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Amendment 1
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SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS

Access networks – In premises networks

Centralized metric-based source routing

Amendment 1

Recommendation ITU-T G.9905 (2013) – Amendment 1

ITU-T

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Recommendation ITU-T G.9905

Centralized metric-based source routing

Amendment 1

Summary

Recommendation ITU-T G.9905 specifies centralized metric based source routing (CMSR), a proactive, layer 2 multi-hop routing protocol. CMSR is a proactive routing protocol which can find and maintain reliable routes considering the link quality of both directions. The routing control packet overhead of CMSR is quite low compared to existing proactive routing protocols such as optimized link state routing (OLSR), so that it can be applied for large-scale networks even on narrow band power line communication (PLC) networks.

Amendment 1 adds the following features: a PAN-INFO sub-message in the Hello message to notify information on the coordinator or network status, message formats for non-6LoWPAN networks, and a procedure for inter-node communication and upstream source routing.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.9905	2013-08-29	15	11.1002/1000/12007
1.1	ITU-T G.9905 (2013) Amd. 1	2016-11-13	15	11.1002/1000/13110

* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at http://www.itu.int/ITU-T/ipr/.

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Centralized metric-based source routing

Amendment 1

Editorial note: This is a complete-text publication. Modifications introduced by this amendment are shown in revision marks relative to Recommendation ITU-T G.9905 (2013).

1 Scope

This Recommendation specifies centralized metric based source routing (CMSR), a proactive, layer 2 multi-hop routing protocol.

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.9903] Recommendation ITU-T G.9903 (2014), *Narrowband orthogonal frequency division multiplexing power line communication transceivers for G3-PLC networks*.

[IETF RFC 4944] IETF RFC 4944 (2007), *Transmission of IPv6 Packets over IEEE 802.15.4 Networks*.

[IETF RFC 6282] IETF RFC 6282 (2011), *Compression Format for IPv6 Datagrams over IEEE 802.15.4-Based Networks*.

3 Definitions

3.1 Terms defined elsewhere

None.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 1WAY link: A link between neighbour nodes for which only the incoming link cost is available.

3.2.2 2WAY link: A link between neighbour nodes for which both incoming and outgoing link costs are available.

3.2.3 Hello message: A message transmitted by each node in order both to notify its existence and to exchange link cost and route information with neighbour nodes.

3.2.4 LC incoming: The cost of a one-way link from a neighbour node.

3.2.5 LC outgoing: The cost of a one-way link toward a neighbour node.

3.2.6 link: A link between two nodes exists if either can receive control messages from the other, according to this specification.

3.2.7 link cost (LC): The cost of a link between a pair of nodes, calculated from bidirectional link quality. The LC value used is the greater of "LC incoming" and "LC outgoing".

3.2.8 LOST link: A broken link where communication is no longer possible.

3.2.9 node: Communication equipment, including the personal area network (PAN) coordinator, which communicates using the CMSR protocol according to this specification.

3.2.10 provisional route cost: The provisional route quality between a node and the coordinator, equal to the sum of the route cost from a neighbour node to the coordinator and the LC incoming from the neighbour node.

3.2.11 route cost: The total route quality between a node and the coordinator, equal to the sum of all link costs in the route from the node to the coordinator.

3.2.12 topology report message: A message transmitted to the coordinator (using unicast) that contains route and neighbour node information.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

CMSR	Centralized Metric based Source Routing
LC	Link Cost
MAC	Media Access Control
NSDU	Network Service Data Unit
PAN	Personal Area Network
PLC	Power Line Communication

5 Protocol overview

Multi-hop routing protocols are a key feature of communication for advanced metering applications over power line communications (PLCs). For a large-scale PLC network, e.g., PLC deployment in a large-scale apartment building, a robust and low overhead routing protocol is required in order to achieve reliable metering.

This Recommendation addresses the following main objectives:

- Perform mesh-under proactive routing on 6LoWPAN in IPv6 networks, and communicate using 16-bit short addresses used by 6LoWPAN.
- Discover a bidirectional route between a node and a coordinator, taking bidirectional link quality into account.
- Establish and maintain multiple reliable routes in case route break occurs.
- Generate control packets which increase as only *O*(N) for route discovery and maintenance (with N being the number of nodes present in the network).
- Deliver data packets with source routing and/or hop-by-hop routing.

5.1 Outline of operation

CMSR performs mesh-under routing basically on 6LoWPAN in IPv6 networks, and communicates using 16-bit short addresses used by 6LoWPAN~~.~~, but it can also work in a network without 6LoWPAN. The usage for non-6LoWPAN networks is defined in Annex B. In order to perform neighbour node detection and route discovery, a Hello message is used for exchanging route and link quality information between nodes, whereas a topology report message is used to notify the coordinator. The coordinator and nodes maintain neighbour tables for storing information on neighbour nodes, and route tables for storing route information. Each node determines an optimal route based on the link quality and the number of hops to the coordinator.

5.1.1 Route discovery

Route discovery is carried out with the three steps shown in Figure 5-1.

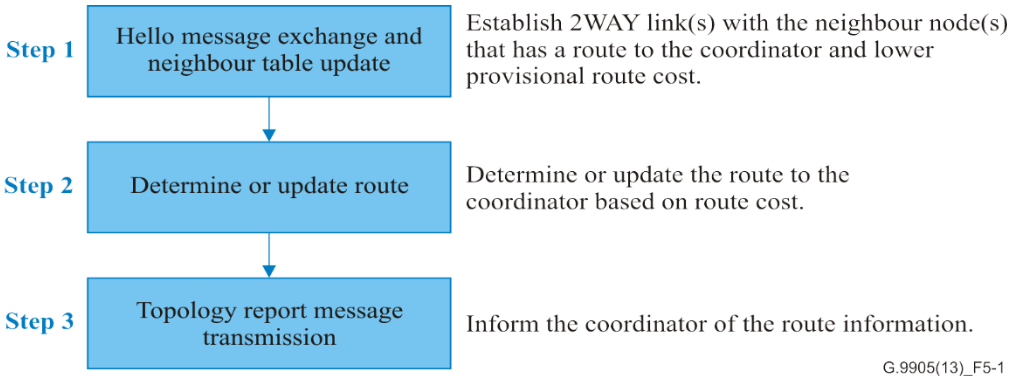

Figure 5-1 – Overview of route discovery steps

Step 1: Hello message exchange and neighbour table update

Each node periodically transmits the Hello message as a 1-hop broadcast message with the interval of HELLO_INTERVAL (or HELLO_INTERVAL_FAST as mentioned in clause 8.1.1). In order to avoid a permanent collision of Hello messages, each node randomly shifts the transmission timing. The maximum timing shift is defined by HELLO_JITTER.

For route discovery, the node establishes a 2WAY link with the node which already has a route to the coordinator. Figure 5-2 shows how the 2WAY link is established. The node that receives the Hello message stores the information included in the Hello message in the neighbour table. When the node receives a Hello message from its neighbour node for the first time, the link between the nodes is considered as a 1WAY link (meaning that the node has measured the LC incoming from that neighbour node but does not know the LC outgoing to that neighbour node). The receiving node calculates the provisional route cost as the sum of the route costs in the received Hello messages and the measured LC incoming. The status, LC incoming and provisional route cost are recorded in the neighbour table (first phase in Figure 5-2).

The node selects the neighbour nodes based on the provisional route costs, i.e., neighbour nodes with lowest provisional route costs. Up to LINK_MAX_PREFERRED neighbour nodes may be selected. The node sends a Hello message with the link request (LINK_REQ sub-message) to the selected neighbour nodes to obtain the LC outgoing. Upon reception of the LINK_REQ sub-message, the neighbour nodes record the LC incoming and LC outgoing according to the received message (second phase in Figure 5-2).

The neighbour nodes transmit LINK_REP sub-messages including the LC incoming to the originator of the LINK_REQ. The originator node stores the LC incoming in the received LINK_REP sub-message as LC outgoing, and sets the link status as "2WAY" (third phase in Figure 5-2).

Note that the LINK_REQ and LINK_REP sub-messages are transmitted in the Hello message that is periodically transmitted with the interval of HELLO_INTERVAL (or HELLO_INTERVAL_FAST).

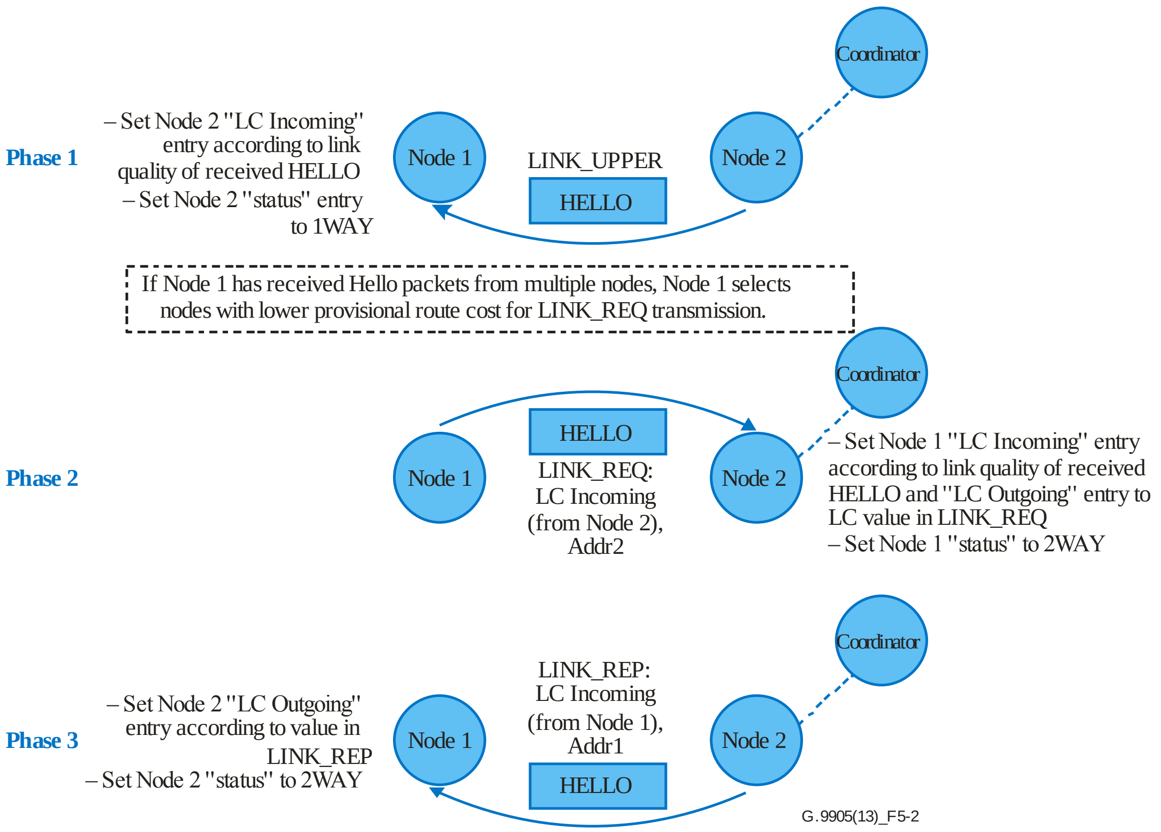

Figure 5-2 – Establishment of 2WAY link using LINK_REQ/LINK_REP sub-messages

Step 2: Route determination/update

The node may receive LINK_REP sub-messages from more than one neighbour node in Step 1. The node calculates the route cost associated with each neighbour node based on the link cost (i.e., greater of LC incoming and LC outgoing) and the route cost information in the LINK_REP sub-message from the neighbour node. The node selects the route with the least route cost. Other routes may be selected as candidates for route recovery. The route information, i.e., relay node addresses and each link cost, is stored in the route table.

If the node already has the route to the coordinator and it finds a better route, the route may be updated.

Step 3: Topology Report message transmission (route update for the coordinator)

The Topology Report message is used to inform the coordinator of the routes used by each node, 2WAY links associated with each node and broken links associated with each node. The node periodically transmits a Topology Report message toward the coordinator. The coordinator updates the route table for each node based on the received Topology Report messages. Note that the coordinator does not transmit the Topology Report message.

The above steps are repeated and each node updates the route based on the Hello messages and the Topology Report messages periodically transmitted by other nodes.

5.1.2 Fast mode operation

Fast mode is used to shorten the route discovery time. The node in fast mode transmits the Hello message with an interval of HELLO_INTERVAL_FAST. If the node does not currently have a route to the coordinator, the node operates with the fast mode and may request its neighbour nodes to operate in fast mode by setting the fast mode flag in the Hello message. Any node which receives a Hello message with fast mode flag set to "enable" shall operate with fast mode for a certain period.

5.1.3 Route recovery

CMSR allows a node to maintain alternative routes in case broken links occur.

For upstream communication, each node has the route to the coordinator and possibly an alternative route. If the node stores an alternative route, it changes the route immediately.

For downstream communication with source routing, the node reports the failure to the source node (i.e., coordinator), which allows the coordinator to select an alternative route.

5.1.4 Packet delivery

5.1.4.1 Unicast packet

The coordinator and the nodes send upper layer packets using the discovered route.

In upstream communication (from a node to the coordinator), the node shall select one of two methods – source routing or hop-by-hop. In hop-by-hop, a source node sends packets only to an upstream destination neighbour node. In order to facilitate rapid route recovery, the route to the coordinator is not included in these packets. Each node relays the packet to the uplink in a hop-by-hop manner. In source routing, the node specifies the entire route to the final destination and the CMSR source route header is attached to the packet.

In downstream communication (from the coordinator to a node), the coordinator shall select one of two methods – source routing or hop-by-hop. In source routing, the coordinator specifies the entire route to the final destination and the CMSR source route header is attached to the packet. This is necessary as, in order to reduce memory resource usage, nodes do not hold route information to other nodes. In hop-by-hop, the coordinator transmits the packet to the next hop, and the relay node forwards the packet based on the route information stored in the route table. These methods can be selected according to system requirements.

In inter-node communication (from a node to a node), the node shall select one of two methods – source routing or hop-by-hop. The originator node sends packets according to the upstream communication procedure. In each node, the route to the coordinator is defined as the default route. If the node (originator node or relay node) has the route to the destination node, it transmits the packet based on the route to the destination. If not, it may discard the packet or transmit the packet based on the default route, i.e., the route to the coordinator. When the coordinator receives the packet destined for a node, the coordinator relays it to the destination node according to the downstream communication procedure.

5.1.4.2 Broadcast packet

Only a limited number of nodes forward a broadcast packet in order to avoid congestion in a large-scale network. Only nodes which are listed in the LINK_UPPER sub-message of the Hello messages from the different nodes are enabled to forward a broadcast packet.

5.2 Table overview

The necessary protocol state is recorded in the route table and the neighbour table. Every node has its own tables.

The route table contains tuples of destination short address, route cost, hop count and short address list of relay nodes to the destination. The node updates the route table when it finds or updates the route based on received Hello messages or when it receives a Topology Report message from a node.

The neighbour table contains tuples of neighbour node address, node type, link status, link cost incoming, link cost outgoing, link cost of relay link, short address list of relay nodes and the route cost. The node updates the neighbour table according to Hello messages received from neighbour nodes.

5.3 Signalling overview

This protocol generates and processes the CMSR message and the source route header. The CMSR message includes three types of messages, Hello message, Topology Report message and Route Error message.

5.3.1 Hello message

The Hello message is used by nodes to notify their existence and status to each other in the route discovery process, and is also used to deliver coordinator information or network status. The Hello message contains one or more of the following fivefour sub-messages.

LINK_UPPER sub-message: Used to notify the route from the node to the coordinator and each link cost within the route. This sub-message contains the list of relay node addresses and the link cost of each link.

LINK_REQ sub-message: Used to request a neighbour node to feedback the link cost from the node to the neighbour node. This sub-message also indicates to the neighbour node that the link between the node and the neighbour node is a 1WAY link. This sub-message contains one or more sets of the target node address and its link cost.

LINK_REP sub-message: Used to respond to the LINK_REQ sub-message received from a neighbour node. This sub-message contains one or more sets of the target node and its link cost (i.e., outgoing link cost for the neighbour node).

LINK_LOST sub-message: Used to notify the existence of a broken link. This sub-message contains one or multiple sets of the target node and its link cost (must be zero). LINK_LOST is determined by the lack of reception of a Hello message from a node for a period given by HELLO_MAX_COUNT multiplied with HELLO_INTERVAL.

PAN_INFO sub-message: This is optionally used to notify coordinator information or network status information, and it contains one or more attribute types. One of the attribute types is coordinator reboot count e.g., to notify encryption key update due to coordinator reboot and encourage nodes to trigger re-authentication for a key update.

For reliable message delivery, more than one transmission of LINK_REQ, LINK_REP and LINK_LOST sub-messages addressed to a certain neighbour node may be conducted. The number of transmissions is given by NOTIFY_MAX_COUNT.

5.3.2 Topology Report message

The Topology Report message contains information on the route to the coordinator and link status with neighbour nodes. Each node generates a Topology Report message based on the route table and the neighbour table, and periodically sends it to the coordinator. A Topology Report message contains one or more of the following three sub-messages.

LINK_UPPER sub-message: Indicates the route information from the node to the coordinator and each link cost. This sub-message contains the list of relay node addresses and the link cost of each link.

LINK_2WAY sub-message: Indicates neighbour nodes have associated with 2WAY links. This sub-message contains one or multiple sets of the target node address and its link cost.

LINK_LOST sub-message: Indicates a broken link. This sub-message contains one or multiple sets of the target node addresses and their link cost (must be zero).

If the Topology Report message from a node is not received by the coordinator for a certain period, the coordinator considers the route for the node is broken.

5.3.3 Route Error message

The Route Error message is used to indicate the failure of packet delivery. If the packet is not correctly delivered to the next hop node in downstream communication, the node transmits the Route Error message to the originator (i.e., the coordinator) so that the originator can re-select the route for packet transmission.

The Route Error message contains a LINK_LOST sub-message that indicates the broken link(s).

5.3.4 Source route header

For source routing, the source route header is attached in the packet. The source route header contains the relay node addresses in the route to the destination. When the node receives a packet with a source route header, the node relays the packet according to the source route header.

5.4 Protocol parameters

CMSR uses the following parameters.

HELLO_INTERVAL: Transmission interval of Hello message.

HELLO_INTERVAL_FAST: Transmission interval of Hello message in fast mode.

HELLO_JITTER: Jitter of Hello message transmission timing, expressed as a ratio (0~1) to HELLO_INTERVAL (or HELLO_INTERVAL_FAST).

TOPOLOGY_REPORT_INTERVAL: Transmission interval of Topology Report message.

TOPOLOGY_REPORT_INTERVAL_FAST: Transmission interval of Topology Report message for fast mode node.

LINK_MAX_PREFERRED: Maximum number of links which can be listed as preferred link.

HELLO_MAX_COUNT: Timer for absence of Hello message from a neighbour node. Used for decision of link lost.

NOTIFY_MAX_COUNT: Number of Hello sub-message transmissions addressed to a certain node.

ROUTE_VALID_COUNT: Timer for absence of Topology Report message from a node. Used for decision of route lost.

6 Table and information base

CMSR uses two tables, "neighbour table" and "route table", which are maintained by all nodes, including the coordinator. In addition, CMSR uses FloodingFlag, which is Boolean type flag (0: disable, 1: enable) and is used to enable or disable relay of broadcast packet for each node.

6.1 Neighbour table

The neighbour table consists of the entries shown in Table 6-1. The neighbour table may contain one or more sets of entries.

Table 6-1 – Neighbour table

Entry	Definition
Neighbour node address	16-bit short address of the neighbour node
Node type	Coordinator(0), non-coordinator node(1)
Link status	The status of the link. 1WAY(1), 2WAY(2), LOST(3)
LC incoming	Link cost from the neighbour node to the node itself
LC outgoing	Link cost from the node itself to the neighbour node
LC of relay link list	Link cost of each link in the route from the neighbour node to the coordinator
Short address of relay node list	Short address of each relay node in the route from the neighbour node to the coordinator
Route cost	Route cost from the node itself to the coordinator

6.2 Route table

The route table is shown in Table 6-2.

Table 6-2 – Route table

Entry	Definition
Destination short address	16-bit short address of final-destination node
Route cost	Route cost from the node itself to the destination node
Hop count	The number of hops to the final-destination node
Short address list	16-bit short addresses of relay nodes

7 Message format

The packet format used for routing is shown in Figure 7-1. "Mesh type and header" and "broadcast type and header" use the format described in [IETF RFC 4944].

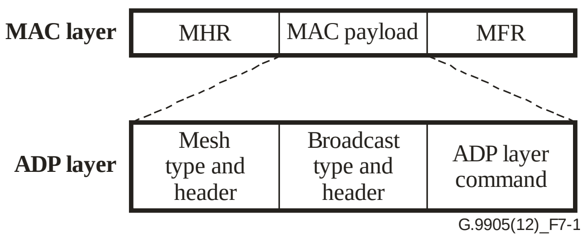

Figure 7-1 – Packet format

CMSR makes use of the ADP layer command frame header of a 6lowPAN frame [IETF RFC 4944]. The ADP layer command frame header is identified using the ESC header type [IETF RFC 6282], followed by an 8-bit command ID field and the command payload, as shown in Figure 7-2. This header must always be in the last position in the 6lowPAN frame.

The command ID indicates that the ADP layer payload contains a CMSR protocol message. The value of the command ID used for the present Recommendation may depend on the ADP layer specification, as shown in Table 7-1.

For a CMSR protocol message, the ADP layer payload shall contain either a source route header or a CMSR message. The CMSR message, in turn, shall contain one of three message types – Hello message, Topology Report message or Route Error message. The content is identified using the message type field at the beginning of the command payload, as shown in Table 7-1a.

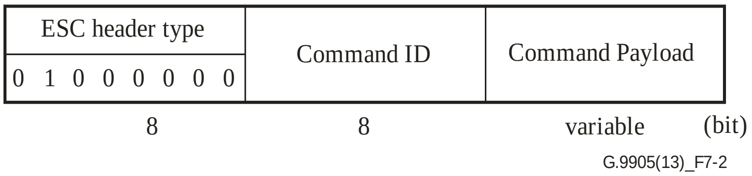

Figure 7-2 – ADP command frame header

Table 7-1 – Command ID used in ADP layer

Command	Command ID
CMSR protocol message	Depending on ADP layer specification

Table 7-1a – Message type

Message type	Message
0x1	CMSR message – Hello
0x2	CMSR message – Topology Report
0x3	CMSR message – Route Error
0x8	Source route header

7.1 CMSR source route header

The source route header is used by the coordinator or nodes when sending a message to a particular node. It contains the route from the originator ~~coordinator~~ to the destination~~node~~ and is constructed by the originator~~coordinator~~. The source route header contains the relay node addresses in the route to the destination. The format of the source route header is shown in Figure 7-3. The definition of the field is given in Table 7-2.

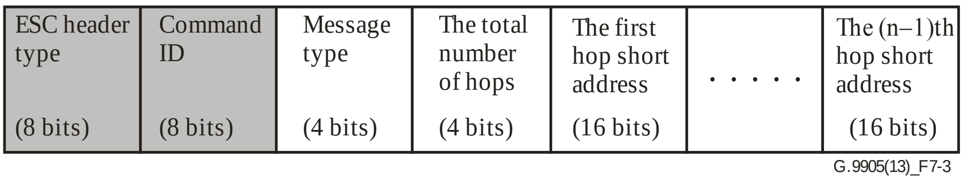

Figure 7-3 – CMSR source route header format

Table 7-2 – Source route header fields

Field	Length	Definition
Total number of hops	4 bits	The number of hops from the originator to the destination ~~node~~
First hop short address	16 bits	Relay node address of the first hop
…	…	…
Nth hop short address	16 bits	Relay node address of the Nth hop. N denotes the total number of hops

The addresses of relay nodes shall be placed in order from the originator~~coordinator~~ to the destination.

7.2 CMSR message

Three types of CMSR messages, Hello message, Topology Report message and route error message, are defined. The general format of the CMSR message is shown in Figure 7-4. The definition of the fields is given in Tables 7-3 and 7-4.

The format of the CMSR message is shown below.

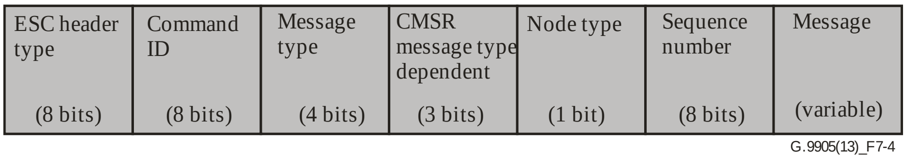

Figure 7-4 – CMSR message format

Table 7-3 – CMSR message fields

Field	Length	Definition
CMSR message type dependent	3 bits	Depends on CMSR message type, shown in Table 7-4
Node type	1 bit	0=coordinator, 1=non-coordinator node
Sequence number	8 bits	Incremented in every transmission
Message	Variable	Depends on message type

Table 7-4 – CMSR message dependent field

CMSR message	CMSR message type dependent field
Hello	Fast_mode flag (1 bit), reserved (2 bits)
Topology report	Reserved (3 bits)
Route error	Reserved (3 bits)

7.2.1 Hello message

The Hello message format is shown in Figure 7-5. In the Hello message, one bit (MSB) in the CMSR message type dependent field is used as fast mode flag. The definition of the fields is given in Table 7-5. The Hello message has five~~four~~ sub-messages. If there is no content to be included in a sub-message, it may be omitted. The format of the sub-messages is given in Figure 7-6, with sub-message types given in Table 7-6.

Message type	Fast mode flag	Reserved	Node type	Sequence number	Sub-message LINK_UPPER	Sub-message LINK_REQ	Sub-message LINK_REP	Sub-message LINK_LOST
(4 bits)	(1 bit)	(2 bits)	(1 bit)	(8 bits)	(variable)	(variable)	(variable)	(variable)

Message type	Fast mode flag	Reserved	Node type	Sequence number	Sub-message LINK_UPPER	Sub-message LINK_REQ	Sub-message LINK_REP	Sub-message LINK_LOST	Sub-message PAN_INFO
(4 bits)	(1 bit)	(2 bits)	(1 bit)	(8 bits)	(variable)	(variable)	(variable)	(variable)	(variable)

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Figure 7-5 – Hello message format

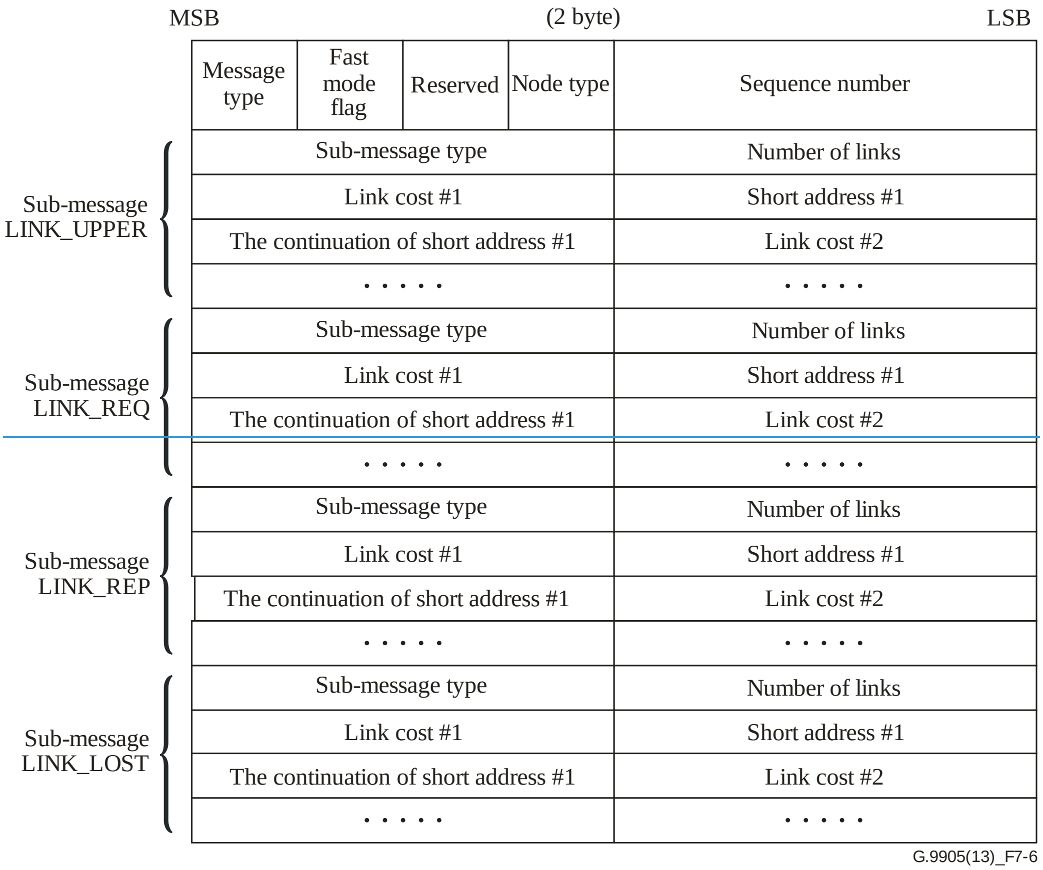
Table 7-5 – Hello message specific field

Field	Length	Definition
Fast mode flag	1 bit	0=no request, 1=request fast mode
Reserved	2 bits	Reserved for future use
LINK_UPPER sub-message	Variable	Indicates information on the route to the coordinator and link cost of each link. Contains the following fields: – sub-message type (shall be 0) – number of links in the route to the coordinator – link cost of each link in the route – short address of each link in the route
LINK_REQ sub-message	Variable	Indicates a request to neighbour nodes for outgoing link cost. Contains the following fields: – sub-message type (shall be 1) – number of neighbour nodes requested – incoming link cost for the neighbour node – short address of the neighbour node. Multiple sets of incoming link cost and short address may be included
LINK_REP sub-message	Variable	Indicates a response to a LINK_REQ sub-message from neighbour nodes. Contains the following fields: – sub-message type (shall be 2) – number of neighbour nodes replied – incoming link cost for the neighbour node – short address of the neighbour node. Multiple sets of incoming link cost and short address may be included
LINK_LOST sub-message	Variable	Indicates broken links. Contains the following fields: – sub-message type (shall be 3) – number of broken links – link cost of each link (shall be set all 0) – short address of the neighbour node associated with broken link.

Table 7-5 – Hello message specific field

Field	Length	Definition
		Multiple sets of incoming link cost and short address may be included

PAN_INFO sub-message	Variable	Indicates information on coordinator attribute and may include one or more attribute types.
		Contains the following fields:
		– sub-message type (shall be 10)
		– sub-message length (all fields in sub-message)
		– attribute information
		    – attribute type
		        type 1:coordinator boot count
		        type 0, 2-127: reserved by ITU-T
		        type 128-255: for proprietary use
		    – attribute length (all fields in attribute information)
		    – attribute value.
		Unknown attribute information shall be ignored.



MSB
(2 byte)
LSB
Message type
Fast mode flag
Reserved
Node type
Sequence number
Sub-message LINK_UPPER
Sub-message type
Number of links
Link cost #1
Short address #1
The continuation of short address #1
Link cost #2
Sub-message LINK_REQ
Sub-message type
Number of links
Link cost #1
Short address #1
The continuation of short address #1
Link cost #2
Sub-message LINK_REP
Sub-message type
Number of links
Link cost #1
Short address #1
The continuation of short address #1
Link cost #2
Sub-message LINK_LOST
Sub-message type
Number of links
Link cost #1
Short address #1
The continuation of short address #1
Link cost #2
G.9905(13)_F7-6

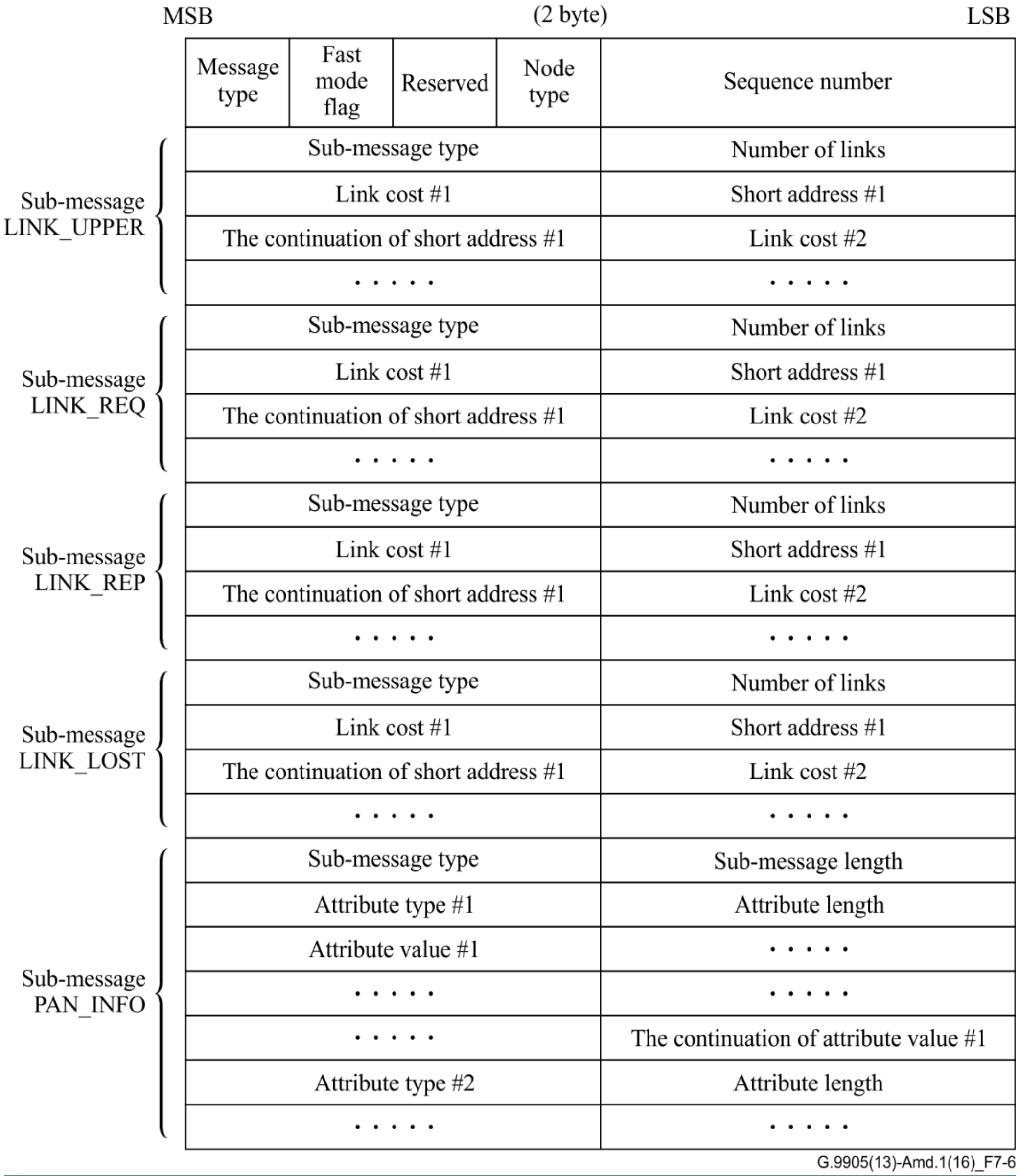


Figure 7-6 – Hello message sub-message formats

Table 7-6 – Sub-message type (Hello message)

Sub-message type	Value
LINK_UPPER	0
LINK_REQ	1
LINK_REP	2
LINK_LOST	3
PAN_INFO	10

7.2.2 Topology Report message

The Topology Report message contains three sub messages – LINK_UPPER, LINK_2WAY and LINK_LOST. The LINK_UPPER sub-message shall always be present. The remaining messages may be omitted if there is no content to be included in them. The Topology Report message format is shown in Figure 7-7. The CMSR message type dependent field is reserved for future use. The definition of the fields is given in Table 7-8. The format of the three sub-messages is shown in Figure 7-8. The definition of sub-message type field is given in Table 7-9.

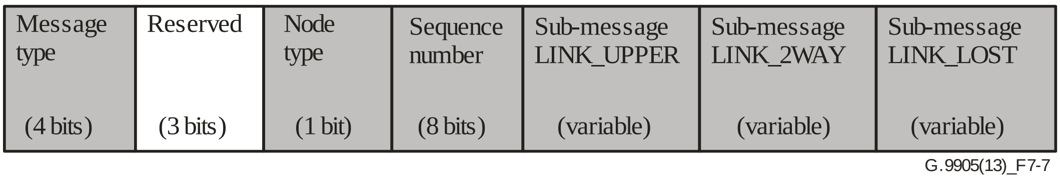


Figure 7-7 – Topology Report message format

Table 7-8 – Topology Report message specific field

Field	Length	Definition
Reserved	3 bits	Reserved for future use
LINK_UPPER sub-message	Variable	Same as LINK_UPPER sub-message field in Hello message (Table 7-6)
LINK_2WAY sub-message	Variable	Indicates available 2WAY links for the node. Contains the following fields: – sub-message type (shall be 1) – number of 2WAY links – link cost for the link – short address of the neighbour node with 2WAY link. Multiple sets of link cost and short address may be included
LINK_LOST sub-message	Variable	Same as LINK_LOST sub-message field in Hello message (Table 7-6)

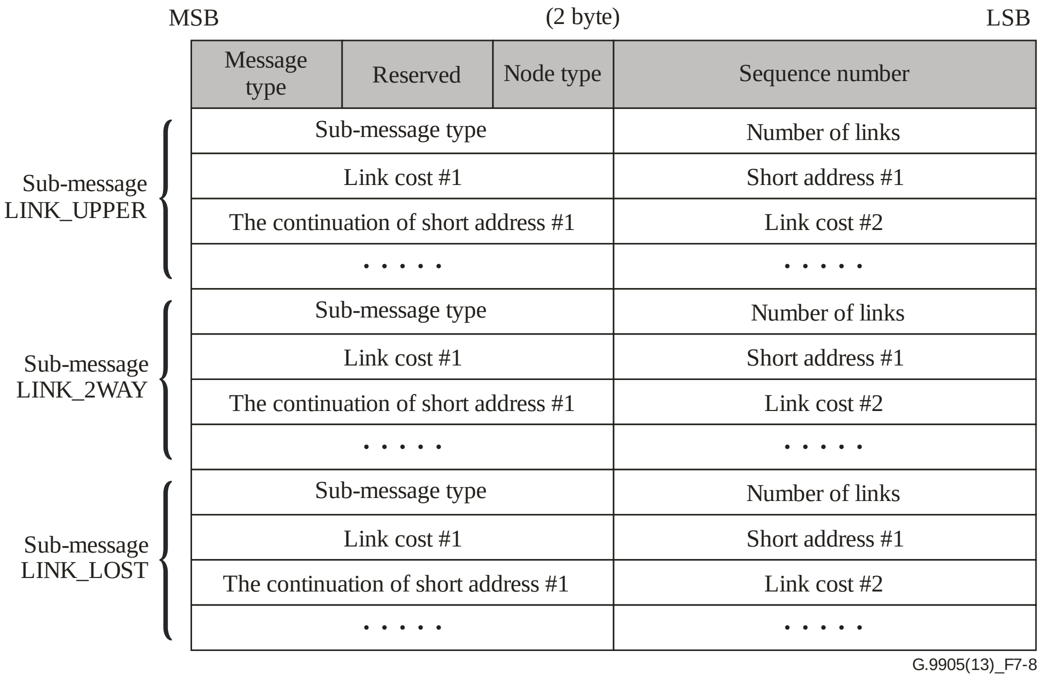


Figure 7-8 – Topology Report message sub-message formats

Table 7-9 – Sub-message type (Topology Report message)

Sub-message type	Value
LINK_UPPER	0
LINK_2WAY	2
LINK_LOST	3

7.2.3 Route Error message

The Route Error message contains the LINK_LOST sub-message. The LINK_LOST sub-message shall always be present. The Route Error message format is shown in Figure 7-9. The CMSR message type dependent field is reserved for future use. The definition of the fields is given in Table 7-10. The format of the sub-messages is shown in Figure 7-10.

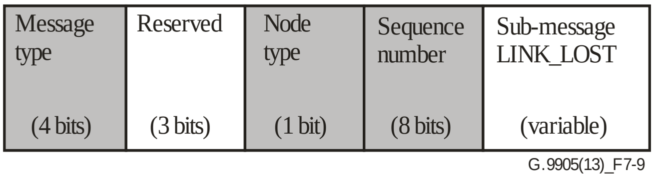


Figure 7-9 – Route Error message format

Table 7-10 – Route Error message specific field

Field	Length	Definition
Reserved	3 bits	Reserved for future use
LINK_LOST sub-message	Variable	Same as LINK_LOST sub-message field in Hello message (Table 7-6)

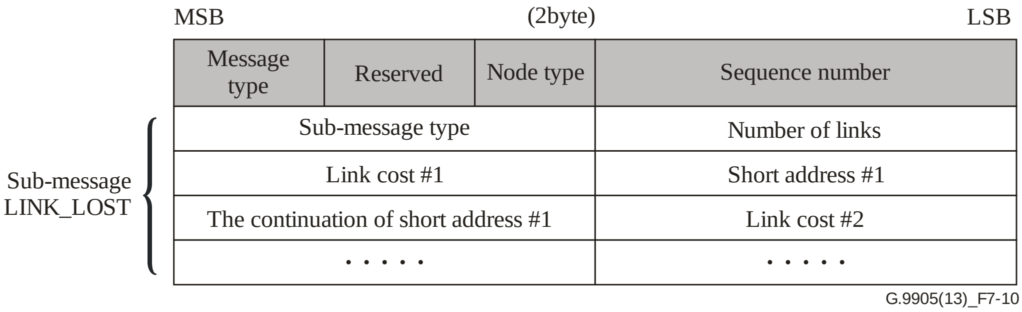


Figure 7-10 – Route Error message sub-message formats

8 Procedure

8.1 Hello message exchange

8.1.1 Generation

Each node generates a Hello message based on the information held in its neighbour table and broadcasts it at the timing given by the following equation.

$$t(i) = t(i-1) + HELLO\_INTERVAL\ (1 - HELLO\_JITTER*r) \qquad \text{(Eq.1)}$$

t(i): the timing for i-th Hello message transmission

r: a random variable whose range is 0~1

A node in fast mode shall use HELLO_INTERVAL_FAST instead of HELLO_INTERVAL in Eq.1. Figure 8-1 shows the Hello transmission timing.

When a node has no route to the coordinator in its route table, the node shall enable the fast mode flag in the Hello message.

If a node has a route to the coordinator, it shall include the LINK_UPPER sub-message in the Hello message. A node may include the LINK_REQ sub-message to request LC outgoing information from a neighbour node depending on the link status and the provisional route cost. Neighbour nodes with "1WAY" link status and in preferred link (i.e., having lower provisional route cost) shall be included in the LINK_REQ sub-message. In this case, the node shall include the short address of the neighbour node and LC incoming in the neighbour table associated with the neighbour node in the LINK_REQ sub-message. Requests to more than one neighbour node may be included in this sub-message, but shall not exceed LINK_MAX_PREFERRED neighbour nodes.

If a node has received a Hello message with LINK_REQ sub-message directed to the node from a neighbour node, the node shall include the LINK_REP sub-message as reply to the received LINK_REQ sub-message in the next Hello message(s). In this case, the node shall include the short address of the neighbour node and LC incoming in the neighbour table associated with the neighbour node. Replies to more than one neighbour node LINK_REQ may be included in this sub-message.

If a node has a neighbour node whose link status is LOST in the neighbour table, the node shall include the LINK_LOST sub-message in the Hello message. In this case, the node shall include the short address of the neighbour node with which the link has lost.

The LINK_REQ sub-message, LINK_REP sub-message and LINK_LOST sub-message addressed to a certain neighbour node shall be transmitted NOTIFY_MAX_COUNT times, irrespective of fast mode or normal mode.

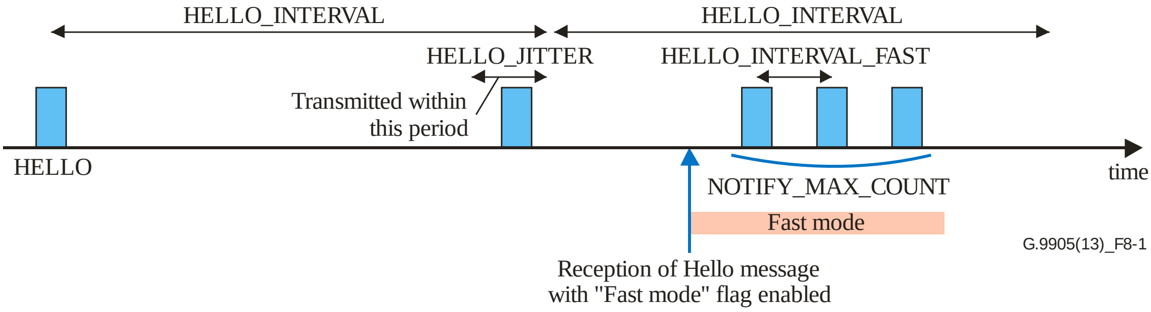


Figure 8-1 – Hello message transmission

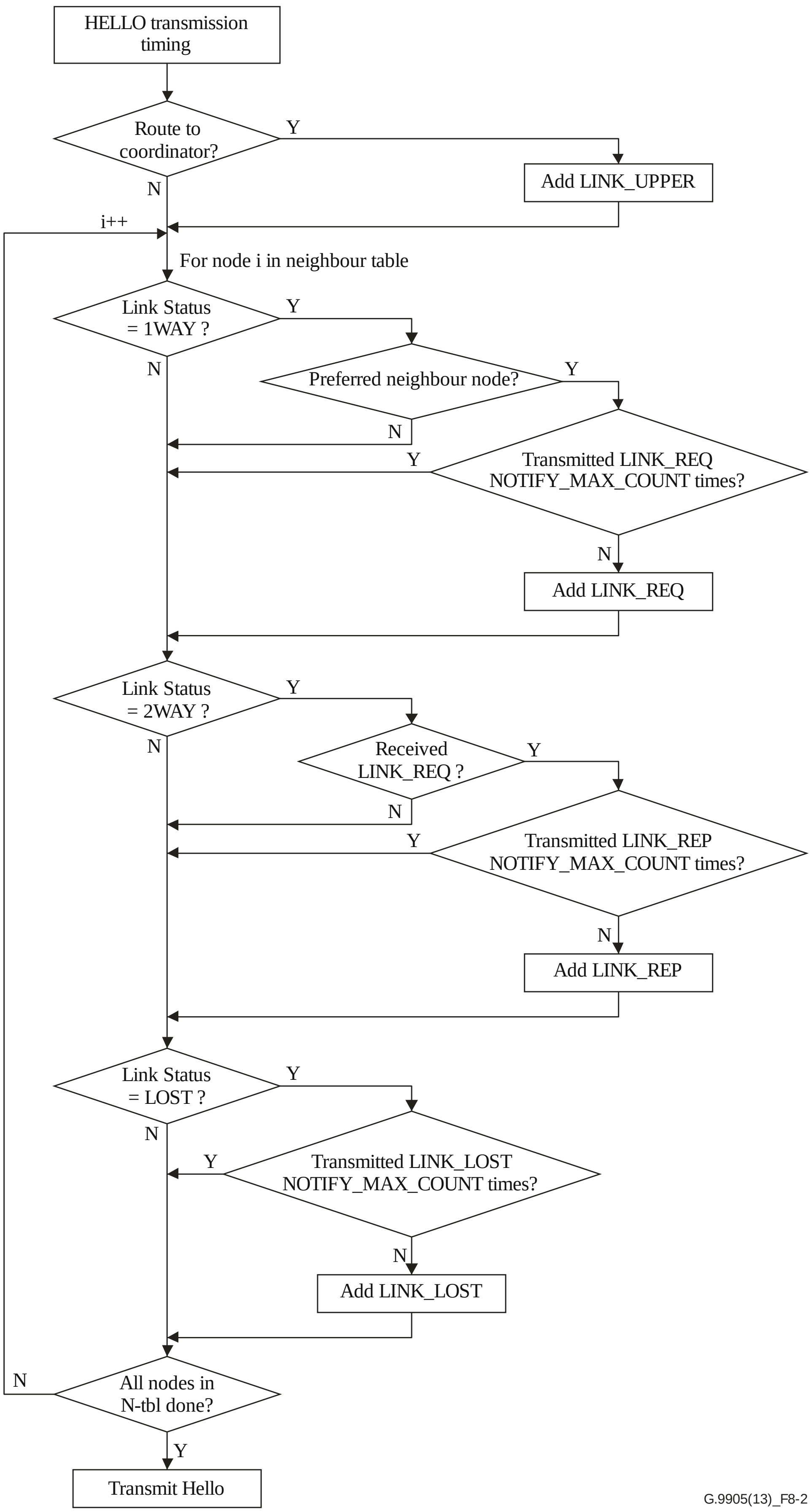


Figure 8-2 – flowchart for Hello message generation

8.1.2 Processing upon reception

Upon receiving a HELLO message, a node shall update its neighbour table based on the contents of the Hello message and measured LC incoming using the received Hello message. The process is as follows.

If a node receives a Hello message with fast mode flag enabled, the node shall enter fast mode. The node shall stay fast mode until the node transmits Hello messages NOTIFY_MAX_COUNT times.

If the source node of the received Hello message is not in its neighbour table, the receiving node shall add a new record for the source node with neighbour node address and node type entries.

The node shall update the LC incoming entry of the neighbour table based on measurement of the Hello message.

If the receiving node is in the LINK_UPPER sub-message of the received Hello message, the node shall update the FloodingFlag enabled. In this case, the node shall not select the neighbour node as a relay node in the route.

If the receiving node is not listed in the LINK_UPPER sub-message of the received Hello message, the node shall calculate the provisional route cost and update the "LC Relay Link List" and "Short Address of Relay Node List" entries in its neighbour table based on the contents in the LINK_UPPER sub-message.

If the receiving node is listed in the LINK_REQ sub-message, the node shall update the corresponding Link Status entry to "2WAY", the corresponding LC outgoing entry to the "Link Cost" value of the LINK_REQ sub-message and Notify Count entry to the initial value (NOTIFY_MAX_COUNT).

If the receiving node is listed in the LINK_REP sub-message, the node shall update the corresponding Link Status entry to "2WAY" and the corresponding LC outgoing entry to the "Link Cost" value of the LINK_REP sub-message.

If the receiving node is listed in the LINK_LOST sub-message, the node shall update the Link Status entry to "1WAY".

If the link status is "2WAY", the node updates the route cost field in the neighbour table according to the route information in the received LINK_UPPER sub-message (if there is) and link cost which is calculated as the maximum of LC incoming measured by the Hello message and LC outgoing obtained from LINK_REQ sub-message or LINK_REP sub-message (if there is).

The node shall select the route with the lowest route cost and may select other low cost routes to be used as alternatives in the case of route recovery. The node populates the "Hop Count" and "Short Address List" fields of its route table accordingly.

Table 6-1 summarizes the update of neighbour table upon reception of Hello message and a flowchart is provided in Figure 8-3.

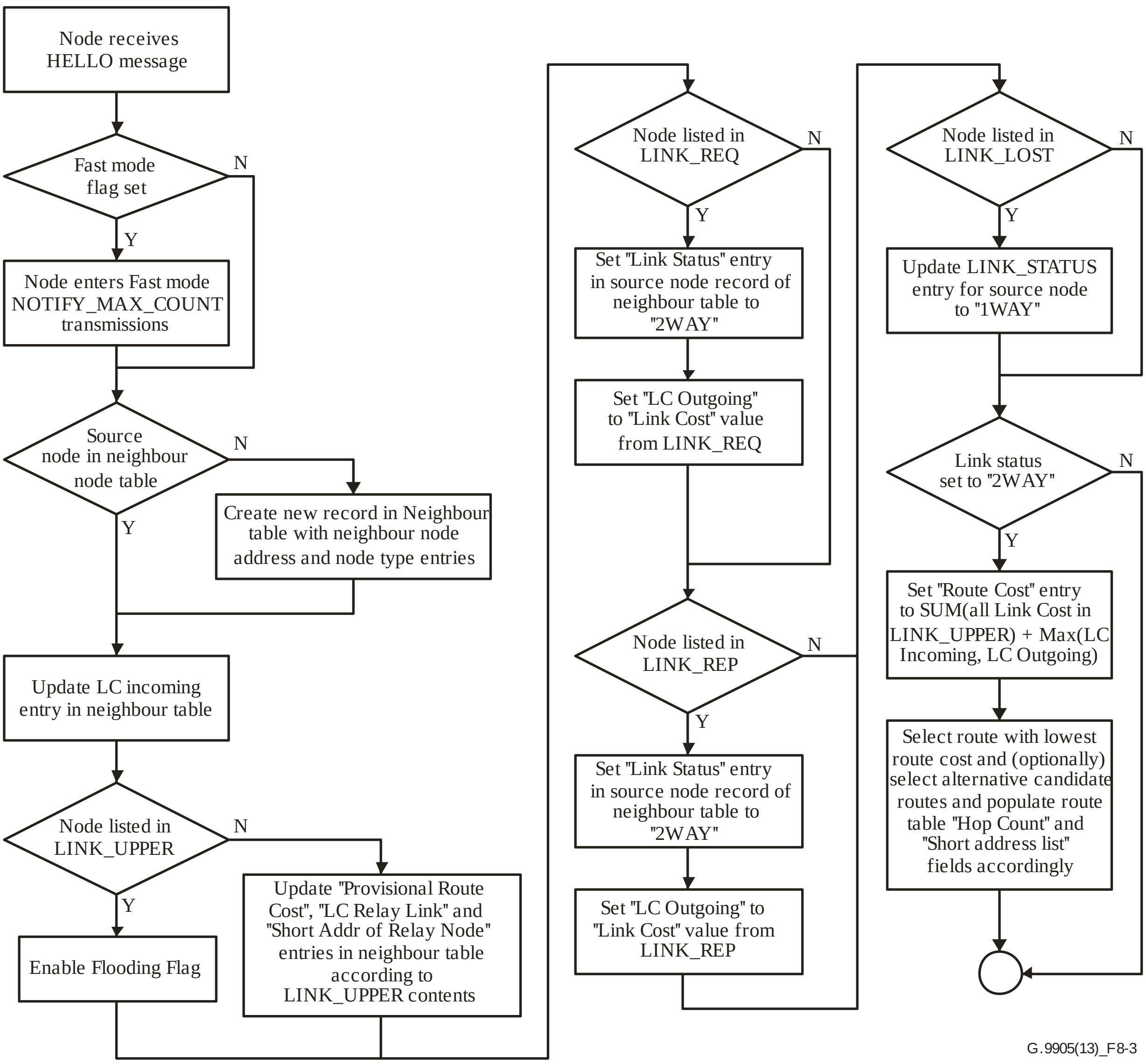


Figure 8-3 – Flowchart for Hello message reception

8.2 Topology report message transmission

8.2.1 Generation

The non-coordinator node shall transmit a Topology Report message as an unicast message at an interval given by TOPOLOGY_REPORT_INTERVAL. For the non-coordinator node in fast mode, the interval is given by TOPOLOGY_REPORT_INTERVAL_FAST. The non-coordinator node shall generate a Topology Report message based on information contained in its route table and neighbour table.

8.2.2 Processing upon reception

For a non-coordinator node, if a node receives a Topology Report message from a neighbour node, the node shall relay the message to the next hop toward the coordinator according to its routing table. If hop-by-hop routing is to be used for downstream packet transmission, a node shall store the downward route information in the route table according to the information contained in the LINK_UPPER sub-message. Also, for inter-node communication, a node may store route information according to the information contained in the LINK_UPPER sub-message.

If the coordinator node receives a Topology Report message and the final-destination of the LINK_UPPER sub-message is its own address, the coordinator node shall perform the following.

– Create new record for the source node in the route table if the source node is not in the route table.
– Calculate the route cost from link cost information in the LINK_UPPER sub-message and update the route cost entry to the new calculated value.
– Populate the "hop count" and "short address list" entries of the route table according to information contained in the LINK_UPPER sub-message.

The information indicated in the LINK_2WAY sub-message and/or LINK_LOST sub-message may be used for alternative route generation or route change.

8.3 Route Error message transmission

If the transmission of a packet whose source node is the coordinator (i.e., downstream communication) has failed, the node shall generate a Route Error message with LINK_LOST sub-message containing the broken link. The node shall transmit the Route Error message to the next hop node in the upstream.

8.4 Link break determination

The coordinator and the non-coordinator node shall detect the link breaks in the following way. If no Hello message is received from a neighbour node for a pre-defined period, the node shall assume that a link break has occurred and shall update the link status to "LOST" in the neighbour table record for the node. The period for the link bread is given by the value of HELLO_INTERVAL multiplied by HELLO_MAX_COUNT.

8.5 Route break determination

The coordinator node shall detect the route breaks in the following way. If no Topology Report message is received from a node for a pre-defined period, the coordinator node shall assume that a route break has occurred. The period for the route break is given by the value of TOPOLOGY_REPORT_INTERVAL multiplied by ROUTE_VALID_COUNT. The coordinator node may update the corresponding route information to the alternative route or delete the corresponding route information in the route table.

9 Packet transmission

9.1 Unicast packet

9.1.1 Generation

~~For the coordinator node, t~~Two methods of packet transmission, source routing and hop-by-hop routing, are possible. The node~~coordinator~~ may select source routing or hop-by-hop routing according to system requirements.

If source routing is used, the ~~coordinator~~ node shall generate the CMSR source route header (SRH) according to the route information to the final-destination in the route table. The coordinator node shall attach the SRH to the packet. Upon reception of the packet with the SRH, the node shall relay the packet including SRH to the next hop node according to the route indicated in the SRH. If the next hop node is the final-destination node, the node may omit the SRH.

If hop-by-hop routing is used, the node~~coordinator~~ shall transmit the packet without SRH to the next hop. Upon reception of the packet without SRH, the node shall relay the packet to the next hop node based on the route information stored in its route table. The final-destination address shall be described in the mesh type and header.

If the source node is a non-coordinator node, hop-by-hop routing is used. The node shall transmit the packet to the next hop node toward the coordinator based on the route information in the route table.

9.1.2 Processing upon reception

If a received packet is a unicast packet addressed to the receiving node, the node shall pass the packet to the higher layer. If not, and HopsLft in the mesh type and header is greater than one, then the node relays the packet to the next hop in accordance with the SRH attached to the packet. If the SRH is not attached, the node relays in accordance with its route table. If the destination is not on the route table, the node may discards the packet or send the packet based on the default route, i.e., the route to the coordinator. The coordinator mayshall not relay packets.

9.2 Broadcast/multicast packet

Upon reception of a broadcast/multicast packet, if the FloodingFlag is enabled, the node shall forward the broadcast/multicast packet. Otherwise, the node shall not forward the broadcast/multicast packet.

10 Configuration parameters

The default values of the parameters used in CMSR are summarized in Table 10-1.

Table 10-1 – Default values of the parameters used in CMSR

Parameter name	Value
HELLO_INTERVAL	300 s
HELLO_INTERVAL_FAST	60 s
HELLO_JITTER	0.1
TOPOLOGY_REPORT_INTERVAL	900 s
LINK_MAX_PREFERRED	3

Annex A

Routing procedure for ITU-T G.9903

(This annex forms an integral part of this Recommendation.)

If Recommendation ITU-T G.9905 is used as the layer 2 routing protocol for [ITU-T G.9903] in place of LOADng, this annex shall apply.

A.1 Defining parameter

An ADP layer IB attribute adpDisableDefaultRouting shall be defined in addition to the attributes defined in Table 9-25 of [ITU-T G.9903].

Table A.0 – Additional adaptation sublayer IB attribute

Attribute	Identifier	Type	Read only	Range	Description	Default
adpDisableDefault Routing	0xF0	Boolean	No	FALSE TRUE	If TRUE, the default routing (behaviour specified in clause 9.4.3 of [ITU-T G.9903]) is disabled. If FALSE, the default routing is enabled	FALSE

The Command ID in the ADP command frame header shall be used according to Table A.1.

Table A.1 – Command frame header identifier

Command	Command ID	Comments
CMSR protocol message	0x10	Use for CMSR source route header and CMSR message

A.2 Mesh routing

Instead of clause 9.4.3 "Mesh routing" of [ITU-T G.9903], the following procedures for L2 routing in the ADP layer shall be applied.

A.2.1 Packet routing

A.2.1.1 Unicast packet routing

The routing of the unicast packet is performed using the following algorithm on receipt of an MCPS-DATA.indication from the MAC layer:

- IF (MAC destination address == address of device)
  - – IF (command ID in command frame header == 0x10)
    - ○ The packet is handled by the non-default routing entity.
  - – ELSE
    - ○ IF (No Mesh header present in 6loWPAN headers)
      - ➢ Generate an ADPD-DATA.indication primitive to indicate the arrival of a frame to the upper layer, with the following characteristics (see clause 9.4.6.1.4 of [ITU-T G.9903]):
        - ▪ DstAddrMode = 0x02

        - DstAddr = MAC destination address
        - SrcAddr = MAC source address
        - NsduLength = length of the payload
        - Nsdu = the payload
        - LinkQualityIndicator = msduLinkQuality (see clause 9.3.11.2 of [ITU-T G.9903])
    - IF (6LoWPAN destination address == 6LoWPAN address of device)
      - Generate an ADPD-DATA.indication primitive to indicate the arrival of a frame to the upper layer, with the following characteristics (see clause 9.4.6.1.4 of [ITU-T G.9903]):
        - DstAddrMode = 0x02
        - DstAddr = 6LoWPAN destination address
        - SrcAddr = The originator address in the 6LoWPAN mesh header
        - NsduLength = length of the payload
        - Nsdu = the payload
        - LinkQualityIndicator = msduLinkQuality (see clause 9.3.11.2 of [ITU-T G.9903])
    - ELSE
      - The packet is handled by the non-default routing entity.
- ELSE IF (MAC Destination address == 0xFFFF)
  - This is a broadcast frame: execute algorithm described in clause A.2.1.2.1.
- ELSE
  - Drop the frame.

A.2.1.2 Multicast/broadcast

A.2.1.2.1 Packet routing

The packet routing mechanism is based on section 11.1 of [IETF RFC 4944]. This clause details more precisely the routing of broadcast and multicast packets.

As described in section 11.1 of [IETF RFC 4944], each broadcast packet has a BC0 header containing a sequence number. Each time a node sends a broadcast packet, it shall increment this sequence number.

Each node shall have a broadcast log table. This table is used for routing broadcast packets and each entry contains the parameters described in Table 9-28 of [ITU-T G.9903].

Each time a device receives a broadcast address with a HopsLft field of a mesh header (see section 5.2 of [IETF RFC 4944]) strictly greater than 0, it shall check if an entry already exists in the broadcast log table having the same SrcAddr and SeqNumber. If an entry exists, the received frame is silently discarded. Otherwise, a new entry is added in the table and the TimeToLive field is initialized with the value adpBroadcastLogTableEntryTTL (see clause 9.4.2 of [ITU-T G.9903]). When this value reaches 0, the entry is removed from the broadcast log table.

When a device receives a broadcast frame, so that it has to create an entry in the broadcast log table, it shall decrement its HopsLft field. If HopsLft is not zero, the received broadcast frame is handled by the non-default routing entity.

This can be summarized by the following algorithm, executed upon receipt of a frame whose destination address is 0xFFFF:

IF (final destination address = broadcast address) or (final destination address is found in adpGroupTable):

- IF (command ID in command frame header ==0x10)
  - The packet is handled by the non-default routing entity
- ELSE
  - IF ((SrcAddr, SeqNumber) exists in broadcast log table)
    - Discard frame
  - ELSE
    - Create one entry (SrcAddr, SeqNumber, adpBroadcastLogTableEntryTTL) in the broadcast log table, with the corresponding frame characteristics.
    - Generate an ADPD-DATA.indication primitive to the upper layer with the following characteristics:
      - DstAddrMode = 0x02
      - DstAddr = Destination address in the 6LoWPAN mesh header (multicast or broadcast address)
      - SrcAddr = The originator address in the 6LoWPAN mesh header
      - NsduLength = length of the data
      - Nsdu = the data
      - LinkQualityIndicator = msduLinkQuality (see clause 9.3.11.2 of [ITU-T G.9903])
    - HopsLft=HopsLft –1
    - If (HopsLft > 0)
      - The packet is handled by the non-default routing entity.

NOTE – In case of a multicast address, the broadcast address 0xFFFF is used at the MAC level as mentioned in section 3 of [IETF RFC 4944]. Multicast frames are routed using the same algorithm as broadcast frames.

The broadcast log table is available in the information base with the attribute adpBroadcastLogTable (see clause 9.4.2 of [ITU-T G.9903]).

A.2.1.2.2 Groups

Each device can belong to one or more groups of devices. The IB attribute adpGroupTable (see clause 9.4.2 of [ITU-T G.9903]) stores a list of 16-bit group addresses.

When the device receives a MAC broadcast message and if the final destination address in the 6LoWPAN mesh header is equal to one of the 16-bit group addresses in adpGroupTable, then an ADPD-DATA.indication primitive is generated to the upper layer (as described in clause 9.4.3.2.2.1 of [ITU-T G.9903]).

Groups can be added or removed from the adpGroupTable using the ADPM-SET.request primitive. The size of this table is implementation specific and shall have at least one entry. The way groups are managed by upper layers is beyond the scope of this Recommendation.

A.3 Transmission of IPv6 packet triggered by ADPD-DATA primitive

The following table shall be applied for packet transmission triggered by the ADPD-DATA primitive.

Table A.2 – Selections from clause 9.4.6.1.2 of [ITU-T G.9903]

Clause	Title and remarks/modifications	Statement
9.4.6.1.2	ADPD-DATA.request	N
9.4.6.1.2.1	Semantics of the service primitive	N
9.4.6.1.2.2	When generated	N
9.4.6.1.2.3	Effect on reception – Once the 6LoWPAN frame is constructed, the frame is handled by the non-default routing entity for both unicast and broadcast/multicast case	E(Extension)

A.4 Packet transmission and reception triggered by non-default routing entity

The non-default routing entity may issue a request of packet transmission. In this case, the packet shall be transferred to the MAC layer by invoking the MCPS-Data.request primitive with the following parameters:

– SrcAddrMode = 0x02, for 16-bit address
– DstAddrMode = 0x02, for 16-bit address
– SrcPANId = DstPANId = the value of macPANId obtained from the MAC PIB
– SrcAddr = the value of macShortAddr obtained from the MAC PIB
– DstAddr = the 16-bit address of the next hop determined by the non-default routing entity
– msduLength = the length of the frame, or fragment in the case of fragmentation, in bytes
– msdu = the frame itself
– msduHandle = NsduHandle
– TxOptions: b0 = 1
– SecurityLevel = dpSecurityLevel
– KeyIdMode, KeySource: Ignored
– KeyIndex: Ignored if SecurityLevel=0; otherwise it depends on the security policy.

The non-default routing entity may also issue a request to transfer the received packet to the upper layer. In this case, the packet (after 6lowPAN procedure) shall be transferred to the upper layer by invoking the ADPD-DATA.indication with the following parameters:

– DstAddrMode = 0x02
– DstAddr = MAC destination address
– SrcAddr = MAC source address
– NsduLength = length of the payload
– Nsdu = the payload
– LinkQualityIndicator = msduLinkQuality (see clause 9.3.11.2 of [ITU-T G.9903])

Necessary information is provided by the non-default routing entity.

A.5 Interface between the ITU-T G.9903 adaptation layer and ITU-T G.9905

NON-DEF-ROUTING-MSG command message may be used as the interface with non-default routing entity.

• NON-DEF-ROUTING-MSG.request

This command is generated by non-default routing entity to transfer a data frame to the ADP layer.

- NON-DEF-ROUTING-MSG.confirm

This command is generated by the ADP layer to notify the results of a previous NON-DEF-ROUTING-MSG.request command to the non-default routing entity.

- NON-DEF-ROUTING-MSG.indication

This command is generated by the ADP layer to transfer a data frame to non-default routing entity.

A.5.1 NON-DEF-ROUTING-MSG.request

NON-DEF-ROUTING-MSG.request (

MacDstAddr,

MacSrcAddr,

NsduLength

Nsdu

NsduHandle

QualityOfService

RouteError

)

Name	Type	Valid range	Description
MacDstAddr	Integer	0x0000-0xFFFF	Destination address: – next hop address determined by the non-default routing entity in case of transmission packet – MAC destination address in case of received packet
MacSrcAddr	Integer	0x0000-0xFFFF	Source address: – MAC source address in case of received packet – short address of own node in case of transmission packet
NsduLength	Integer	0-1280	The size of the NSDU, in bytes
Nsdu	Set of octets	–	The NSDU
NsduHandle	Integer	0x00-0xFF	The handle of the NSDU
QualityOfService	Integer	0x00-0x01	The requested quality of service (QoS) of the frame to send. Allowed values are: 0x00 = normal priority 0x01 = high priority
RouteError	Boolean	FALSE, TRUE	TRUE if the packet is for transmission but the next hop information is not available

NOTE – If MacSrcAddr is the short address of own node, the ADP layer may consider the packet is for transmission. If not, the ADP layer may consider the packet is for reception.

A.5.1 NON-DEF-ROUTING-MSG.confirm

NON-DEF-ROUTING-MSG.confirm (

Status,

NsduHandle

)

Name	Type	Valid range	Description
Status	Enum	SUCCESS, INVALID_IPV6_FRAME, INVALID_REQUEST, NO_KEY, BAD_CCM_OUTPUT, ROUTE_ERROR, BT_TABLE_FULL, FRAME_NOT_BUFFERED or any status values returned from security suite or the MCPS-DATA.confirm primitive	The status code of a previous NON-DEF-ROUTING-MSG.request identified by its NsduHandle
NsduHandle	Integer	0x00-0xFF	The handle of the NSDU confirmed by this command

A.5.2 NON-DEF-ROUTING-MSG.indication

NON-DEF-ROUTING-MSG.indication (

MacDstAddr,

MacSrcAddr

NsduLength

Nsdu

NsduHandle

LinkQualityIndicator

Retry

)

Name	Type	Valid range	Description
MacDstAddr	Integer	0x0000-0xFFFF	destination address
MacSrcAddr	Integer	0x0000-0xFFFF	source address
NsduLength	Integer	0-1280	The size of the NSDU, in bytes
Nsdu	Set of Octets	–	The NSDU
NsduHandle	Integer	0x00-0xFF	The Handle of the NSDU
LinkQualityIndicator	Integer	0x00-0xFF	The value of the link quality during reception of the frame
Retry	Boolean	FALSE, TRUE	TRUE if the corresponding packet is retry packet in ADP layer

When the ADP layer transfers a transmission packet (i.e., either an IPv6 packet originating from the node itself or a retry packet) to the non-default routing entity, the following parameters shall be set.

- ○ DstAddr = next hop address used for the latest transmission of the corresponding packet if RetryFlag is set to TRUE, otherwise any value
- ○ SrcAddr = the short address of the own node
- ○ NsduLength = length of the payload
- ○ Nsdu = the payload including ADP header
- ○ LinkQualityIndicator = Any
- ○ RetryFlag = TRUE if the packet is retry packet, otherwise FALSE.

When the ADP layer transfers the received packet to the non-default routing entity, the following parameters shall be set.

- ○ DstAddr = MAC destination address of the received packet
- ○ SrcAddr = MAC source address of the received packet
- ○ NsduLength = length of the payload
- ○ Nsdu = the payload including ADP header
- ○ LinkQualityIndicator = msduLinkQuality (see clause 9.3.11.2 of [ITU-T G.9903])
- ○ RetryFlag = FALSE.

Annex B

Applying CMSR to a network without 6LoWPAN

(This annex forms an integral part of this Recommendation.)

If Recommendation ITU-T G.9905 is used as a mesh-under routing protocol in a network without 6LoWPAN, this annex shall apply. Changes to the ITU-T G.9905 main body are summarized as follows:

- A MAC layer address is used in the CMSR message instead of the short address.
- Use of a non-6LoWPAN packet format is allowed.

B.1 Packet format

The packet format described in Figure 7-1 is modified for a network without 6LowPAN. A CMSR protocol message shall be included in the MAC payload. Information for routing, i.e., source route header and the information equivalent to "Mesh type and header" and "broadcast type and header" in Figure 7-1, may be carried in the MAC header instead of MAC payload.

B.2 CMSR message

B.2.1 Hello message

The sub-message format in the Hello message for a network without 6LoWPAN is shown in Figure B.1. A MAC layer address is used instead of the short address defined in clause 7.2.1.

MSB (2 byte) LSB

	Message type | Fast mode flag | Reserved | Node type	Sequence number
Sub-message LINK_UPPER	Sub-message type	Number of links
	Link cost #1	MAC layer address #1
	. . . . .	. . . . .
	The continuation of MAC layer address #1	Link cost #2
	. . . . .	. . . . .
Sub-message LINK_REQ	Sub-message type	Number of links
	Link cost #1	MAC layer address #1
	. . . . .	. . . . .
	The continuation of MAC layer address #1	Link cost #2
	. . . . .	. . . . .
Sub-message LINK_REP	Sub-message type	Number of links
	Link cost #1	MAC layer address #1
	. . . . .	. . . . .
	The continuation of MAC layer address #1	Link cost #2
	. . . . .	. . . . .
Sub-message LINK_LOST	Sub-message type	Number of links
	Link cost #1	MAC layer address #1
	. . . . .	. . . . .
	The continuation of MAC layer address #1	Link cost #2
	. . . . .	. . . . .
Sub-message PAN_INFO	Sub-message type	Sub-message length
	Attribute type #1	Attribute length
	Attribute value #1	. . . . .
	. . . . .	. . . . .
	. . . . .	The continuation of attribute value #1
	Attribute type #2	Attribute length
	. . . . .	. . . . .

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Figure B.1 – Hello message sub-message format

B.2.2 Topology Report message

The sub-message format in the Topology Report message for a network without 6LoWPAN is shown in Figure B.2. A MAC layer address is used instead of the short address defined in clause 7.2.2.

MSB (2 byte) LSB

	Message type	Reserved	Node type	Sequence number
Sub-message LINK_UPPER	Sub-message type			Number of links
	Link cost #1			MAC layer address #1
	. . . . .			. . . . .
	The continuation of MAC layer address #1			Link cost #2
	. . . . .			. . . . .
Sub-message LINK_2WAY	Sub-message type			Number of links
	Link cost #1			MAC layer address #1
	. . . . .			. . . . .
	The continuation of MAC layer address #1			Link cost #2
	. . . . .			. . . . .
Sub-message LINK_LOST	Sub-message type			Number of links
	Link cost #1			MAC layer address #1
	. . . . .			. . . . .
	The continuation of MAC layer address #1			Link cost #2
	. . . . .			. . . . .

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Figure B.2 – Topology Report message sub-message format

B.2.3 Route Error message

The sub-message format in the Route Error message for a network without 6LoWPAN is shown in Figure B.3. A MAC layer address is used instead of the short address defined in clause 7.2.3.

MSB (2 byte) LSB

	Message type	Reserved	Node type	Sequence number
Sub-message LINK_LOST	Sub-message type			Number of links
	Link cost #1			MAC layer address #1
	. . . . .			. . . . .
	The continuation of MAC layer address #1			Link cost #2
	. . . . .			. . . . .

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Figure B.3 – Route Error message sub-message format

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