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G.9959

Amendment 1

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

Access networks – In premises networks

Short range narrow-band digital radiocommunication transceivers – PHY and MAC layer specifications

Amendment 1

Recommendation ITU-T G.9959 (2012) – Amendment 1

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Recommendation ITU-T G.9959

Short range narrow-band digital radiocommunication transceivers – PHY and MAC layer specifications

Amendment 1

Summary

Amendment 1 to Recommendation ITU-T G.9959 (2012) contains:

- The relaxation of the transmitter frequency separation tolerance level from ±10% to ±20%, for all data rates.
- The addition of a Logical Link Control (LLC) layer, in new clause 9.
- The addition of a Segmentation and Reassembly (SAR) adaptation layer, in new clause 10.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.9959	2012-02-13	15	11.1002/1000/11529-en
1.1	ITU-T G.9959 (2012) Amd.1	2013-10-07	15	11.1002/1000/12006-en

* 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.

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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.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Recommendation ITU-T G.9959

Short range narrow-band digital radiocommunication transceivers – PHY and MAC layer specifications

Amendment 1

Modifications introduced by this amendment are shown in revision marks. Unchanged text is replaced by ellipsis (…). Some parts of unchanged text (clause numbers, etc.) may be kept to indicate the correct insertion points.

…

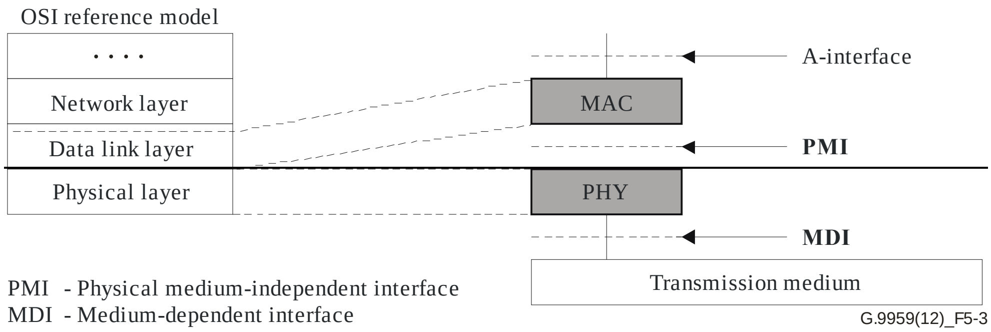
5.2 Reference models

5.2.1 Protocol reference model of a transceiver

The protocol reference model of a transceiver is presented in Figure 5-3. It includes ~~three~~ four ~~main~~ reference points: ~~application interface (A-interface)~~the data link layer interface (DLI), the MAC layer interface (MLI), the physical medium-independent interface (PMI), and the medium-dependent interface (MDI)~~, Figure 5-3. The shaded part of the reference model is defined in this Recommendation.~~

The MDI is a physical interface defined in terms of the physical signals transmitted over a medium (clause 5.2.3).

The PMI is both medium independent and application independent. ~~The A-interface is network layer (Layer 3) protocol specific (e.g., Ethernet, IP). Both~~ The PMI, MLI and DLI interfaces ~~and A-interface~~ are defined as functional interfaces, in terms of sets of primitives exchanged across the interface.



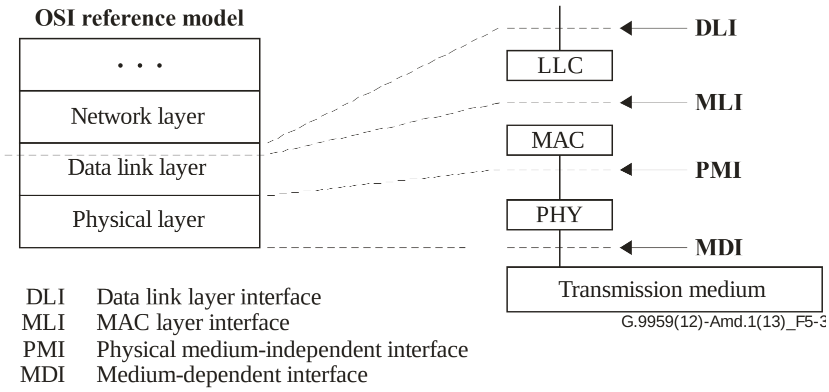


Figure 5-3 – Protocol reference model of an ITU-T G.9959 transceiver

The logical link control (LLC) layer enables access of different instances of network protocol stacks to the MAC layer.

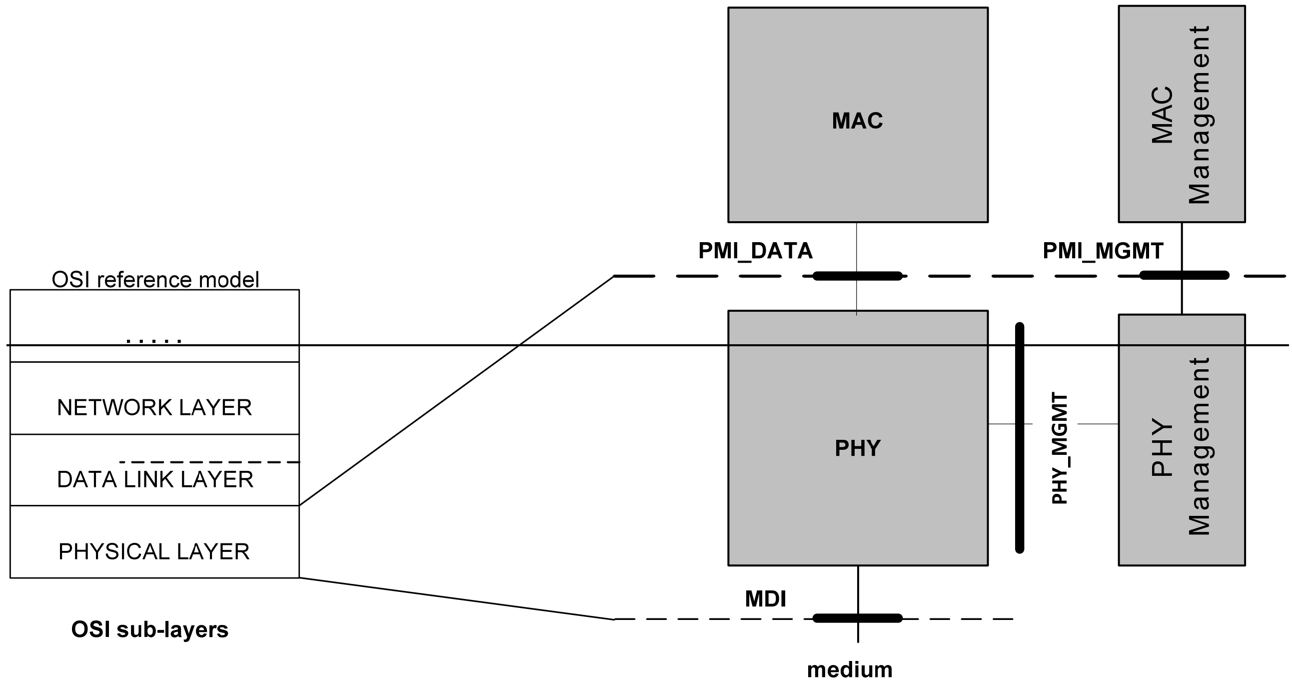
The medium access control layer (MAC) controls access of the node to the medium using the medium access protocols defined. The MAC layer also provides checksum protection to the MAC information.

The physical layer (PHY) provides bit rate adaptation (data flow control) between the MAC and PHY and encapsulates transmit MPDUs into the PHY frame and adds PHY-related control and management overhead.

The PHY layer provides encoding of the PHY frame content (header and payload) and modulates the encoded PHY frames for transmission over the medium.

5.2.2 Functional description of the interface

This section contains the functional description of the transceiver interfaces (reference points) based on the protocol reference model presented in Figure 5-4. The interfaces shown in Figure 5-4 are defined in this Recommendation.



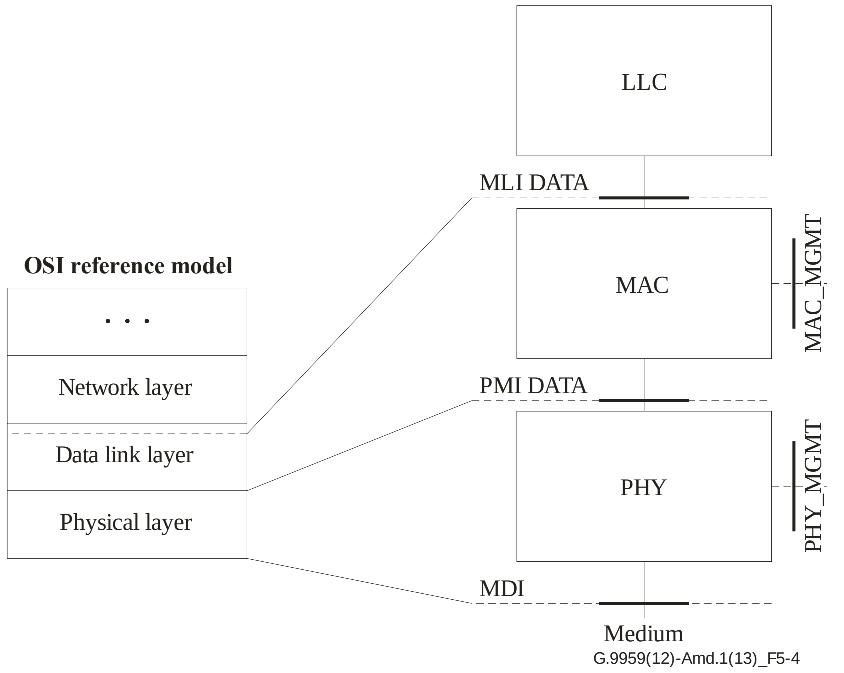


Figure 5-4 − Transceiver reference points related to PHY/MAC

The model in Figure 5-4 shows interfaces related to the application data path (MLI_DATA, PMI_DATA, and MDI)~~, the management data path (PMI_MGMT),~~ and the management interfaces between data and management planes of the PHY (PHY_MGMT). All interfaces are specified as reference points in terms of primitive flows exchanged between the corresponding entities. The description does not imply any specific implementation of the transceiver interfaces.

5.2.3 Functional model of a transceiver

The functional model of a transceiver is presented in Figure 5-5. It addresses nodes without extended capabilities as well as nodes with extended capabilities such as the domain master.

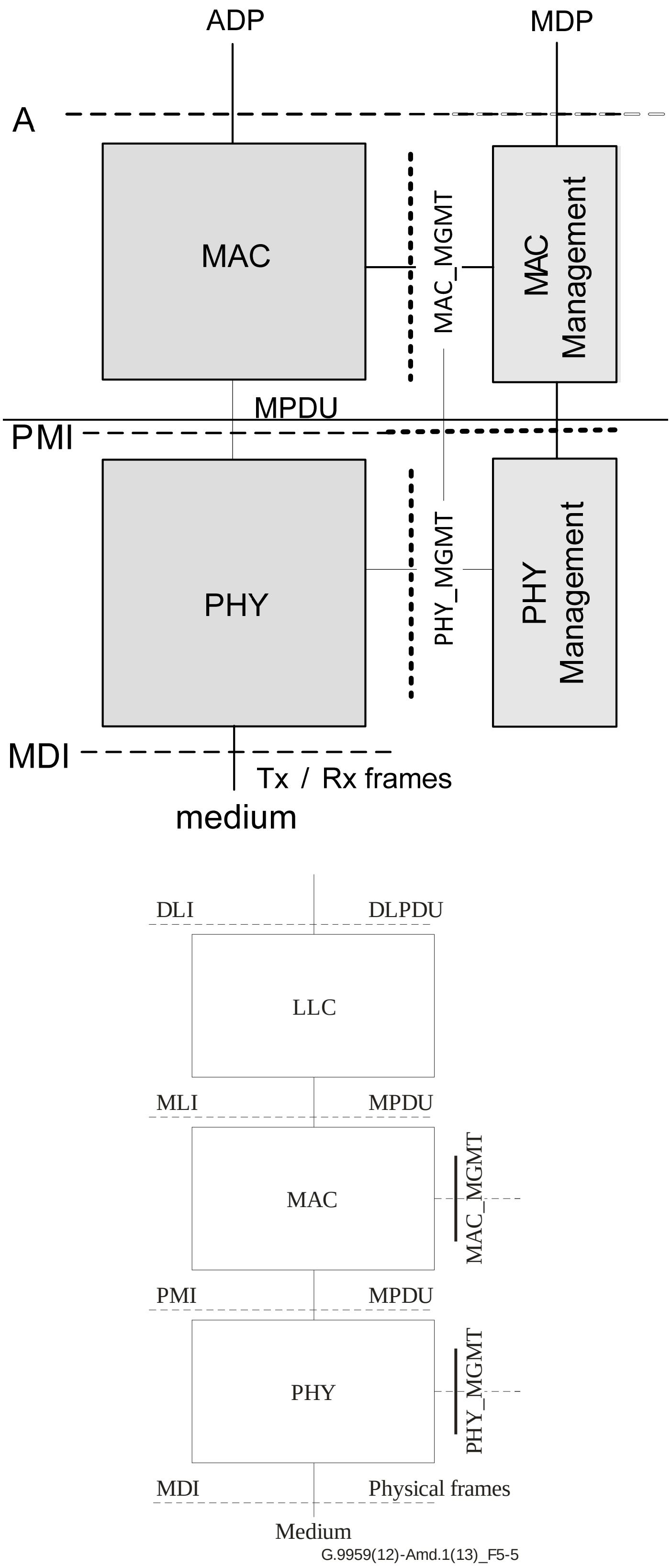


Figure 5-5 − Functional model of an ITU-T G.9959 transceiver

The detailed description of the functional model of the PHY layer is presented in clause 7.1. The detailed description of the functional model of the MAC layer is presented in clause 8.1. The MAC Layer Interface (MLI) deviates from the OSI reference stack in that it exchanges MAC PDUs (MPDU) with the MAC layer rather than MAC SDUs (MSDU). This allows upper layers to perform mesh routing, segmentation, and IP header compression operations, based on information carried in the MPDU header. The detailed description of the functional model of the LLC layer is presented in clause 9.1.

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7.1.2.4 Modulation and encoding

The PHY shall employ frequency shift keying (FSK) for RF modulation of R1 and R2. The PHY shall employ Gaussian frequency shift keying (GFSK) for R3.

Manchester code shall be used for data symbol encoding for R1 and non-return-to-zero for data symbol encoding for R2 and R3.

The modulation and the coding format is summarized in the table below.

Table 7-4 – Modulation and coding format

Data Rate	Modulation	Coding	Separation	Symbols
R1	FSK	Manchester	40 kHz ±2~~1~~0%	Binary
R2	FSK	NRZ	40 kHz ±2~~1~~0%	Binary
R3	GFSK, BT = 0.6	NRZ	58 kHz ±2~~1~~0%	Binary

The mapping of NRZ symbols to the physical medium ~~assuming high side LO~~ is given below~~. The mapping should be inverted for low side LO~~:

Table 7-5 – Symbol mapping~~, for high side LO~~

Symbol	Frequency
0	$f_{center\ frequency}$ – separation/2
1	$f_{center\ frequency}$ + separation/2

The mapping of Manchester symbols to the physical medium ~~assuming high side LO~~ is given below:

Table 7-6 – Manchester symbols, for high side LO

Symbol	Frequency
0	Transition from ($f_{center\ frequency}$ ~~+~~– separation/2) to ($f_{center\ frequency}$ ~~–~~+ separation/2)
1	Transition from ($f_{center\ frequency}$ ~~–~~+ separation/2) to ($f_{center\ frequency}$ ~~+~~– separation/2)

• • •

9 LLC layer specification

In the OSI 7-layer stack, the LLC layer is the upper part of the data link layer (DLL).

9.1 General

The purpose of the LLC layer is to enable de-multiplexing of incoming MPDUs. The LLC layer shall not change the contents of the data link PDU (DLPDU) payload.

The following DLI interfaces are defined, as shown in Figure 9-1:

- DLI.6LoWPAN: Interface for IPv6 packets carried in 6LoWPAN frames
- DLI.Default: Interface for non-IP PDUs

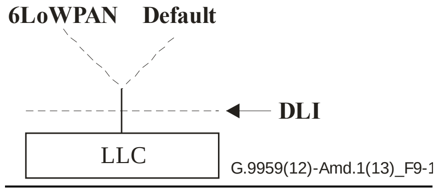

Figure 9-1 – Instances of the DLI interface

The DLI.Default interface shall receive all traffic which is not explicitly targeting other instances of the DLI interface.

9.2 Cascaded adaptation layer architecture

One or more adaptation layers may be injected into the DLL between the MAC and LLC layers, as shown in Figure 9-2. Each adaptation layer serves a specific purpose, such as handling mesh routing, segmentation or security encryption. The function of an adaptation layer may be triggered by the presence of a routing header or specific DLPDU header values. Each adaptation layer shall implement the MLI interface on each of its interfaces. Each adaptation layer may modify or entirely discard an incoming MPDU. An adaptation layer shall transparently forward incoming MPDUs to the next layer in case the actual function is not triggered.

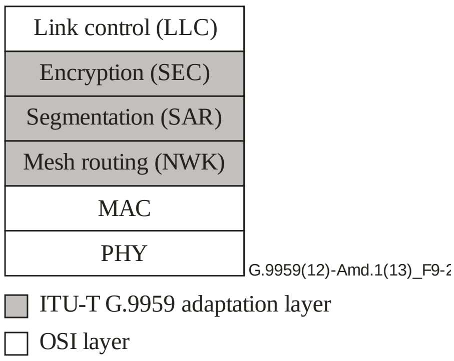

Figure 9-2 – Ordering of adaptation layers

9.3 DLPDU format

The LLC receives an MPDU from the MLI interface. The MAC layer specifies MPDU formats for singlecast and multicast transmission modes (see Figure 9-3).

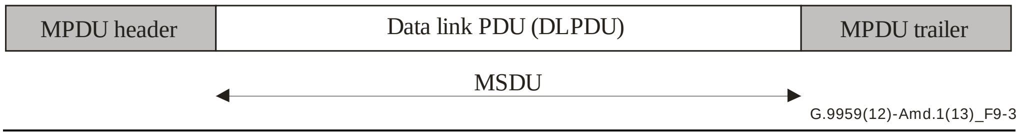

Figure 9-3 – General MPDU format

It is further specified that MPDUs may carry mesh routing information when the "Routed" flag of the frame control field is set or if the "Routed Frame" header type is used. In this case, a routing header is prepended to the DLPDU carried in the MSDU, as shown in Figure 9-4.

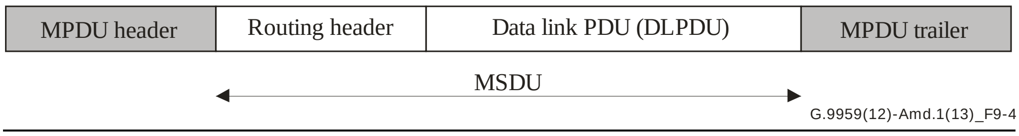

Figure 9-4 – MPDU format for routed frame

For correctly configured network nodes, the LLC layer should never receive an MPDU which carries routing information. The LLC layer shall ignore an MPDU which carries routing information. The following text assumes that no routing header is prepended to the MPDU payload when it is received by the LLC layer.

The DLPDU shall carry a DLPDU header, and may carry a payload field, as shown in Figure 9-5. The payload field may have any length up to 1 350 bytes. The payload field may carry another encapsulated DLPDU.

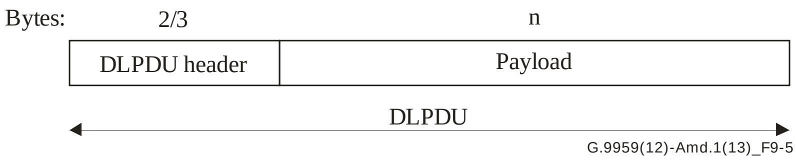

Figure 9-5 – DLPDU format

9.3.1 DLPDU header

The DLPDU header comprises two fields: the Command Class and the Command, as shown in Figure 9-6.

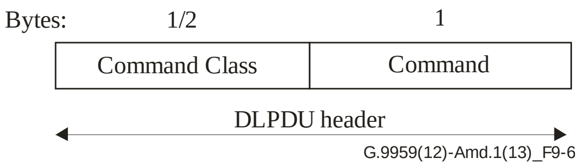

Figure 9-6 – DLPDU header

9.3.1.1 Command Class

The Command Class field may be 1 or 2 bytes in length.

In the general case, the Command Class field shall be 1 byte long. If the first byte of the Command Class is a value in the range 0xF1..0xFF, the DLPDU header contains an Extended Command Class identifier. An Extended Command Class field shall be 2 bytes in length.

Table 9-1 – Command Class types

Cmd Cls 1	Cmd Cls 2	Command Class Type
0x00..0xF0	(not present)	Normal
0xF1..0xFF	0x00..0xFF	Extended

9.3.1.2 Command

The Command field shall be 1 byte in length and specifies one particular command for a given Command Class.

9.4 Data link interface selection

The LLC layer shall extract the DLPDU contained in an incoming MPDU and forward the DLPDU to a target DLI. The target DLI shall be determined by an evaluation of the DLPDU header Command Class field.

9.4.1 DLI.IPv6 interface selection

The LLC layer shall forward the DLPDU to the DLI.6LoWPAN interface if the DLPDU header Command Class field carries the 6LoWPAN Command Class identifier (0x4F).

9.4.2 DLI.Default interface selection

Any DLPDU which does not match the explicit selection criterion for another DLI interface instance shall be forwarded to the DLI.Default interface.

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10 Adaptation layers

As specified in clause 9 ("LLC layer specification"), one or more adaptation layers may be injected in between the MAC and LLC layers.

10.1 SAR adaptation layer

The segmentation and reassembly (SAR) adaptation layer allows ITU-T G.9959 nodes to exchange long payloads. Examples of such payloads include security certificates for ITU-T G.9959 network bootstrapping or IPv6 packets.

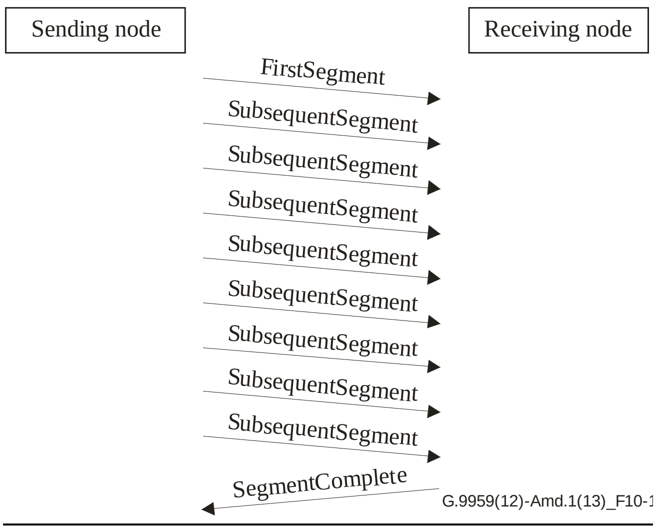

Figure 10-1 – Example of datagram transferred as segments

10.1.1 Terminology overview

The SAR adaptation layer provides segmentation and reassembly of a datagram by splitting up the datagram into segments, as shown in Figure 10-1, each of which fits into a MAC data payload (i.e., the MSDU). The datagram is formatted as a DLPDU with two header fields (Command Class, Command) like any other DLPDU.

The SAR adaptation layer defines the Transport Service Command Class. As with all other command classes, the Transport Service Command Class is unconcerned with whether segments are transported in direct range or by a mesh routing protocol.

10.1.2 SAR adaptation layer specification

The SAR adaptation layer shall provide the following features in order to obtain reliable data transfer of datagrams larger than the MSDU can accommodate.

Typical examples are security encapsulated datagrams and 6LoWPAN encapsulated IPv6 packets.

10.1.2.1 Transparent functionality

The SAR adaptation layer shall support segmentation and reassembly of any datagram up to 1 350 bytes.

A node implementing the SAR adaptation layer shall automatically determine if a datagram fits into the available MPDU payload length. A node should not use segmentation if a datagram can be sent in one MPDU.

10.1.2.2 Relaxed transmission timing for long payloads

In order not to congest the network, large data transfers shall leave transmit opportunities for other nodes in the network. If sending a command longer than 2 MSDUs, a node shall implement a delay between every transmitted MSDU. The minimum required time delay and number of MSDUs before a delay shall be inserted depends on the actual bit rate as follows:

- 40 kbit/s: At least 35 ms if sending more than 2 MSDUs back-to-back
- 100 kbit/s: At least 15 ms if sending more than 2 MSDUs back-to-back.

10.1.2.3 Varying PHY PDU size

Depending on bit rate, MPDUs support application payloads of 46 bytes or larger. This value does not include adaptation layer headers such as the routing header. Future developments may introduce longer MSDUs. The SAR adaptation layer shall support all MSDU sizes offered by the actual MAC/PHY layer.

10.1.2.4 Segment re-transmission

The segment reassembly process may end up missing a number of segments in the receive buffer, e.g., due to a checksum error. The receiving node shall be able to request the retransmission of individual segments to complement the segments already received. The algorithm shall be able to handle the case where retransmitted segments are also lost. If segments are received via broadcast or multicast transmission, the receiving node shall not request the retransmission of segments.

10.1.2.5 Robust error handling

In case no segments are received in response to a retransmission request, a receiving node shall discard all segments previously received.

If a sending node repeatedly fails to deliver a segment to a destination node, the node shall abort transmission of all remaining segments.

10.1.3 The Transport Service Command Class

The SAR adaptation layer shall use the Transport Service Command Class to transfer long datagrams between two nodes. The datagram shall start with two fields carrying a Command Class and Command; refer to clause 9 ("LLC layer specification").

10.1.3.1 First Segment command

The First Segment command initiates the transfer of a datagram, as shown in Figure 10-2.

7	6	5	4	3	2	1	0
Command Class = COMMAND_CLASS_TRANSPORT_SERVICE							
Command = COMMAND_FIRST_SEGMENT					datagram_size_1 [10..8]		
datagram_size_2 [7..0]							
Session ID				Ext	*Reserved*		
Header Extension Length (OPTIONAL)							
Header Extension (OPTIONAL)							
Payload 1							
…							
Payload N							
Frame Check Sequence 1 [15..8]							
Frame Check Sequence 2 [7..0]							

Figure 10-2 – Frame format of First Segment command

10.1.3.1.1 Command (5 bits) = "11000"

The Command field is reduced to a 5-bit field in order to limit the overhead introduced by the segment header. The LS 3 bits shall be masked out before decoding the command code when detecting the Transport Service Command Class.

The command code shall be the binary value "11000".

10.1.3.1.2 Datagram size (11 bits)

Indicates the overall size of the datagram carried in the segments. The unit is 1 byte. Bit 0 is the least significant bit. The value shall not exceed 1 350 bytes.

10.1.3.1.3 Reserved (3 bits)

This field shall be set to 0 by a sending node and shall be ignored by a receiving node.

10.1.3.1.4 Ext (1 bit)

This field shall be used to indicate the presence of the Header Extension Length and Header Extension fields. The field shall be set to 1 if there is a header extension. A receiving node shall ignore unsupported header extensions and process the command, skipping unsupported extensions.

10.1.3.1.5 Session ID (4 bits)

This field identifies the session. The Session ID shall be incremented when a new datagram transmission is initiated. A receiver shall verify the Session ID of all received segments. Segments shall be discarded if an unknown Session ID is detected.

10.1.3.1.6 Header Extension Length (8 bits)

This field is only present if the Ext bit is set to 1.

A sending node may add header extension fields to the command header. In this case, the Ext bit shall be set to 1 and the following fields shall be present in the command header:

- Header Extension Length
- Header Extension

10.1.3.1.7 Header Extension (variable size)

This field is only present if the Ext bit is set to 1. Refer to clause 10.1.3.1.4.

10.1.3.1.8 Payload (variable size)

The Payload field of a First Segment shall carry the first segment of a datagram.

A receiving node shall derive the size of the payload field from the size of entire command; subtracting all header fields as well as the checksum field.

10.1.3.1.9 Frame Check Sequence (16 bits)

This field carries a CRC-16 Frame Check Sequence (FCS). The FCS shall be calculated using the CRC-16-CCITT mechanism with the following parameters:

- Polynomium code shall be 0x1021; representing the polynomium $x^{16}+x^{12}+x^5+x^0$;
- CRC register shall be initialized to 0x1D0F by the transmitter as well as receiver;
- The calculated CRC-16 value shall cover all fields of the First Segment command except for the FCS fields;
- The calculated CRC-16 value shall not include padding after the frame; neither zeros nor any other value;
- The CRC-16 value shall be calculated one byte at a time in the transmission order; starting with the Command Class field;
- The most significant bit of a byte shall be transmitted and received first, and likewise be the first to be processed in a serialized implementation;
- Bit 0 of the CRC-16 value corresponds to the input register of a serialized implementation of the CRC-16 calculation. Bit 0 is the least significant bit of the 16-bit word.

A conceptual serial example is provided in Figure 10-3 below on how the polynomium $x^{16}+x^{12}+x^5+x^0$ may be implemented.

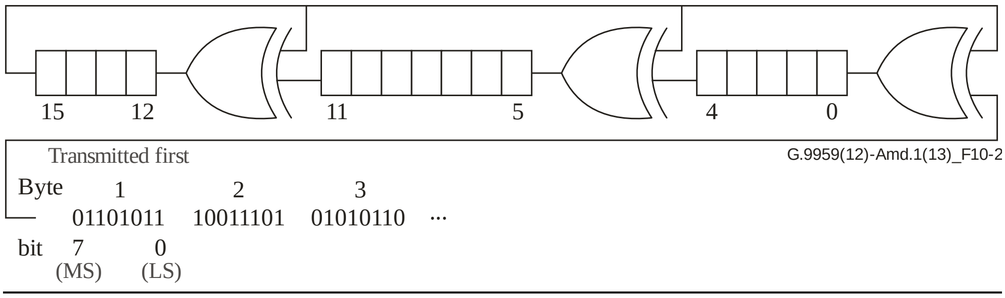

Figure 10-3 – CRC-16 implementation example

The following test vector shown in Figure 10-4 may be used for ensuring compliance with this Recommendation.

Test frame	CRC
C2 A2 15 0D 03 03 02 0B 01	2C 66

Figure 10-4 – CRC-16 implementation test vector

10.1.3.2 Subsequent Segment command

One or more Subsequent Segment commands follow the First Segment command and carry the remaining part of the datagram. (See frame format shown in Figure 10-5.)

7	6	5	4	3	2	1	0
Command Class = COMMAND_CLASS_TRANSPORT_SERVICE							
Command = COMMAND_SUBSEQUENT_SEGMENT					datagram_size_1 [10..8]		
datagram_size_2 [7..0]							
Session ID				Ext	datagram_offset_1 [10..8]		
datagram_offset_2 [7..0]							
Header Extension Length (OPTIONAL)							
Header Extension (OPTIONAL)							
Payload 1							
...							
Payload N							
Frame Check Sequence 1 [15..8]							
Frame Check Sequence 2 [7..0]							

Figure 10-5 – Frame format of Subsequent Segment command

Receiving the last segment of a singlecast datagram, the receiving node shall return either a Segment Request command or a Segment Complete command. The receiving node shall not respond to a broadcasted datagram.

10.1.3.2.1 Command (5 bits) = "11100"

The command code shall be the binary value "11100".

10.1.3.2.2 Datagram size (11 bits)

Refer to clause 10.1.3.1.2.

10.1.3.2.3 Ext (1 bit)

Refer to clause 10.1.3.1.4.

10.1.3.2.4 Session ID (4 bits)

Refer to clause 10.1.3.1.5.

10.1.3.2.5 Datagram offset (11 bits)

This field indicates the offset to apply to this segment when reassembling the datagram in the receive buffer. The unit is 1 byte. Bit 0 is the least significant bit.

10.1.3.2.6 Header Extension Length (8 bits)

This field is only present if the Ext bit is set to 1.

Refer to clause 10.1.3.1.6.

10.1.3.2.7 Header Extension (variable size)

This field is only present if the Ext bit is set to 1.

Refer to clause 10.1.3.1.7.

10.1.3.2.8 Payload (variable size)

The Payload field of a Subsequent Segment may carry any portion of a datagram.

A receiving node shall derive the size of the payload field from the size of entire command; subtracting all header fields as well as the checksum field.

10.1.3.2.9 Frame check sequence (16 bits)

Refer to clause 10.1.3.1.9.

10.1.3.3 Segment Request command

The Segment Request command may be used by a receiving node to request a missing segment. (See frame format shown in Figure 10-6.) Multiple missing segments should be requested one at a time.

This message shall not be used in response to segments received via broadcast or multicast.

7	6	5	4	3	2	1	0
Command Class = COMMAND_CLASS_TRANSPORT_SERVICE							
Command = COMMAND_SEGMENT_REQUEST					*reserved*		
Session ID				*reserved*	datagram_offset_1 [10..8]		
datagram_offset_2 [7..0]							

Figure 10-6 – Frame format of Segment Request command

10.1.3.3.1 Command (5 bits) = "11001"

The command code shall be the binary value "11001".

10.1.3.3.2 Reserved

This field shall be set to 0 by a sending node and shall be ignored by a receiving node.

10.1.3.3.3 Session ID (4 bits)

Refer to clause 10.1.3.1.5.

10.1.3.3.4 Datagram Offset

Refer to clause 10.1.3.2.5.

10.1.3.4 Segment Complete command

The Segment Complete command is returned from the receiving node when all segments have been correctly received. (See frame format shown in Figure 10-7.)

This message shall not be used in response to segments received via broadcast or multicast.

7	6	5	4	3	2	1	0
Command Class = COMMAND_CLASS_TRANSPORT_SERVICE							
Command = COMMAND_SEGMENT_COMPLETE					*reserved*		
Session ID				*reserved*			

Figure 10-7 – Frame format of Segment Complete command

10.1.3.4.1 Command (5 bits) = "11101"

The command code shall be the binary value "11101".

10.1.3.4.2 Reserved

This field shall be set to 0 by a sending node and shall be ignored by a receiving node.

10.1.3.4.3 Session ID (4 bits)

Refer to clause 10.1.3.1.5.

10.1.3.5 Segment Wait command

The Segment Wait command may be returned in response to a First Segment command or a Subsequent Segment command by a node which is already receiving segments from another node. (See frame format shown in Figure 10-8.)

This message shall not be used in response to segments received via broadcast or multicast.

7	6	5	4	3	2	1	0
Command Class = COMMAND_CLASS_TRANSPORT_SERVICE							
Command = COMMAND_SEGMENT_WAIT					*Reserved*		
Pending Segments							

Figure 10-8 – Frame format of Segment Wait command

10.1.3.5.1 Command (5 bits) = "11110"

The command code shall be the binary value "11110".

10.1.3.5.2 Reserved

This field shall be set to 0 by a sending node and shall be ignored by a receiving node.

10.1.3.5.3 Pending segments (8 bits)

The value indicates the number of segments not yet received by the receiving node. Since the delivery time of any segment depends on path length (direct vs. 5 hop routing), the value does not represent an absolute time. Furthermore, the node currently sending may initiate another transfer immediately after the completion of the actual segmented datagram.

A sending node shall stop sending segments for a minimum period of (100 ms × [number of pending segments]) if receiving a Segment Wait command. When resuming transmission, the sending node shall restart segment transmission with the First Segment command.

10.1.3.6 Managing segment transfer and handling exceptions

The following clauses present the mechanisms for handling segments and exceptions such as missing segments.

10.1.3.6.1 Avoiding concurrent peer-to-peer transfers

The SAR adaptation layer shall not allow other multi-MSDU datagrams to be transmitted to any destination node before the ongoing transmission of one multi-MSDU datagram has been completed. Doing so could delay the datagram transmission, causing security timers to timeout. While the SAR adaptation layer is transmitting a datagram to a given destination, the SAR adaptation layer may transmit a single-MSDU command to another destination node.

A receiving node may return a Segment Wait command in response to a singlecast segment if the node is already receiving another segmented datagram.

10.1.3.6.2 Completing the transfer (receiving node)

A receiving node shall request missing segments. The receiving node shall wait the following time after the reception of a segment before requesting missing segments:

- 40 kbit/s: at least 800 ms
- 100 kbit/s: at least 400 ms.

If the datagram is broadcasted, the node shall drop already received segments and shall not send a Segment Request command.

10.1.3.6.3 Completing the transfer (sending node)

When a sending node has completed transmission of a datagram, the sending node shall wait for a Segment Complete message from the receiving node. Depending on the transmission speed, the sending node shall wait the following time before sending another datagram:

- 40 kbit/s: at least 1 000 ms
- 100 kbit/s: at least 500 ms.

As retransmission is provided by the MAC layer, the sending node shall not retransmit the last segment in case of a timeout.

10.1.3.6.4 Tie-breaking

In a special case, two nodes may start sending segments at the same time. The following algorithm shall be used to avoid a deadlock situation where both nodes consistently send Wait messages to the other node.

A receiving node which is already transmitting segments should perform a tie-breaking check before dropping an incoming segment. If the tie-breaking check is positive, the receiving node should accept the incoming segment and abort the ongoing transmission. The tie-break check is positive if the following three conditions are all met:

1. The receiving node is currently transmitting a datagram.
2. The recipient of the datagram being transmitted is also the originator of the received segment
3. The receiving node has a lower NodeID than the originator.

• • •

A.3.1.5 Modulation and coding

The PHY shall employ frequency shift keying (FSK) for RF modulation of R1 and R2. The PHY shall employ Gaussian frequency shift keying (GFSK) for R3.

Manchester code shall be used for data symbol encoding for R1 and non-return-to-zero for data symbol encoding for R2 and R3.

The modulation and the coding format are summarized in Table A.4 below:

Table A.4 – Modulation and coding format

Data Rate	Modulation	Coding	Separation	Symbols
R1	FSK	Manchester	40 kHz ±~~1~~20%	Binary
R2	FSK	NRZ	40 kHz ±~~1~~20%	Binary
R3	GFSK, BT = 0.6	NRZ	58 kHz ±~~1~~20%	Binary

The mapping of NRZ symbols to the physical medium is given in Table A.5 below ~~assuming high side LO (The mapping should be inverted for low side LO) is given below~~:

Table A.5 – Symbol mapping~~, for high side LO~~

Symbol	Frequency
0	$f_{center\ frequency}$ – separation/2
1	$f_{center\ frequency}$ + separation/2

The mapping of Manchester symbols to the physical medium ~~assuming high side LO (The mapping should be inverted for low side LO)~~ is given in Table A.6 below:

Table A.6 – Manchester symbols~~, for high side LO~~

Symbol	Frequency
0	Transition from ($f_{center\ frequency}$ –~~+~~ separation/2) to ($f_{center\ frequency}$ ~~–~~+ separation/2)
1	Transition from ($f_{center\ frequency}$ ~~–~~+ separation/2) to ($f_{center\ frequency}$ ~~+~~– separation/2)

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