be used.

5) RC_{A3} on Node H computes the possible paths from the links entering Area A3 from Area A2 to the destination within Area A3. From this, it can determine the costs of using either of the paths, and returns this information to RC_{A0} on Node C.

6) As with RC_{A3} on Node H, RC_{A0} on Node C sends a query to RC_{A2} on Node D to determine the paths between the egress links that egress Area A2 and enter Area A3 and the ingress links that enter Area A2 from Area A1.

7) RC_{A2} on Node D computes the possible paths across Area A2, and returns this information to RC_{A0} on Node C.

8) RC_{A0} on Node C provides to RC_{A1} on Node A the list of paths developed from the edge of Area A1 to the destination in Area A3 and includes the aggregate cost for each path developed.

9) RC_{A1} on Node A now has the necessary information to compute a path across Area A1 utilizing the cost information provided by RC_{A0} on Node C to determine the lowest cost end-to-end path. For the remainder of this example, we assume the path chosen is from A, via L1 to B, via L2 to C, via L3 to E, via L4 to F, via L5 to G, and via L6 to I. It then sends the response back to CC on Node A, which starts the process to form the end-to-end connection request using route (A, L1, L2, L3, L4, L5, L6 and Z).

10) L1 is local to Node A, and a link connection for L1 is obtained from LRM_A over the link connection request interface.

11) The appropriate SNC is established on the local switch (controller not shown).

12) The connection request (L2, L3, L4, L5, L6 and Z) is then forwarded to the next CC on Node B (over the peer coordination_out/in interface).

13) LRM_B controls L2, so a link connection is obtained from this link over the link connection_request interface.

14) The appropriate SNC is established on the local switch (controller not shown).

15) The connection request (L3, L4, L5, L6 and Z) is then forwarded to the next CC on Node C (over the peer coordination_out/in interface).

16) LRM_C controls L3, so a link connection is obtained from this link over the link connection_request interface.

17) The appropriate SNC is established on the local switch (controller not shown).

18) The connection request (L4, L5, L6 and Z) is then forwarded to the next CC on Node E (over the peer coordination_out/in interface).

19) LRM_E controls L4, so a link connection is obtained from this link over the link connection_request interface.

20) The appropriate SNC is established on the local switch (controller not shown).

21) The connection request (L5, L6 and Z) is then forwarded to the next CC on Node F (over the peer coordination_out/in interface).

22) LRM_F controls L5, so a link connection is obtained from this link over the link connection_request interface.

23) The appropriate SNC is established on the local switch (controller not shown).

24) The connection request (L6 and Z) is then forwarded to the next peer CC on Node G (over the peer coordination_out/in interface).

25) LRM_G controls L6, so a link connection is obtained from this link over the link connection_request interface.

26) The appropriate SNC is established on the local switch (controller not shown).

27) The connection request (Z) is then forwarded to the next CC on Node I.

28) LRM_I controls the egress link to the destination node, so a link connection is obtained from this link over the link connection request interface.

29) The appropriate SNC is established on the local switch (controller not shown).

The CC on Node I then sends a confirmation back to the CC on Node G, and the confirmation propagates further hop-by-hop in the reversed direction, as indicated by step 30 through 35 in Figure I.11, until it reaches the connection originator CC on Node A.

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