

INTERNATIONAL STANDARD

NORME INTERNATIONALE



Industrial communication networks – Wireless communication network and communication profiles – WirelessHART™

Réseaux de communications industriels – Réseau de communications sans fil et profils de communication – WirelessHART™



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INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORK AND COMMUNICATION PROFILES – WirelessHART™

FOREWORD

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International Standard IEC 62591 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial process measurement, control and automation.

This standard cancels and replaces IEC/PAS 62591 published in 2009. This first edition constitutes a technical revision.

This bilingual version, published in 2011-07, corresponds to the English version.

The text of this standard is based on the following documents:

FDIS	Report on voting
65C/587/FDIS	65C/595/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

The French version of this standard has not been voted upon.

This publication has been drafted in accordance with ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

Withdrawn

INTRODUCTION

This International standard provides the specification, definitions, and profile for a Wireless communication network. It supplements IEC 61158-5-20, IEC 61158-6-20 where some commands are specified and it supplements IEC 61784-1 where a Communication Profile CP 9/1, universal command, is specified.

This document follows the structure and conventions of IEC 61158 series (for example separation of DL-service definitions and DL-protocol specification) and conventions of IEC 61784-1. IEC 61158 series specify different communication networks. These are structured in different Types. The Type 20 is assigned to technologies of Hart™¹ Communication Foundation (HCF). For other assignments of Type numbers see IEC/TR 61158-1.

NOTE IEC 61158 series do not contain a DLL specification for Type 20. However, this standard includes a DLL specification.

IEC 61784-1, and IEC 61784-2 provide Communication Profile Families (CPF), and, within a family, one to n Communication Profiles. The assigned CPF number for technologies of the HCF is CPF 9. For other assignments of CPF numbers see IEC/TR 61158-1.

A new project number IEC 62591 was assigned to the Type 20 enhancements and the associated CP 9/2, so that this document contains the equivalent subparts of the IEC 61158 series and of IEC 61784-1 organized here in different clauses.

The Type 20 protocol supports two way digital communications for process measurement and control devices. Applications include remote process variable interrogation, cyclical access to process data, parameter setting and diagnostics. This document defines the specification that comprises the Type 20 field communications protocol for wireless devices. Specification of the Type 20 protocol is based largely on the OSI 7-layer Communication Model.

The International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this document may involve the use of patents concerning the claims of the patents listed below given in the normative Clauses.

US08/04750 & PCT 12/100986 [HCF] Combined Wired and Wireless Communications with Field Devices
 US08/04777 & PCT 12/100927 [HCF] Increasing Reliability and Reducing Latency in a Wireless Network
 US08/04677 & PCT 12/100995 [HCF] Adaptive Scheduling in a Wireless Network
 US08/04716 & PCT 12/101000 [HCF] Wireless Protocol Adaptor
 US08/04775 & PCT 12/101005 [HCF] Synchronizing Timeslots in a Wireless Communication Protocol
 US08/04751 & PCT 12/101011 [HCF] Suspending Transmissions in a Wireless Communication Network
 US08/04678 & PCT 12/101021 [HCF] Enhancing Security in a Wireless Network
 US08/04746 & PCT 12/101037 [HCF] Wireless Gateway in a Process Control Environment
 US08/04676 & PCT 12/101043 [HCF] Efficient Addressing in Wireless HART Protocol
 US08/04745 & PCT 12/101049 [HCF] Support for Network Management and Device Communications in a Wireless Network
 US08/04749 & PCT 12/101054 [HCF] Priority Based Scheduling and Routing in a Wireless Network
 US08/04740 & PCT 12/101071 [HCF] Routing Packets on a Network Using Directed Graphs
 US08/04761 & PCT 12/101074 [HCF] Scheduling Communication Frames in a Wireless Network

IEC takes no position concerning the evidence, validity and scope of these patent rights.

¹ HART™ and WirelessHART™ are the trade names of HART™ Communication Foundation (HCF). HCF is a non-profit trade organization to support the HART™ Communication. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by IEC of the trade name holder or any of its products. Compliance to this document does not require use of the trade name. Use of the trade name HART™ and WirelessHART™ requires permission of the trade name holder.

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[HCF] Hart Communication Foundation
9390 Research Boulevard
Suite I-350
Austin TX 78759, USA

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ISO (www.iso.org/patents) and IEC (http://www.iec.ch/tctools/patent_decl.htm) maintain on-line data bases of patents relevant to their standards. Users are encouraged to consult the data bases for the most up to date information concerning patents.

Withdrawn

INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORK AND COMMUNICATION PROFILES – WirelessHART™

1 Scope

This International Standard specifies an additional Type 20 communication network to IEC 61158-5-20, IEC 61158-6-20 and a Communication Profile CP 9/2 in addition to IEC 61784-1 CPF 9.

This standard specifies the following:

- Physical layer service definition and protocol specification,
- Data-link layer service and protocol,
- Application layer service and protocol,
- Network management,
- Security,
- Communication profile,
- Wireless procedures and
- Gateway.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60559, *Binary floating-point arithmetic for microprocessor systems*

IEC/TR 61158-1:2010, *Industrial communication networks – Fieldbus specifications – Part 1: Overview and guidance for the IEC 61158 and IEC 61784 series*

IEC 61158-5-20:2010, *Industrial communication networks – Fieldbus specifications – Part 5-20: Application layer service definition – Type 20 elements*

IEC 61158-6-20:2010, *Industrial communication networks – Fieldbus specifications – Part 6-20: Application layer protocol specification – Type 20 elements*

IEC 61784-1:2010, *Industrial Communication Networks – Profiles – Part 1: Fieldbus profiles*

IEC 61784-2:2010, *Industrial Communication Networks – Profiles – Part 2: Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3*

ISO/IEC 7498-1, *Information technology – Open Systems Interconnection — Basic Reference Model: The Basic Model*

ISO/IEC 8824, *Information Technology – Open Systems Interconnection – Specification of Abstract Syntax Notation One (ASN.1)*

ISO/IEC 8859-1, *Information technology – 8-bit single-byte coded graphic character sets – Part 1: Latin alphabet No. 1*

ISO/IEC 9545, *Information technology – Open Systems Interconnection – Application Layer structure*

ISO/IEC 10731, *Information technology – Open Systems Interconnection – Basic Reference Model – Conventions for the definition of OSI services*

IEEE 802-2001, *IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture*

IEEE 802.15.4-2006, *IEEE Standard for Information technology- Telecommunications and information exchange between systems- Local and metropolitan area networks- Specific requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs)*

3 Terms, definitions, symbols, abbreviations and conventions

For the purposes of this document, the following terms as defined in these publications apply.

3.1 Reference model terms and definitions

This standard is based in part on the concepts developed in ISO/IEC 7498-1 and ISO/IEC 7498-3, and makes use of the following terms defined therein.

DL-entity (N=2)	[7498-1]
DL protocol-data-unit	[7498-1]
DL service-data-unit	[7498-1]
DLS user-data	[7498-1]
NL-entity (N=3)	[7498-1]
NL protocol-data-unit	[7498-1]
NL service-data-unit	[7498-1]
NLS user-data	[7498-1]
TL-entity (N=4)	[7498-1]
TL protocol-data-unit	[7498-1]
TL service-data-unit	[7498-1]
TLS user-data	[7498-1]

3.2 Terms and definitions from ISO/IEC 7498-1 terms

- a) abstract syntax
- b) application entity

- c) application process
- d) application protocol data unit
- e) application service element
- f) application entity invocation
- g) application process invocation
- h) application transaction
- i) presentation context
- j) real open system
- k) transfer syntax

3.2.1 Terms and definitions from ISO/IEC 9545

- a) application-association
- b) application-context
- c) application context name
- d) application-entity-invocation
- e) application-entity-type
- f) application-process-invocation
- g) application-process-type
- h) application-service-element
- i) application control service element

3.2.2 Terms and definitions from ISO/IEC 8824

- a) object identifier
- b) type
- c) value
- d) simple type
- e) structured type
- f) component type
- g) tag
- i) true
- j) false
- k) integer type
- m) octet string type
- n) null type
- o) sequence type
- p) sequence of type
- q) choice type
- r) tagged type
- s) any type
- t) module
- u) production

3.2.3 Terms and definitions from ISO/IEC 8825

- a) encoding (of a data value)
- b) data value
- c) identifier octets (the singular form is used in this standard)
- d) length octet(s) (both singular and plural forms are used in this standard)
- e) contents octets

3.3 Specific terms and definitions

3.3.1

absolute slot number

count of all slots that have occurred since the network was formed

NOTE This number always increments and is never reset to any fixed value or zero. Its current value is always the sequence number of the current slot. Its maximum value is $(2^{40} - 1)$ after that it rolls over to zero.

3.3.2

acknowledge

explicit data-link response to the successful reception of a directed, non-broadcast DLPDU from a DLE source device and the second DLPDU of a two-DLPDU transaction

3.3.3**adapter**

network device that enables connection and communication with a field device which does not have a direct connection to a Type 20 network

3.3.4**advertise DLPDU**

invite new devices into the network

NOTE When a device wishes to join a network, it listens for these DLPDUs and then uses the information in the DLPDU to synchronize with the network and initiate the join process.

3.3.5**analog channel**

continuously varying electrical signal connecting a field device to the remainder of the data acquisition or control system

NOTE 1 Some field devices support multiple analog channels (input or output).

NOTE 2 Each analog channel transmits a single dynamic variable to or from the field device.

3.3.6**application**

function or data structure for which data is consumed or produced

[IEC 61158-6-9]

3.3.7**application domain**

classification of the application process based on communication priority and capacity requirement

3.3.8**application object**

object class that manages and provides the run time exchange of messages across the network and within the network device

NOTE Multiple types of application object classes may be defined.

[IEC 61158-6-9]

3.3.9**application relationship**

cooperative association between two or more application-entity-invocations for the purpose of exchange of information and coordination of their joint operation

NOTE This relationship is activated either by the exchange of application-protocol-data-units or as a result of pre-configuration activities.

[IEC 61158-6-9]

3.3.10**application relationship endpoint**

context and behavior of an application relationship as seen and maintained by one of the application processes involved in the application relationship

NOTE Each application process involved in the application relationship maintains its own application relationship endpoint.

3.3.11

ASN time

time represented as absolute slot number; any instance in time is equal to absolute slot number at that instance

3.3.12

attribute

description of an externally visible characteristic or feature of an object

NOTE The attributes of an object contain information about variable portions of an object. Typically, they provide status information or govern the operation of an object. Attributes may also affect the behavior of an object. Attributes are divided into class attributes and instance attributes.

3.3.13

behavior

indication of how the object responds to particular events

NOTE Its description includes the relationship between attribute values and services.

3.3.14

broadcast

process of sending a PDU to all devices that are connected to the network and are able to receive the transmission

3.3.15

broadcast address

address used by a master to send a command to all devices

3.3.16

busy

state of a device which is active on different tasks and cannot execute a command at the time

3.3.17

channel

RF frequency band used to transmit a modulated signal carrying packets

3.3.18

channel blacklisting

method of eliminating an RF channel from usage

3.3.19

channel hopping

regular change of transmit or receive frequency to combat interference and fading

3.3.20

channel offset

link-specific value provided by the network manager that is used to calculate the channel to use when channel hopping

3.3.21

class

set of objects, all of which represent the same kind of system component

NOTE A class is a generalization of the object; a template for defining variables and methods. All objects in a class are identical in form and behavior, but usually contain different data in their attributes.

3.3.22

class attributes

attribute that is shared by all objects within the same class

3.3.23**class code**

unique identifier assigned to each object class

3.3.24**class specific service**

service defined by a particular object class to perform a required function which is not performed by a common service

NOTE A class specific object is unique to the object class which defines it.

3.3.25**clear channel assessment**

testing while the RF channel is in use to avoid initiating a transaction

NOTE It is performed by listening to the channel prior to sending the first DLDPDU of a transaction. If signal is detected, then the transaction is deferred to a later TDMA slot.

3.3.26**client**

a) object which uses the services of another (server) object to perform a task

b) initiator of a message to which a server reacts, such as the role of an AR endpoint in which it issues confirmed service request APDUs to a single AR endpoint acting as a server

[IEC 61158-6-9]

3.3.27**conveyance path**

unidirectional flow of APDUs across an application relationship

3.3.28**cyclic**

term used to describe events which repeat in a regular and repetitive manner

3.3.29**device**

any entity containing an implementation of Type 20 fieldbus

3.3.30**device ID**

serial number for a device that is unique among all instances of one type of device

3.3.31**device profile**

collection of device dependent information and functionality providing consistency between similar devices of the same device type

3.3.32**expanded device type**

manufacturer's type of a device as specified in IEC 61158-6-20:2010, Table 7

3.3.33**device variable**

uniquely defined data item within a Field Device that is always associated with cyclical process information

NOTE A device variable's value varies in response to changes and variations in the process to which the device is connected.

3.3.34

discovery

process of finding a new neighbor by listening to the special DLPDU that indicates the presence of the device

3.3.35

discovery link

link that is used for transmitting and receiving the special DLPDU that indicates the presence of the device

3.3.36

dynamic variable

connection between a process and an analog channel

NOTE A device may contain primary, secondary, tertiary, and quaternary variables. These are collectively called the dynamic variables.

3.3.37

endpoint

one of the communicating entities involved in a connection

3.3.38

error

discrepancy between a computed, observed or measured value or condition and the specified or theoretically correct value or condition

3.3.39

error code

identification of a specific type of error within an error class

3.3.40

field device

network device that is connected to the process or to plant equipment

NOTE It directly connects to the sensor or actuator or performs process control function and it is directly connected to the physical layer of Type 20.

3.3.41

frequency channel

allocation of the frequency spectrum in a given frequency range

3.3.42

gateway

network device containing at least one host interface such as serial or Ethernet, acting as ingress or an egress point enabling communication between host applications and field devices

3.3.43

graph

collection of directed paths among network devices such that more than one route is possible from a source device to destination device

3.3.44

Graph_ID

identifier used to indicate a specific graph entry

3.3.45

handheld

a) host application residing on a portable device

b) qualifier to other terms such as key, superframe

3.3.46

hop

movement of a packet directly between two adjacent neighbors in one network transaction without the participation of any other node in the network

3.3.47

hop to live

field in the network header of each packet that specifies how many more hops a packet can travel before being discarded

3.3.48

join

process by which a network device is authenticated and allowed to participate in the network

NOTE A device is considered Joined when it has the network key, a network manager session and a normal (not join) superframe and links.

3.3.49

join_key

security key that is used to start the join process

3.3.50

latency

time it takes for a packet to cross a network connection, from sender to receiver

3.3.51

link

full communication specification between adjacent devices in a network and it includes the communication parameters necessary to move a DLPDU one hop

NOTE A Link is a function of source and destination address pairing, slot and channel offset assignment, direction of communication, dedicated or shared communication, and type. Links are assigned to superframes as part of the scheduling process.

3.3.52

logical link control

higher of the two data-link layer sublayers and used for error detection, flow control, framing, and addressing

3.3.53

long_tag

32-character restricted ISO Latin-1 string used to identify a field device

3.3.54

loop current

value measured by a mA in series with the field device

NOTE The loop current is a near DC analog 4 mA to 20 mA signal used to communicate a single value between the control system and the field device. Voltage mode devices use "Volts DC" as their engineering units where "loop current" values are used.

3.3.55

maintenance port

interface in the network device that is used for provisioning

NOTE This interface is used to write the Join_key and network identifier, and to monitor the join process.

3.3.56

management information

network-accessible information that supports managing the operation of the fieldbus system, including the application layer

NOTE Managing includes functions such as controlling, monitoring, and diagnosing.

3.3.57

manufacturer ID

2 octet enumeration identifying the manufacturer that produced a device

NOTE A manufacturer is required to use the value assigned to it and is not permitted to use the value assigned to another manufacturer.

3.3.58

master

device that initiates communication activity by sending request APDU to a device and expecting a response PDU

3.3.59

medium access control

lower of the two data-link sublayers and used for controlling the access to the communication channel

3.3.60

multicast

sending of one packet to more than one device in the network using only one transmission

3.3.61

neighbor

adjacent node in the network such that the receive signal level (RSL) from it suggests that the communication is possible in at least one direction

3.3.62

neighbor table

list of all devices that the device considers as neighbor

NOTE It also stores the attributes of the neighbor.

3.3.63

network

series of nodes connected by some type of communication medium

NOTE The connection paths between any pair of nodes can include repeaters, routers and gateways.

3.3.64

network device

device with a direct physical layer connection to the network

NOTE Each network device has a unique address that is used in communication with the device. Network devices include field device, access point (i.e. gateway), adapter and handheld.

3.3.65

network_ID

identifier used to indicate a network to which all inter-communicating devices are connected

3.3.66

network manager

entity that is responsible for configuration of the network, scheduling communication between network devices, management of the routing tables and monitoring and reporting the health of the network

3.3.67**nickname**

identifier assigned to a device such that it is unique within the network to which the device is connected

3.3.68**node**

addressable logical or physical device attached to the network

3.3.69**nonce**

non-repeating number constructed so as to be unique to the current packet and to ensure that old communications cannot be reused in replay attacks

NOTE Nonce is necessary for maintaining packet secrecy and providing sender authenticity and packet integrity.

3.3.70**packet**

formatted, aggregated bits that are transmitted together in time across the physical medium

[IEEE 802.15.4, modified]

3.3.71**path**

direct communication link between two neighbor devices in the mesh

3.3.72**payload data**

contents of a data message that is being transmitted

3.3.73**pipe**

secure, bi-directional, virtual communication connection between peer devices

3.3.74**polling address**

integer used to identify a device

NOTE The polling address is used to construct a one-octet address.

3.3.75**pre-defined AR endpoint**

AR endpoint that is defined locally within a device without use of the create service

NOTE Pre-defined ARs that are not pre-established are established before being used.

3.3.76**pre-established AR endpoint**

AR endpoint that is placed in an established state during configuration of the AEs that control its endpoints

3.3.77**route**

one sequence of unidirectional paths from one device to another connecting a source device to a destination device

3.3.78**route ID**

identifier used to indicate a specific route

3.3.79

server

<communication> role of an AREP in which it returns a confirmed service response APDU to the client that initiated the request

3.3.80

server

<system> object which provides services to another (client) object

3.3.81

service

operation or function than an object and/or object class performs upon request from another object and/or object class

NOTE A set of common services is defined and provisions for the definition of object-specific services are provided. Object-specific services are those which are defined by a particular object class to perform a required function which is not performed by a common service.

3.3.82

session ID

identifier used to indicate a specific session entry

3.3.83

slave

device that initiates communication activity only after it receives a request PDU from a master device and it is required to send a response to that request

3.3.84

slot

fixed time interval that may be used for communication between neighbors

3.3.85

superframe

collection of slots repeating at a constant rate; each slot has a link associated with it

3.3.86

superframe_ID

identifier used to indicate a specific superframe entry

3.3.87

tag

8-character ASCII string used to identify a field device

3.3.88

time division multiple access

medium access control technique that uses time slots where communications between devices can occur

NOTE It provides collision free, deterministic communications.

3.3.89

transaction

exchange of related, consecutive frames between two peer medium access control entities, required for a successful transmission

NOTE A transaction consists of either (a) a single PhPDU transmission from a source device, or (b) one PhPDU from the source device followed by a second, link-level acknowledgement PhPDU from the destination device.

3.3.90**unicast**

sending of a packet to a single device in the network

3.3.91**unique ID**

identifier assigned to a device which is unique among all instances of the devices compliant to this standard and compliant to Communication Profile CP 9/2 using identical organization name as specified in 9.3.1

3.4 Abbreviations

ACK	Acknowledge
AE	Application entity
AL	Application layer
AP	Application process
APDU	Application protocol data unit
APO	Application Object
AR	Application relationship
AREP	Application relationship endpoint
ARPM	Application Relationship Protocol Machine
ASCII	American Standard Code for Information Interchange
ASE	Application Service Element
ASN	Absolute Slot Number
BACK	Burst acknowledge
CCA	Clear channel assessment
Cnf	Confirmation
CP	Communication Profile
CPF	Communication Profile Family
CRC	Cyclic redundancy check
dBm	Abbreviation for the power ratio in decibels (dB) of the measured power, referenced to one mW (1 mW), 0 dBm = 1 mW, 10 dBm = 10 mW, 20 dBm = 100 mW, 30 dBm = 1 W
DL-	Data-link layer (as a prefix)
DLE	DL-entity (the local active instance of the data-link layer)
DLL	Data-link layer
DLM	DL-management
DLMS	DL-management service
DLPDU	Data-link protocol data unit
DLS	DL-service
DLSDU	DL-service-data-unit
DR	Delayed response
DRM	Delayed response mechanism
EUI-64	Extended unique identifier (64 bits long)
FAL	Fieldbus application layer
FSMP	FAL Service Protocol Machine
HCF	HART™ Communication Foundation

HTL	Hop to live	
ID	Identifier	
IEC	International Electrotechnical Commission	
Ind	Indication	
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector	
LLC	Logical link control	
LSB	Least significant byte	
MAC	Medium access control	
MIC	Message integrity code	
MSB	Most significant byte	
NL	Network layer	
NL-	Network layer (as a prefix)	
NLE	NL-entity (the local active instance of the network layer)	
NLM	NL-management	
NLMS	NL-management service	
NLS	NL-service	
NLSDU	NL-service-data-unit	
NPDU	NL-protocol-data-unit	
NSDU	NL-service-data-unit	
O-QPSK	Offset Quadrature Phase-Shift Keying	
OSI	Open Systems Interconnect	
OUI	Organizationally Unique Identifier	
PDU	Protocol data unit	
PhE	PhL-entity (the local active instance of the physical layer)	
PhL-	Physical layer (as a prefix)	
PhPDU	PhL-protocol-data-unit	[ISO/IEC 7498-1]
PhS	Physical layer service	[ISO/IEC 7498-1]
QoS	Quality-of-service	
Req	Request	
RF	Radio Frequency	
RSL	Receive signal level	
Rsp	Response	
RSV	Reserved	
SAP	Service access point	
SN	Sign bit	
SOM	Start of message	
STX	Start of a transaction	
TDMA	Time Division Multiple Access	
TL	Transport layer	
TL-	Transport layer (as a prefix)	
TLE	TL-entity (the local active instance of the transport layer)	
TLM	TL-management	

TLMS	TL-management service
TLS	TL-service
TMPM	Transport layer Mapping Protocol Machine
TPDU	TL-protocol-data-unit
TSDU	TL-service-data-unit
VFD	Virtual field device

3.5 Conventions

3.5.1 Conventions used for service

This standard uses the descriptive conventions given in ISO/IEC 10731.

The service model, service primitives, and time-sequence diagrams used are entirely abstract descriptions; they do not represent a specification for implementation.

Service primitives, used to represent service user/service provider interactions (see ISO/IEC 10731), convey parameters that indicate information available in the user/provider interaction.

This standard uses a tabular format to describe the component parameters of the Physical, Data Link, Network, Transport and Application layer service primitives. The parameters that apply to each group of primitives are set out in tables throughout the remainder of this standard. Each table consists of up to six columns, containing the name of the service parameter, and a column each for those primitives and parameter-transfer directions used by the service:

- the request primitive's input parameters;
- the request primitive's output parameters;
- the indication primitive's output parameters;
- the response primitive's input parameters; and
- the confirm primitive's output parameters.

One parameter (or part of it) is listed in each row of each table. For local services, only request primitive with input and output parameters is used. Under the appropriate service primitive columns, a code is used to specify the type of usage of the parameter on the primitive and parameter direction specified in the column:

M parameter is mandatory for the primitive;

U parameter is a user option and may or may not be provided depending on the dynamic usage of the DLS-user. When not provided, a default value for the parameter is assumed;

S only one parameter in a group of parameters using this code is required.

C parameter is conditional upon other parameters or upon the environment of the DLS-user;

CU parameter is a conditional user option, and may or may not be permitted depending upon other parameters or upon the environment of the DLS-user. When permitted, it may or may not be provided depending on the dynamic usage of the DLS-user. When permitted and not provided, a default value for the parameter is assumed.

(blank) parameter is never present.

Some entries are further qualified by items in brackets. These may be:

a) a parameter-specific constraint

(=) indicates that the parameter is semantically equivalent to the parameter in the service primitive to its immediate left in the table;

- ($\leq$) indicates that the set of parameter values has an implicit order and that the parameter's value is less than or equal to that of the parameter in the service primitive to its immediate left in the table (that is, left by one or two columns);
- ($\geq$) indicates that the set of parameter values has an implicit order and that the parameter's value is greater than, or equal to, that of the parameter in the service primitive to its immediate left in the table (that is, left by one or two columns).
- b) an indication that some note applies to the entry
- (n) indicates that the following note n contains additional information pertaining to the parameter and its use.

3.5.2 Conventions used for DL-protocol (state machine)

This standard uses a diagram to represent a state machine. The following convention is used.

- The labeled rectangles represent states that a component can be in.
- State transitions are directed lines. They show which state a component leaves and which state it transitions to.
- A transition is labeled with the events that caused it and the corresponding actions (this may be empty). The events (above the line) causing the transition is separated from the resulting actions (below the line) by a horizontal line.
- A tilde (" ~ ") means the one's complement or negation.

3.5.3 Conventions for Application Layer service

3.5.3.1 Overview

The Fieldbus Application Layer (FAL) is defined as a set of object-oriented Application Service Elements (ASE). Each ASE is specified in a separate subclause. Each ASE specification is composed of two parts, its class specification, and its service specification.

The class specification defines the attributes of the class. The service specification defines the services that are provided by the ASE.

3.5.3.2 Conventions for class definitions

Class definitions are described using templates. Each template consists of a list of attributes for the class. An example of the template is shown below:

FAL ASE:		ASE Name
CLASS:	Class Name	
CLASS ID:	#	
PARENT CLASS:	Parent Class Name	
ATTRIBUTES:		
1	(o) Key Attribute:	numeric identifier
2	(o) Key Attribute:	name
3	(m) Attribute:	attribute name(values)
4	(m) Attribute:	attribute name(values)
4.1	(s) Attribute:	attribute name(values)
4.2	(s) Attribute:	attribute name(values)
4.3	(s) Attribute:	attribute name(values)
5.	(c) Constraint:	constraint expression
5.1	(m) Attribute:	attribute name(values)
5.2	(o) Attribute:	attribute name(values)
6	(m) Attribute:	attribute name(values)
6.1	(s) Attribute:	attribute name(values)
6.2	(s) Attribute:	attribute name(values)

SERVICES:

- 1 (o) OpsService: service name
- 2. (c) Constraint: constraint expression
- 2.1 (o) OpsService: service name
- 3 (m) MgtService: service name

- (1) The "FAL ASE:" entry is the name of the FAL ASE that provides the services for the class being specified.
- (2) The "CLASS:" entry is the name of the class being specified. All objects defined using this template will be an instance of this class. The class may be specified by this standard, or by a user of this standard.
- (3) The "CLASS ID:" entry is a number that identifies the class being specified. This number is unique within the FAL ASE that will provide the services for this class. When qualified by the identity of its FAL ASE, it unambiguously identifies the class within the scope of the FAL. The value "NULL" indicates that the class cannot be instantiated. Class IDs between 1 and 255 are reserved by this standard to identify standardized classes. They have been assigned to maintain compatibility with existing national standards. CLASS IDs between 256 and 2048 are allocated for identifying user defined classes.
- (4) The "PARENT CLASS:" entry is the name of the parent class for the class being specified. All attributes defined for the parent class and inherited by it are inherited for the class being defined, and therefore do not have to be redefined in the template for this class.

NOTE The parent-class "TOP" indicates that the class being defined is an initial class definition. The parent class TOP is used as a starting point from which all other classes are defined. The use of TOP is reserved for classes defined by this standard.

- (5) The "ATTRIBUTES" label indicate that the following entries are attributes defined for the class.
 - a) Each of the attribute entries contains a line number in column 1, a mandatory (m) / optional (o) / conditional (c) / selector (s) indicator in column 2, an attribute type label in column 3, a name or a conditional expression in column 4, and optionally a list of enumerated values in column 5. In the column following the list of values, the default value for the attribute may be specified.
 - b) Objects are normally identified by a numeric identifier or by an object name, or by both. In the class templates, these key attributes are defined under the key attribute.
 - c) The line number defines the sequence and the level of nesting of the line. Each nesting level is identified by period. Nesting is used to specify
 - i) fields of a structured attribute (4.1, 4.2, 4.3),
 - ii) attributes conditional on a constraint statement (5). Attributes may be mandatory (5.1) or optional (5.2) if the constraint is true. Not all optional attributes require constraint statements as does the attribute defined in (5.2).
 - iii) the selection fields of a choice type attribute (6.1 and 6.2).
- (6) The "SERVICES" label indicates that the following entries are services defined for the class.
 - a) An (m) in column 2 indicates that the service is mandatory for the class, while an (o) indicates that it is optional. A (c) in this column indicates that the service is conditional. When all services defined for a class are defined as optional, at least one has to be selected when an instance of the class is defined.

- b) The label "OpsService" designates an operational service (1).
- c) The label "MgtService" designates a management service (2).
- d) The line number defines the sequence and the level of nesting of the line. Each nesting level is identified by period. Nesting within the list of services is used to specify services conditional on a constraint statement.

3.5.3.3 Conventions for service definitions

3.5.3.3.1 General

This standard uses the descriptive conventions given in ISO/IEC 10731.

The service model, service primitives, and time-sequence diagrams used are entirely abstract descriptions; they do not represent a specification for implementation.

3.5.3.3.2 Service parameters

Service primitives are used to represent service user/service provider interactions (ISO/IEC 10731). They convey parameters which indicate information available in the user/provider interaction.

NOTE 1 See the note under 3.5.3.3.3 relative to the non-inclusion of service parameters that are appropriate to a protocol specification or programming interface specification or implementation specification, but not to an abstract service definition.

This standard uses a tabular format to describe the component parameters of the service primitives. The parameters that apply to each group of service primitives are set out in tables throughout the remainder of this standard. Each table consists of up to six columns: a column for the name of the service parameter, and a column each for those primitives and parameter-transfer directions used by the service. The possible six columns are

- 1) the parameter name;
- 2) the request primitive's input parameters;
- 3) the request primitive's output parameters;

NOTE 2 This is a seldom-used capability. Unless otherwise specified, request primitive parameters are input parameters.

- 4) the indication primitive's output parameters;
- 5) the response primitive's input parameters; and
- 6) the confirm primitive's output parameters.

NOTE 3 The request, indication, response and confirm primitives are also known as requestor.submit, acceptor.deliver, acceptor.submit, and requestor.deliver primitives, respectively (see ISO/IEC 10731).

One parameter (or component of it) is listed in each row of each table. Under the appropriate service primitive columns, a code is used to specify the type of usage of the parameter on the primitive specified in the column:

- M parameter is mandatory for the primitive
- U parameter is a User option, and may or may not be provided depending on dynamic usage of the service user. When not provided, a default value for the parameter is assumed.
- C parameter is conditional upon other parameters or upon the environment of the service user.
- (blank) parameter is never present.
- S parameter is a selected item.

Some entries are further qualified by items in brackets. These may be

- a) a parameter-specific constraint:
“(=)” indicates that the parameter is semantically equivalent to the parameter in the service primitive to its immediate left in the table.
- b) an indication that some note applies to the entry:
“(n)” indicates that the following note "n" contains additional information pertaining to the parameter and its use.

3.5.3.3.3 Service procedures

The procedures are defined in terms of

- the interactions between application entities through the exchange of fieldbus Application Protocol Data Units, and
- the interactions between an application layer service provider and an application layer service user in the same system through the invocation of application layer service primitives.

These procedures are applicable to instances of communication between systems which support time-constrained communications services within the fieldbus application layer.

NOTE The IEC 61158-5 subseries of standards define sets of abstract services. They are neither protocol specifications nor implementation specifications nor concrete programming interface specifications. Therefore there are restrictions on the extent to which service procedures can be mandated in the parts of IEC 61158-5 subseries. Protocol aspects that can vary among different protocol specifications or different implementations that instantiate the same abstract services are unsuitable for inclusion in these service definitions, except at the level of abstraction that is necessarily common to all such expressions. In this document, Clause 7 is the equivalent of the IEC 61158-5 subseries.

For example the means by which service providers pair request and reply Protocol data units (PDU) is appropriate for specification in an IEC 61158-6 subseries protocol specification standard but not in an IEC 61158-5 subseries abstract service definition standard. Similarly, local implementation methods by which a service provider or service user pairs request and confirm(-ation) primitives, or indication and response primitives, is appropriate for an implementation specification or for a programming interface specification, but not for an abstract service standard or for a protocol standard, except at a level of abstraction that is necessarily common to all embodiments of the specifying standard. In all cases, the abstract definition is not permitted to over-specify the more concrete instantiating realization.

Further information on the conceptual service procedures of an implementation of a protocol that realizes the services of one of the IEC 61158-5 subseries abstract service definitions can be found in IEC/TR 61158-1:2007, 9.6.

3.5.4 Conventions for the AL-protocol

3.5.4.1 General concept

The FAL is defined as a set of object-oriented ASEs. Each ASE is specified in a separate subclause. Each ASE specification is composed of three parts: its class definitions, its services, and its protocol specification. The first two are contained in IEC 61158-5. The protocol specification for each of the ASEs is defined in this standard.

The class definitions define the attributes of the classes supported by each ASE. The attributes are accessible from instances of the class using the Management ASE services specified in IEC 61158-5. The service specification defines the services that are provided by the ASE.

This standard uses the descriptive conventions given in ISO/IEC 10731.

3.5.4.2 Conventions for class definitions

The data-link layer mapping definitions are described using templates. Each template consists of a list of attributes for the class. The general form of the template is defined in IEC 61158-5-20:2010, 3.8.2.

3.5.4.3 Conventions used in state machines

The state machines are described in Table 1.

Table 1 – Conventions used for state machines

#	Current state	Event / condition => action	Next state
Name of this transition	The current state to which this state transition applies	Events or conditions that trigger this state transaction. => The actions that are taken when the above events or conditions are met. The actions are always indented below events or conditions	The next state after the actions in this transition is taken

The conventions used in the state machines are as follows:

:= Value of an item on the left is replaced by value of an item on the right. If an item on the right is a parameter, it comes from the primitive shown as an input event.

xxx A parameter name.

Example:
Identifier := reason
means value of a 'reason' parameter is assigned to a parameter called 'Identifier.'

"xxx" Indicates fixed value.

Example:
Identifier := "abc"
means value "abc" is assigned to a parameter named 'Identifier.'

= A logical condition to indicate an item on the left is equal to an item on the right.

< A logical condition to indicate an item on the left is less than the item on the right.

> A logical condition to indicate an item on the left is greater than the item on the right.

<> A logical condition to indicate an item on the left is not equal to an item on the right.

&& Logical "AND"

|| Logical "OR"

This construct allows the execution of a sequence of actions in a loop within one transition. The loop is executed for all values from start_value to end_value.

Example:
for (Identifier := start_value to end_value)
actions
endfor

This construct allows the execution of alternative actions depending on some condition (which might be the value of some identifier or the outcome of a previous action) within one transition.

Example:
If (condition)
actions
else
actions
endif

Readers are strongly recommended to refer to the subclauses for the Application relationship endpoint (AREP) attribute definitions, the local functions, and the FAL-PDU definitions to

understand protocol machines. It is assumed that readers have sufficient knowledge of these definitions, and they are used without further explanations.

3.5.4.4 Class diagram

3.5.4.4.1 General

UML is used in this document to show class diagram. The purpose of a class diagram is to show the objects and their relationships within a system. In a class diagram objects are classes (as opposed to an instance diagram where the objects are instances of classes). There are several forms of relationships including associations, generalization/specialization, aggregation, and dependency.

3.5.4.4.2 Classes

Classes contain three compartments arranged vertically. The top compartment is the class name. The middle compartment lists the class's attributes. The bottom compartment lists the class's operations. When drawing a class element on a class diagram, the top compartment is mandatory, and the bottom two compartments are optional. The bottom compartment is not required in a diagram in which the purpose is to show only the relationship between classes. It is not necessary to show all attributes in all drawings where the class is used. Figure 1 shows a Superframe class with operations suppressed. In this figure, the class name is 'Superframe'. The class is illustrated with three attributes, Superframe_ID, NumSlots, and Active.

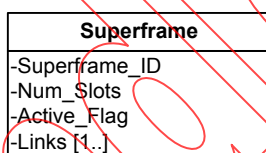


Figure 1 – Superframe class example

3.5.4.4.3 Relationships

The forms of relations used in this document are summarized in Table 2.

Table 2 – Class relationship notation

Relationship	Function	Notation
Bi-directional association	A bi-directional association is indicated by a solid line between the two classes.	
Uni-directional association	In a uni-directional association, two classes are related, but only one class knows that the relationship exists. It is indicated by a line with one arrow between the two classes.	
Association showing multiplicity	Multiplicity specifies how many instances of one class can be related to one instance of another class. In this example the 0..1 means that when an instance of a 'A' exists, it can either have zero or one instance of a 'B' associated with it (B may not have yet been created).	
Generalization	A relationship more specific and more general description, used for inheritance.	
Basic aggregation	Part-whole relationship – the lifecycle of a part class is independent from the whole class's lifecycle.	
Composite aggregation	Part-whole relationship – the lifecycle of a part class is dependent on the containing object.	
Dependency	Shows a relationship between two model elements; it indicates that one object depends on another object for some behavior.	

3.5.4.4.4 Inheritance

An important concept in object-oriented design is inheritance. Inheritance refers to the ability of one class (child class) to inherit the identical functionality of another class (super class), and then add new functionality of its own. To model inheritance on a class diagram, a solid line is drawn from the child class (the class inheriting the behavior) with a closed, arrowhead (or triangle) pointing to the super class. Figure 2 shows a Superframe class modeled as a specialized type of Graph.



Figure 2 – Inheritance example

3.5.4.4.5 Basic aggregation

Another important concept in object-oriented design is aggregation. Aggregation is used to model a "whole to its parts" relationship. There are two forms of aggregation; basic aggregation and composition aggregation. In basic aggregation relationships, the lifecycle of a part class is independent from the whole class's lifecycle. As shown in Figure 3, Car is a whole entity and Wheel is part of the overall Car. The Wheel can be created ahead of time, and it can sit in a warehouse before being placed on a car during assembly.

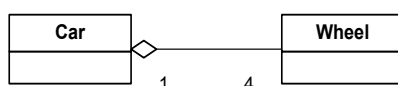


Figure 3 – Basic aggregation example

3.5.4.4.6 Composition aggregation

The other form of aggregation is composition aggregation, usually simply referred to as composition. Figure 4 shows the relationship of a superframe and its links. In this case a link cannot exist without the superframe. Composition is drawn with a filled diamond shape.

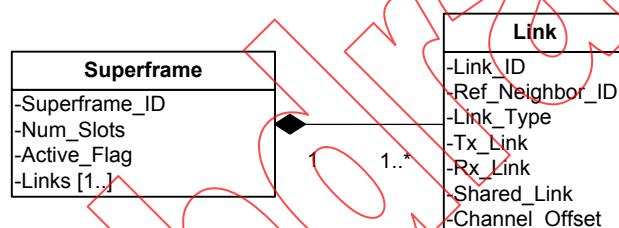


Figure 4 – Composition aggregation example

3.5.4.4.7 Multiplicity

Multiplicity shows how many instances of one class can be related to one instance of another class. Table 3 lists the examples of multiplicity indicators along with their meanings.

Table 3 – Multiplicity notation

Potential Multiplicity Values	
Indicator	Meaning
0..1	Zero or one
1	Only one
0..*	Zero or more
*	Zero or more
1..*	One or more
1..2	One or Two
4	Only four
0..5	Zero to Five

4 Physical layer specification and service definition

4.1 Physical layer service definition

4.1.1 General overview

Type 20 uses Radio Frequencies (RF) to communicate between devices. The distance between two devices can be 100 meters or more depending upon the transmitter power, antenna type and lack of obstruction between two devices. Devices complying with Type 20 can be powered either by mains power, battery, energy harvesting devices (for example solar, vibration, etc), or a combination there of.

This standard defines the Type 20 physical layer (PhL). It is used for devices implementing wireless mesh network communication as defined by this standard. The PhL is responsible for the signaling method, signal strength, device sensitivity, and environment for sending bits across the network media. This wireless PhL specification is based on the 2 450 MHz DSSS physical layer and the employing offset quadrature phase-shift keying (O-QPSK) modulation according to IEEE STD 802.15.4-2006. This standard defines the services that the physical layer provides to higher layers of this standard to send and receive data on the media. It also defines the local management parameters used to control the operation of the PhL.

The PhL of this standard deals with radio characteristics making a network connection. It associates with any part of the network structure that doesn't process information in any way. It is responsible for sending the bits across the network media. It does not define what a bit is or how it is used, merely how it's sent. The PhL is responsible for transmitting and receiving the data.

4.1.2 Physical layer services

4.1.2.1 Facilities of the physical layer services

The PhL provides following services:

- Control service – it supports enabling or disabling of the PhL entity (PhE) and to do clear channel assessment of the underlying medium,
- Message service – it supports the transfer of Physical layer service (PhS) -user-data from a source PhS-user to a destination PhS-user, and
- PhL-management services – it supports configuration of the PhL.

4.1.2.2 Sequence of primitives

The relations of primitives of each type at the interface of PhS-user and one PhE to primitives at the PhS-user and the other PhEs for error-free cases are summarized in the diagrams of Figure 5.

Before using the PhE, the PhS-user has to enable it as shown in the sequence a). The sequence c) shows the transmission of PhPDU from the source PhL-entity (PhE) to the destination PhE. The transmission starts with clear channel assessment as shown in the sequence b). At the destination, the reception starts with PH-RECV-SD indication after the start delimiter has been received by the PhE. The error free reception ends with PH-DATA indication. If there is any error in the reception then the PhE at the destination indicates it by a status parameter and does not deliver any Physical layer service (PhS) user-data.

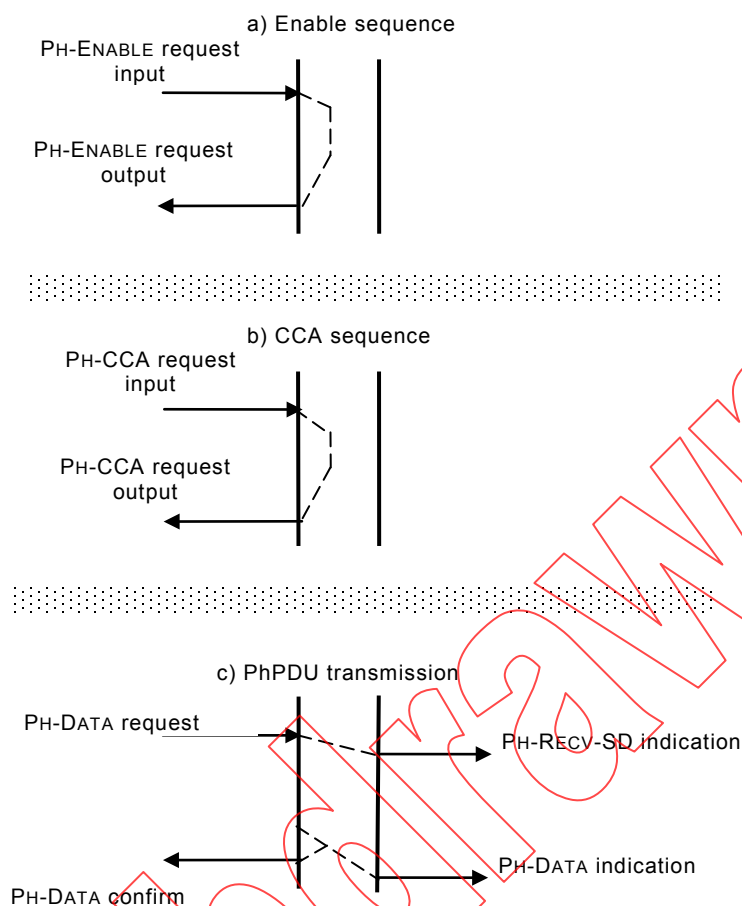


Figure 5 – Physical layer service sequences

4.1.2.3 PH-ENABLE service

4.1.2.3.1 Types of primitives and parameters

Table 4 indicates the types of primitives and the parameters needed for the PhL-Enable service. This service is used to enable or to disable the PhE and to place it in transmit or receive mode on the specified frequency channel. The request service is successful only if the channel is in idle state.

Table 4 – PH-ENABLE primitives and parameters

Parameter name	Request	
	Input	Output
Channel	M	M
State	M	M

4.1.2.3.2 Parameters

4.1.2.3.2.1 Channel

It specifies one of the available channels for which this service is used.

4.1.2.3.2.2 State

In the request primitive, it specifies the state in which the channel should be, when this service is completed. In the confirm primitive, it specifies the current state of the channel after the service is completed. Its value can be either Enable or Disable.

4.1.2.4 PH-CCA service

4.1.2.4.1 Types of primitives and parameters

Table 5 indicates the types of primitives and the parameters needed for the PH-CCA service. This service is used to check the state of the channel. The request service is successful only if the channel is enabled in receive mode.

Table 5 – PH-CCA primitives and parameters

Parameter name	Request	
	Input	Output
State		M
NOTE The request primitive does not require any parameter.		

4.1.2.4.2 Parameter - state

This parameter shows the result of clear channel assessment. The values of this parameter are:

- Channel Idle,
- Channel busy,
- Transceiver off and unable to perform assessment.

4.1.2.5 PH-RCV-SD service

The only primitive of this service is indication and it has no parameter. This primitive is used by the PhE at the end of reception of the start delimiter in receive mode.

4.1.2.6 PH-DATA service

4.1.2.6.1 Types of primitives and parameters

Table 6 indicates the types of primitives and the parameters needed for the PH-DATA service.

Table 6 – PH-DATA primitives and parameters

Parameter name	Request	Indication	Confirm
PhS-user-data	M	C(=)	
Receive signal level		C	
Status		M	M

4.1.2.6.2 Parameters

4.1.2.6.2.1 PhS-user-data

This parameter allows the transmission of data between PhS-users without alteration by the PhS-provider. If there is any error in reception then this parameter is absent in the indication primitive. Else, its value is identical to the value in the request primitive.

4.1.2.6.2.2 Receive signal level

This parameter indicates the estimated receive signal level for this PhPDU. It is present only if there is no reception error.

4.1.2.6.2.3 Status

In the indication primitive, this parameter indicates either success or one of the following reasons for error:

- Receive buffer overflow,
- Incomplete packet.

In the Confirm primitive, this parameter indicates either success or one of the following reasons for error:

- Transceiver off,
 - Receiver on,
- NOTE If the Receiver is on, then the PhE cannot transmit.
- Transmitter busy.

4.1.2.7 PHM-SET service

4.1.2.7.1 Types of primitives and parameters

Table 7 indicates the primitive and parameters of this service.

Table 7 – PHM-SET primitive and parameters

Parameter name	Request	
	Input	Output
PHM-object-identifier	M	
Desired-value	M	
Status		M

4.1.2.7.2 Parameters

4.1.2.7.2.1 PHM-object-identifier

This parameter specifies the object within the PhE whose value is to be altered. The naming-domain of the PHM-object-identifier is the local-view.

4.1.2.7.2.2 Desired-value

This parameter specifies the desired value for the object specified by the associated PHM-object-identifier. Its type is identical to that of the specified object.

4.1.2.7.2.3 Status

This parameter allows the PhS-user to determine whether the requested service was provided successfully, or failed.

NOTE The failure reason may also be provided.

4.1.2.8 PHM-GET service

4.1.2.8.1 Types of primitives and parameters

Table 8 indicates the primitive and parameters of this service.

Table 8 – PHM-GET primitive and parameters

Parameter name	Request	
	Input	Output
PHM-object-identifier	M	
Status		M
Current-value		C

4.1.2.8.2 Parameters

4.1.2.8.2.1 PHM-object-identifier

This parameter specifies the object within the PhE whose value is being requested. The naming-domain of the PHM-object-identifier is the local-view.

4.1.2.8.2.2 Status

This parameter allows the PhS-user to determine whether the requested service was provided successfully, or failed.

NOTE The failure reason may also be provided.

4.1.2.8.2.3 Current-value

This parameter is present when the status parameter indicates that the requested service was performed successfully. This parameter specifies the current value for the object specified by the associated PHM-object-identifier. Its type is identical to that of the specified object.

4.2 Physical layer protocol specification

The physical layer protocol is specified in IEEE 802.15.4-2006. The profile for this standard is specified in 9.3.3.

5 Data-link layer service definition – Type 20 elements

5.1 Data-link layer services

5.1.1 Facilities of the data-link layer services

5.1.1.1 Data transfer service

The Message services support the transfer of DL-service-data-unit (DLSDU) from a source DLS-user to a destination DLS-user. The data-link layer supports automatic retransmission to ensure error-free data transfer.

5.1.1.2 Data receive service

This service supports reception only of a DL-service-data-unit (DLSDU) without sending any acknowledgement.