

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Industrial communication networks – Fieldbus specifications –
Part 4-24: Data-link layer protocol specification – Type 24 elements**

**Réseaux de communication industriels – Spécifications des bus de terrain –
Partie 4-24: Spécification du protocole de la couche liaison de données –
Éléments de type 24**

WITNESS



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2014 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

Droits de reproduction réservés. Sauf indication contraire, aucune partie de cette publication ne peut être reproduite ni utilisée sous quelque forme que ce soit et par aucun procédé, électronique ou mécanique, y compris la photocopie et les microfilms, sans l'accord écrit de l'IEC ou du Comité national de l'IEC du pays du demandeur. Si vous avez des questions sur le copyright de l'IEC ou si vous désirez obtenir des droits supplémentaires sur cette publication, utilisez les coordonnées ci-après ou contactez le Comité national de l'IEC de votre pays de résidence.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

IEC Catalogue - webstore.iec.ch/catalogue

The stand-alone application for consulting the entire bibliographical information on IEC International Standards, Technical Specifications, Technical Reports and other documents. Available for PC, Mac OS, Android Tablets and iPad.

IEC publications search - www.iec.ch/searchpub

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in 14 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

More than 55 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

A propos de l'IEC

La Commission Electrotechnique Internationale (IEC) est la première organisation mondiale qui élabore et publie des Normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications IEC

Le contenu technique des publications IEC est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

Catalogue IEC - webstore.iec.ch/catalogue

Application autonome pour consulter tous les renseignements bibliographiques sur les Normes internationales, Spécifications techniques, Rapports techniques et autres documents de l'IEC. Disponible pour PC, Mac OS, tablettes Android et iPad.

Recherche de publications IEC - www.iec.ch/searchpub

La recherche avancée permet de trouver des publications IEC en utilisant différents critères (numéro de référence, texte, comité d'études,...). Elle donne aussi des informations sur les projets et les publications remplacées ou retirées.

IEC Just Published - webstore.iec.ch/justpublished

Restez informé sur les nouvelles publications IEC. Just Published détaille les nouvelles publications parues. Disponible en ligne et aussi une fois par mois par email.

Electropedia - www.electropedia.org

Le premier dictionnaire en ligne de termes électroniques et électriques. Il contient plus de 30 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans 14 langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International (IEV) en ligne.

Glossaire IEC - std.iec.ch/glossary

Plus de 55 000 entrées terminologiques électrotechniques, en anglais et en français, extraites des articles Termes et Définitions des publications IEC parues depuis 2002. Plus certaines entrées antérieures extraites des publications des CE 37, 77, 86 et CISPR de l'IEC.

Service Clients - webstore.iec.ch/csc

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions contactez-nous: csc@iec.ch.

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Industrial communication networks – Fieldbus specifications –
Part 4-24: Data-link layer protocol specification – Type 24 elements**

**Réseaux de communication industriels – Spécifications des bus de terrain –
Partie 4-24: Spécification du protocole de la couche liaison de données –
Éléments de type 24**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX

XE

ICS 25.040.40; 35.100.20; 35.110

ISBN 978-2-8322-1730-6

**Warning! Make sure that you obtained this publication from an authorized distributor.
Attention! Veuillez vous assurer que vous avez obtenu cette publication via un distributeur agréé.**

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	10
1.1 General.....	10
1.2 Specifications.....	10
1.3 Procedures.....	10
1.4 Applicability.....	11
1.5 Conformance.....	11
2 Normative references	11
3 Terms, definitions, symbols, abbreviations and conventions	12
3.1 Reference model terms and definitions.....	12
3.2 Service convention terms and definitions.....	13
3.3 Common terms and definitions	13
3.4 Symbols and abbreviations.....	15
3.5 Additional type 24 symbols and abbreviations.....	16
3.6 Common Conventions	17
3.7 Additional Type 24 conventions.....	18
4 Overview of DL-protocol	19
4.1 Characteristic feature of DL-protocol.....	19
4.2 DL layer component	20
4.3 Timing sequence.....	20
4.4 Service assumed from PhL.....	28
4.5 Local parameters, variable, counters, timers	29
5 DLPDU structure	34
5.1 Overview.....	34
5.2 Basic format DLPDU structure.....	35
5.3 Short format DLPDU structure.....	43
6 DLE element procedure.....	47
6.1 Overview.....	47
6.2 Cyclic transmission control sublayer.....	47
6.3 Send Receive Control.....	96
7 DL-management layer (DLM).....	103
7.1 Overview.....	103
7.2 Primitive definitions	103
7.3 DLM protocol machine.....	104
7.4 Functions	113
Bibliography.....	115
Figure 1 – Data-link layer component.....	20
Figure 2 – Timing chart of fixed-width time slot type cyclic communication.....	21
Figure 3 – Timing chart of configurable time slot type cyclic communication	23
Figure 4 – Schematic Diagram of Communication Interrupt Occurrence	25
Figure 5 – Timing relationship between cyclic transmission and data processing	27
Figure 6 – Timing chart example of acyclic communication	28

Figure 7 – Basic format DLPDU structure.....	35
Figure 8 – Short format DLPDU structure.....	43
Figure 9 – The state diagram of C1 master for fixed-width time slot	49
Figure 10 – The state diagram of C2 master for fixed-width time slot	55
Figure 11 – The state diagram of slave for fixed-width time slot	59
Figure 12 – The state diagram of C1 master for configurable time slot	62
Figure 13 – The state diagram of C2 master for configurable time slot	70
Figure 14 – The state diagram of slave for configurable time slot	73
Figure 15 – The state diagram of message initiator for basic format.....	77
Figure 16 – The state diagram of message responder for basic format	81
Figure 17 – The state diagram of message initiator for short format	85
Figure 18 – The state diagram of message responder for short format.....	89
Figure 19 – The state diagram of acyclic transmission protocol machine.....	94
Figure 20 – Internal architecture of one-port SRC	98
Figure 21 – Internal architecture of multi-port SRC	98
Figure 22 – Internal architecture of serializer	98
Figure 23 – Internal architecture of deserializer	100
Figure 24 – State diagram of C1 master DLM	105
Figure 25 – State diagram of Slave and C2 master DLM	110
Table 1 – State transition descriptions	18
Table 2 – Description of state machine elements	18
Table 3 – Conventions used in state machines	18
Table 4 – Characteristic features of the fieldbus data-link protocol.....	19
Table 5 – List of the values of variable Cyc_sel	29
Table 6 – List of the values of variable Tunit.....	30
Table 7 – List of the values of variable PDUType	32
Table 8 – List of the values of variable SlotType	32
Table 9 – Transfer syntax for bit sequences.....	34
Table 10 – Bit order.....	35
Table 11 – Destination and Source address format	36
Table 12 – Station address	36
Table 13 – Extended address	36
Table 14 – Message control field format (Information transfer format).....	36
Table 15 – Message control field format (Supervisory format).....	37
Table 16 – The list of Supervisory function bits	37
Table 17 – Frame type and Data length format	37
Table 18 – The list of Frame type.....	38
Table 19 – Data format of Synchronous frame	38
Table 20 – The field list of Synchronous frame.....	39
Table 21 – Data format of Output data or Input data frame.....	39
Table 22 – The field list of Output data or Input data frame.....	39
Table 23 – Data format of Delay measurement start frame.....	40

Table 24 – The field list of Delay measurement start frame	40
Table 25 – Data format of Delay measurement frame.....	40
Table 26 – The field list of Delay measurement frame	40
Table 27 – Data format of Status frame.....	41
Table 28 – The field list of Status frame	41
Table 29 – The list of the DLE status	41
Table 30 – The list of Repeater status	42
Table 31 – Data format of Delay measurement frame.....	42
Table 32 – The field list of Cycle Information frame.....	42
Table 33 – Data format of Message frae	43
Table 34 – The field list of Message frame.....	43
Table 35 – Range of Station address field.....	44
Table 36 – Control field format (I/O data exchange format)	44
Table 37 – Control field format (Message format)	44
Table 38 – The field list of Message format.....	45
Table 39 – Data format of Synchronous frame	45
Table 40 – The field list of Sync frame	46
Table 41 – Data format of Output data frame	46
Table 42 – The field list of Output data frame.....	46
Table 43 – Data format of Input data frame.....	46
Table 44 – The field list of Input data frame.....	46
Table 45 – The primitives and parameters for DLS-user interface issued by DLS-user	47
Table 46 – The primitives and parameters for DLS-user interface issued by CTC	47
Table 47 – The state table of C1 master for fixed-width time slot	49
Table 48 – The state table of C2 master for fixed-width time slot	56
Table 49 – The state table of slave for fixed-width time slot	59
Table 50 – The state table of C1 master for configurable time slot	62
Table 51 – The state table of C2 master for configurable time slot	71
Table 52 – The state table of slave for configurable time slot	73
Table 53 – The list of functions used by cyclic transmission machine.....	75
Table 54 – The state table of message initiator for basic format.....	77
Table 55 – The state table of message responder for basic format.....	81
Table 56 – The state table of message initiator for short format	85
Table 57 – The state table of message responder for short format	89
Table 58 – List of functions used by the message segmentation machine	93
Table 59 – The state table of acyclic transmission protocol machine.....	94
Table 60 – The list of functions used acyclic transmission protocol machine	95
Table 61 – Primitives and parameters exchanged between CTC and DLM	96
Table 62 – Error event primitive and parameters.....	96
Table 63 – primitives and parameters for SRC-CTC interface	97
Table 64 – Send frame primitive and parameters	97
Table 65 – Receive frame primitives and parameters	97
Table 66 – Primitives and parameters exchanged between SRC and DLM.....	102

Table 67 – Get value primitive and parameters	103
Table 68 – Error event primitive and parameters	103
Table 69 – The list of primitives and parameters (DLMS-user source)	103
Table 70 – The list of primitives and parameters (DLM source)	104
Table 71 – State table of C1-Master DLM	105
Table 72 – State table of Slave and C2 master DLM	110
Table 73 – The list of the functions used by DLM protocol machine	113

Withdrawn

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**INDUSTRIAL COMMUNICATION NETWORKS –
FIELDBUS SPECIFICATIONS –****Part 4-24: Data-link layer protocol specification –
Type 24 elements**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

Attention is drawn to the fact that the use of the associated protocol type is restricted by its intellectual-property-right holders. In all cases, the commitment to limited release of intellectual-property-rights made by the holders of those rights permits a layer protocol type to be used with other layer protocols of the same type, or in other type combinations explicitly authorized by its intellectual-property-right holders.

NOTE Combinations of protocol types are specified in IEC 61784-1 and IEC 61784-2.

International Standard IEC 61158-4-24 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation.

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

FDIS	Report on voting
65C/762/FDIS	65C/772/RVD

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

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

A list of all parts of the IEC 61158 series, published under the general title *Industrial communication networks – Fieldbus specifications*, can be found on the IEC web site.

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.

Withdrawn

INTRODUCTION

This part of IEC 61158 is one of a series produced to facilitate the interconnection of automation system components. It is related to other standards in the set as defined by the “three-layer” fieldbus reference model described in IEC 61158-1.

The data-link protocol provides the data-link service by making use of the services available from the physical layer. The primary aim of this standard is to provide a set of rules for communication expressed in terms of the procedures to be carried out by peer data-link entities (DLEs) at the time of communication. These rules for communication are intended to provide a sound basis for development in order to serve a variety of purposes:

- a) as a guide for implementors and designers;
- b) for use in the testing and procurement of equipment;
- c) as part of an agreement for the admittance of systems into the open systems environment;
- d) as a refinement to the understanding of time-critical communications within OSI.

This standard is concerned, in particular, with the communication and interworking of sensors, effectors and other automation devices. By using this standard together with other standards positioned within the OSI or fieldbus reference models, otherwise incompatible systems may work together in any combination.

NOTE Use of some of the associated protocol types is restricted by their intellectual-property-right holders. In all cases, the commitment to limited release of intellectual-property-rights made by the holders of those rights permits a particular data-link layer protocol type to be used with physical layer and application layer protocols in Type combinations as specified explicitly in the profile series. Use of the various protocol types in other combinations may require permission from their respective intellectual-property-right holders.

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 as follows, where the [xx] notation indicates the holder of the patent right:

US 8223804	[YE]	COMMUNICATION DEVICE, SYNCHRONIZED
JP 4760978		SYSTEM, AND SYNCHRONIZED COMMUNICATION METHOD
CN 200880002225.3		
EPC 08738862.5		
KR 10-2009-7011514		
TW 97111183		

US 7769935	[YE]	MASTER SLAVE COMMUNICATION SYSTEM AND MASTER
JP 4683346		SLAVE COMMUNICATION METHOD
US 8046542		
EPC 07850686.2		
TW 96150287		

JP 4356698	[YE]	COMMUNICATION DEVICE, SYNCHRONIZED COMMUNICATION
		SYSTEM, AND SYNCHRONIZED COMMUNICATION METHOD

IEC takes no position concerning the evidence, validity and scope of this patent right.

The holders of these patent rights have assured IEC that they are willing to negotiate licenses either free of charge or under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holders of these patent rights is registered with IEC. Information may be obtained from

[YE] YASKAWA ELECTRIC CORPORATION
2-1 Kurosakishiroishi, Yahatanishi-ku, Kitakyushu 806-0004, Japan
Attention: Intellectual Property Rights Section.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights other than those identified above. IEC shall not be held responsible for identifying any or all such patent rights.

ISO (www.iso.org/patents) and IEC (<http://patents.iec.ch>) 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 – FIELDBUS SPECIFICATIONS –

Part 4-24: Data-link layer protocol specification – Type 24 elements

1 Scope

1.1 General

The data-link layer provides basic time-critical messaging communications between devices in an automation environment.

This protocol provides communication opportunities to all participating data-link entities

- a) in a synchronously-starting cyclic manner, according to a pre-established schedule, or
- b) in an acyclic manner, as requested by each of those data-link entities.

Thus this protocol can be characterized as one which provides cyclic and acyclic access asynchronously but with a synchronous restart of each cycle.

1.2 Specifications

This standard specifies

- a) procedures for the timely transfer of data and control information from one data-link user entity to a peer user entity, and among the data-link entities forming the distributed datalink service provider;
- b) procedures for giving communications opportunities to all participating DL-entities, sequentially and in a cyclic manner for deterministic and synchronized transfer at cyclic intervals up to 64 ms;
- c) procedures for giving communication opportunities available for time-critical data transmission together with non-time-critical data transmission without prejudice to the time-critical data transmission;
- d) procedures for giving cyclic and acyclic communication opportunities for time-critical data transmission with prioritized access;
- e) procedures for giving communication opportunities based on standard ISO/IEC 8802-3 medium access control, with provisions for nodes to be added or removed during normal operation;
- f) the structure of the fieldbus DLPDUs used for the transfer of data and control information by the protocol of this standard, and their representation as physical interface data units.

1.3 Procedures

The procedures are defined in terms of

- a) the interactions between peer DL-entities (DLEs) through the exchange of fieldbus DLPDUs;
- b) the interactions between a DL-service (DLS) provider and a DLS-user in the same system through the exchange of DLS primitives;
- c) the interactions between a DLS-provider and a Ph-service provider in the same system through the exchange of Ph-service primitives.

1.4 Applicability

These procedures are applicable to instances of communication between systems which support time-critical communications services within the data-link layer of the OSI or fieldbus reference models, and which require the ability to interconnect in an open systems interconnection environment.

Profiles provide a simple multi-attribute means of summarizing an implementation's capabilities, and thus its applicability to various time-critical communications needs.

1.5 Conformance

This standard also specifies conformance requirements for systems implementing these procedures. This standard does not contain tests to demonstrate compliance with such requirements.

2 Normative references

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

NOTE All parts of the IEC 61158 series, as well as IEC 61784-1 and IEC 61784-2 are maintained simultaneously. Cross-references to these documents within the text therefore refer to the editions as dated in this list of normative references.

IEC 61158-2, *Industrial communication networks – Fieldbus specifications – Part 2: Physical layer specification and service definition*

IEC 61158-3-24:2014, *Industrial communication networks – Fieldbus specifications – Part 3-24: Data-link layer service definition – Type 24 elements*

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

ISO/IEC 7498-3, *Information technology – Open Systems Interconnection – Basic Reference Model: Naming and addressing*

ISO/IEC 8802-3:2000, *Information technology – Telecommunications and information exchange between systems – Local and metropolitan area networks – Specific requirements – Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications*

ISO/IEC 9899, *Information technology – Programming languages – C*

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

ISO/IEC 13239:2002, *Information technology – Telecommunications and information exchange between systems – High-level data link control (HDLC) procedures*

ISO/IEC 19501:2005, *Information technology – Open Distributed Processing – Unified Modeling Language (UML) Version 1.4.2*

3 Terms, definitions, symbols, abbreviations and conventions

For the purposes of this document, the following terms, definitions, symbols, abbreviations and conventions 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.

3.1.1	acknowledgement	[ISO/IEC 7498-1]
3.1.2	correspondent (N)-entities	[ISO/IEC 7498-1]
	correspondent DL-entities (N=2)	
	correspondent Ph-entities (N=1)	
3.1.3	DL-address	[ISO/IEC 7498-3]
3.1.4	DL-protocol	[ISO/IEC 7498-1]
3.1.5	DL-protocol-data-unit	[ISO/IEC 7498-1]
3.1.6	DL-service-data-unit	[ISO/IEC 7498-1]
3.1.7	DLS-user	[ISO/IEC 7498-1]
3.1.8	DLS-user-data	[ISO/IEC 7498-1]
3.1.9	event	[ISO/IEC 19501]
3.1.10	layer-management	[ISO/IEC 7498-1]
3.1.11	primitive name	[ISO/IEC 7498-1]
3.1.12	reset	[ISO/IEC 7498-1]
3.1.13	segmenting	[ISO/IEC 7498-1]
3.1.14	state	[ISO/IEC 19501]
3.1.15	state machine	[ISO/IEC 19501]
3.1.16	systems-management	[ISO/IEC 7498-1]
3.1.17	transition	[ISO/IEC 19501]
3.1.18	(N)-entity	[ISO/IEC 7498-1]
	DL-entity (N=2)	
	Ph-entity (N=1)	
3.1.19	(N)-layer	[ISO/IEC 7498-1]
	DL-layer (N=2)	
	Ph-layer (N=1)	
	(N)-service	[ISO/IEC 7498-1]
	DL-service (N=2)	

Ph-service (N=1)

(N)-service-access-point

[ISO/IEC 7498-1]

DL-service-access-point (N=2)

Ph-service-access-point (N=1)

3.2 Service convention terms and definitions

This standard also makes use of the following terms defined in ISO/IEC 10731 as they apply to the data-link layer:

- 3.2.1 confirm (primitive)**
- 3.2.2 DL-service-primitive;**
- 3.2.3 DL-service-provider**
- 3.2.4 DL-service-user**
- 3.2.5 indication (primitive)**
- 3.2.6 request (primitive)**
- 3.2.7 requestor**
- 3.2.8 response (primitive)**

3.3 Common terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.3.1

acyclic transmission

non-periodic exchange of telegrams

3.3.2

C1 master

one of the station type that initiates and control cyclic transmission

3.3.3

C1 message

message communication that C1 master operates as initiator to exchange messages with slave or C2 master

3.3.4

C2 master

one of the station type that has the function of monitoring all process data transmitted through the network and may initiates message communication

3.3.5

C2 message

message communication that C2 master operates as initiator to exchange messages with slave or C1 master

3.3.6

cyclic transmission

periodic exchange of telegrams

3.3.7

data

generic term used to refer to any information carried over a fieldbus

3.3.8

device

physical entity connected to the fieldbus composed of at least one communication element (the network element) and which may have a control element and/or a final element (transducer, actuator, etc.)

3.3.9

event driven mode

transmission mode for the application layer protocol of the communication type 24 in which a transaction of command-response-exchanging arises as user's demands

3.3.10

frame

synonym for DLPDU

3.3.11

initiator

station that initiates the exchange of process data or message

3.3.12

interface

shared boundary between two functional units, defined by functional characteristics, signal characteristics, or other characteristics as appropriate

3.3.13

input data

process data sent by the slave and received by the C1 master

3.3.14

message

ordered series of octets intended to convey information

Note 1 to entry: Normally used to convey information between peers at the application layer.

3.3.15

monitor slave

slave that has the function of monitoring all process data transmitted through the network

3.3.16

network

set of nodes connected by some type of communication medium, including any intervening repeaters, bridges, routers and lower-layer gateways

3.3.17

node

- a) single DL-entity as it appears on one local link
- b) end-point of a link in a network or a point at which two or more links meet

3.3.18

output data

process data sent by the C1 master and received by the slaves

3.3.19

protocol

convention about the data formats, time sequences, and error correction in the data exchange of communication systems

3.3.20**real-time communication**

transfer of data in real-time

3.3.21**receiving DLS-user**

DL-service user that acts as a recipient of DL-user-data

Note 1 to entry: A DL-service user may be concurrently both a sending and receiving DLS-user.

3.3.22**responder**

station that responds process data or message after it has been initiated by Initiator

3.3.23**send data with acknowledge**

data transfer service with acknowledge of reception from corresponding DLE

3.3.24**send data without acknowledge**

data transfer service without acknowledge of reception from corresponding DLE

3.3.25**slave**

one of the station type that accesses the medium only after it has been initiated by C1-master or C2 master

3.3.26**sending DLS-user**

DL-service user that acts as a source of DL-user-data

3.3.27**station**

node

3.3.28**topology**

physical network architecture with respect to the connection between the stations of the communication system"

3.3.29**transmission cycle**

fixed time period of cyclic transmission

3.3.30**time slot**

Time period reserved so that initiator and responder may exchange one frame respectively

3.4 Symbols and abbreviations

3.4.1	DA	Destination address
3.4.2	DL-	Data-link layer (as a prefix)
3.4.3	DLE	DL-entity (the local active instance of the data-link layer)
3.4.4	DLL	DL-layer
3.4.5	DLM	DL-management

3.4.6	DLME	DL-management entity (the local active instance of DL-management)
3.4.7	DLMS	DL-management service
3.4.8	DLPDU	DL-protocol-data-unit
3.4.9	DLS	DL-service
3.4.10	DLSAP	DL-service-access-point
3.4.11	DLSDU	DL-service-data-unit
3.4.12	FIFO	First-in first-out (queuing method)
3.4.13	ID	Identifier
3.4.14	OSI	Open systems interconnection
3.4.15	PDU	Protocol data unit
3.4.16	Ph-	Physical layer (as a prefix)
3.4.17	PhE	Ph-entity (the local active instance of the physical layer)
3.4.18	PhL	Ph-layer
3.4.19	PHY	Physical layer device (specified in ISO/IEC 8802-3)
3.4.20	QoS	Quality of service
3.4.21	RT	Real-time
3.4.22	SAP	Service access point
3.4.23	SDU	Service data unit
3.5 Additional type 24 symbols and abbreviations		
3.5.1	ACK	Acknowledge
3.5.2	C1MSG	C1 message
3.5.3	C2MSG	C2 message
3.5.4	I/O	Input and/or output
3.5.5	MSG	Message
3.5.6	Rx	Receive
3.5.7	SDA	Send data with acknowledge
3.5.8	SDN	Send data without acknowledge
3.5.9	SM	State machine
3.5.10	Tcycle	Transmission cycle
3.5.11	Tslot	Time slot
3.5.12	Tx	Transmit

3.6 Common Conventions

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 DLS primitives. The parameters that apply to each group of DLS 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 DLS:

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

NOTE 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 part 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 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.
- C parameter is conditional upon other parameters or upon the environment of the DLS-user.
- (blank) parameter is never present.

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

In any particular interface, not all parameters need be explicitly stated. Some may be implicitly associated with the primitive.

In the diagrams which illustrate these interfaces, dashed lines indicate cause-and-effect or time-sequence relationships, and wavy lines indicate that events are roughly contemporaneous.

3.7 Additional Type 24 conventions

3.7.1 Primitive conventions

The following notation, a shortened form of the primitive classes defined in 3.2, is used in the figures.

req	request primitive
ind	indication primitive
cnf	confirm primitive (confirmation)

3.7.2 State machine conventions

The protocol sequences are described by means of state machines.

In state diagrams, states are represented as boxes and state transitions are shown as arrows.

Names of states and transitions of the state diagram correspond to the names in the state table. The textual listing of the state transitions is structured as shown in Table 1.

Table 1 – State transition descriptions

No.	Current state	Event / condition => action	Next state

The description of state machine elements are shown in Table 2.

Table 2 – Description of state machine elements

Description element	Meaning
No	Number of the transition.
Current state, Next state	Names of the originating state and the target state of transition.
Event	Name or description of the trigger event that fire the transition.
/ conditions	Boolean expression, which must be true for the transition to be fired.
=>action	List of assignments and service or function invocations. The action should be atomic. The preceding “=>” is not part of the action.
NOTE “/ conditions” can be omitted.	

The conventions used in the state machines are shown in Table 3.

Table 3 – Conventions used in state machines

Convention	Meaning
+ - * /	Arithmetic operators
:=	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.
=	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.

Convention	Meaning
<=	A logical condition to indicate an item on the left is less than or equal to the item on the right.
>=	A logical condition to indicate an item on the left is greater than or equal to 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"

4 Overview of DL-protocol

4.1 Characteristic feature of DL-protocol

Table 4 shows the characteristic features of DL protocol of Type 24.

Table 4 – Characteristic features of the fieldbus data-link protocol

Profiles	Description
Station type and max. stations	-C1 master (active station with bus access control, 1 station (mandatory)) -C2 master (active station with restricted bus access control, max.1 (optional)) -Slave (passive stations without bus access control, max.62)
Station addressing	1 to 255 (255 = global addresses for broad-cast messages), 8 bit-width address extension for integrated device
Transmission cycle	31,25 μ s to 64 ms
DLSDU size	8 to 64 octets
Transmission characteristic	-Cyclic data exchange and cyclic event, synchronized with accurate cycle time (jitter below 1 μ s) -Max 62 times (n times/1 station) retry within cycle time -Acyclic message transmission

There are three types of stations, C1 master, C2 master and slave. Data exchange is executed between one master station (C1 master or C2 master) and N slave stations. This protocol supports 2 communication modes, cyclic transmission and acyclic transmission.

In cyclic transmission mode, transmission is executed cyclically with an accurate period. The transmission cycle is set by the C1 master to a value within a range of 31,25 [μ s] to 64 [ms]. Since the set value of transmission cycle is specific to the transmission line, all of the connected slaves shall support that value. It is not permitted to set different transmission cycle values for slaves connected in the same network.

The transmission cycle has I/O data exchange band to transmit process data and message communication band to transmit message. The protocol machine in C1 master controls transmission sequence in cyclic transmission mode. The time period for a master station to exchange with one slave station is called time slot. There are two types of communication sequence, one is "fixed-width time slot type" whose time slot is same width for all stations and the other is "configurable time slot type" whose time slot can be defined for each station. All stations shall use the same-data-length frame when fixed-width time slot type. The width of the time slot is static in both type, and the value is set by DL-management during initialization. Once cyclic communication starts, it shall not be changed.

Acyclic transmission mode is used by DLS-user that operates in event driven mode. In acyclic transmission mode, transmissions are executed sporadically. The same transmission sequence and message communication may be executed in acyclic transmission, as in cyclic transmission mode without fixing the transmission cycle.

4.2 DL layer component

DL layer is composed of three sublayers, CTC (Cyclic transmission control), SRC (Send Receive Control) and DLM (Data-link management). SRC is positioned at lower layer of CTC and DLM covers both CTC sublayer and SRC sublayer. The data-link layer component is shown in Figure 1.

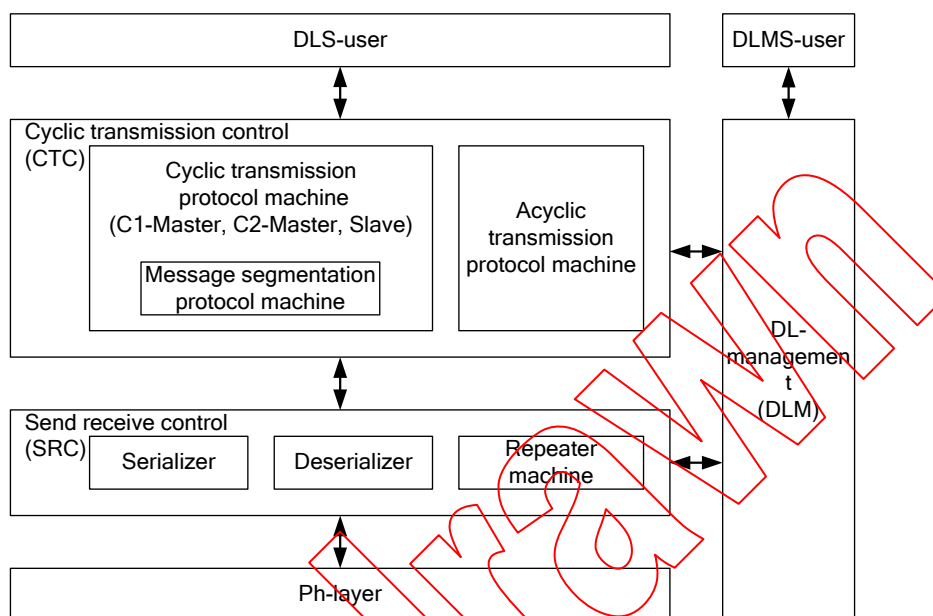


Figure 1 – Data-link layer component

4.2.1 Cyclic transmission control (CTC)

This is a sublayer that builds DLPDU and executes a protocol machine. It has 2 communication modes, i.e. cyclic transmission mode and acyclic transmission mode. CTC executes either of them according to a request from DLMS user.

4.2.2 Send Receive Control (SRC)

SRC sends or receives frames by request of CTC sublayer. It is serialized or de-serialized according to corresponding PHY. When the SRC implements two or more PHY port, the SRC provides frame repeat function between the implemented PHY ports.

4.2.3 DL-management

This is a sublayer that configures DLE operation by setting the internal variables and manages errors detected by each sublayer.

4.3 Timing sequence

4.3.1 Overview

There are two types of transmission mode, cyclic transmission mode and acyclic transmission mode. Cyclic transmission has two types, one is “fixed-width time slot type” whose time slot is same width for all stations and the other is “configurable time slot type” whose time slot can be defined for each station.

The width of the time slot is static in both type, and the value is set by DL-management during initialization. Once cyclic communication starts, it shall not be changed.

4.3.2 Cyclic transmission mode

4.3.2.1 Fixed-width time slot type

4.3.2.1.1 Overview

Figure 2 shows transmission sequence of fixed-width time slot type. In this type, the width of time slots that are allocated to execute exchange of process data one by one between the master and the slave is identical for all slaves. One or more time slots are allocated to each bandwidth shown in the timing chart.

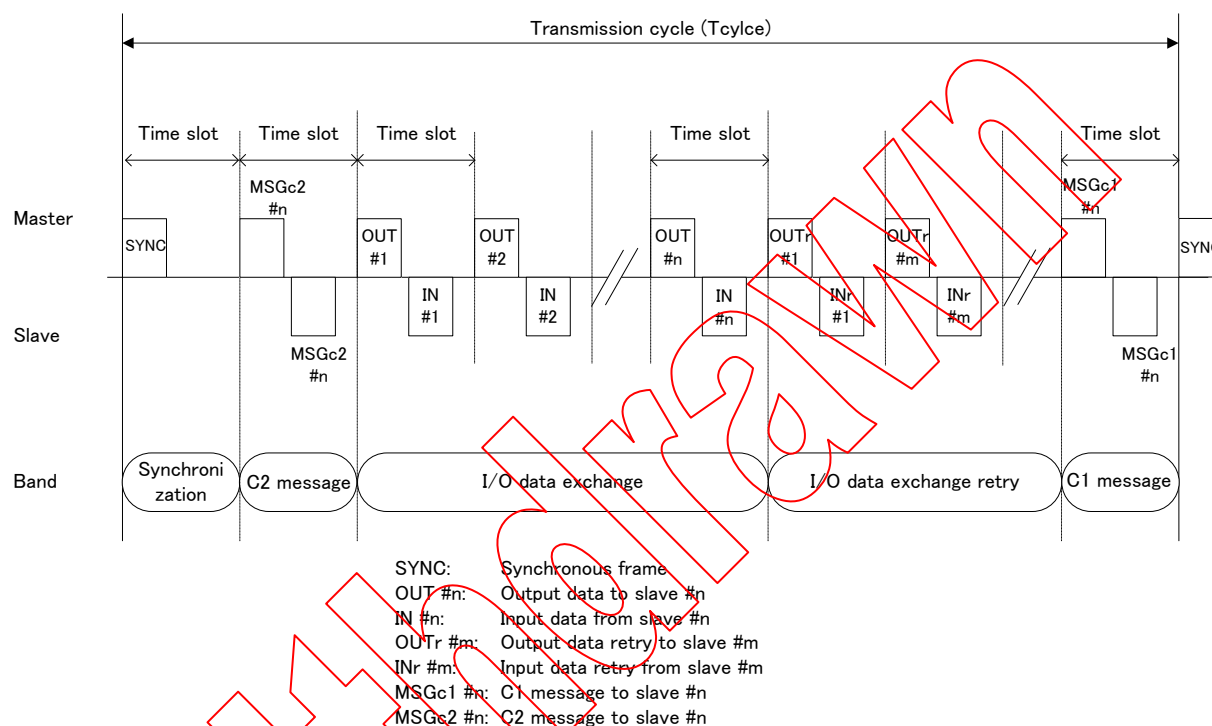


Figure 2 – Timing chart of fixed-width time slot type cyclic communication

4.3.2.1.2 Detailed description of communication band

4.3.2.1.2.1 Synchronization

This is a bandwidth through which C1 master broadcasts a synchronous frame to slave and C2 master. One time slot is allocated to this bandwidth. Within this bandwidth, only the transition of synchronizing frame from C1 master is allowed; slave and C2 master are prohibited transmitting any frame.

4.3.2.1.2.2 C2 message

This is a bandwidth for a message transmission (C2 message transmission) where C2 master is the client (primary station) and C1 master or slave is the server (secondary station). One time slot is allocated to this bandwidth, and request and response are transmitted once, respectively.

4.3.2.1.2.3 I/O data exchange

This is a bandwidth through which C1 master exchanges I/O data with all slaves that are connected to the network. The time slots of the number of slaves are assigned to this bandwidth. C1 master and one slave station execute I/O data exchange once within one time slot.

C1 master registers the slave with which it has failed to exchange I/O data through this bandwidth into the retry list as a retry target for re-transmission through a following I/O data exchange retry bandwidth.

4.3.2.1.2.4 I/O data exchange retry

This is a bandwidth through which C1 master retries the I/O data exchange that has not been completed successfully through the I/O data exchange bandwidth. C1 master re-executes the I/O exchange with the retry target slave that has been registered in the I/O data exchange bandwidth. Time slots of the number that is set in C1 master before starting cyclic transmission are allocated to this bandwidth. C1 master retries according to the registered order of the retry list for up to the number of the allocated time slots. DLE quits retry when it uses all allocated time slots even if a slave that is waiting for retry is registered in the retry list.

C1 master retries the I/O data exchange once for each of the registered slave. If the retry is not completed successfully, C1 master will not repeat the retry for the same slave.

4.3.2.1.2.5 C1 message

This is a bandwidth for a message transmission (C1 message transmission) where C1 master is the client (initiator) and C2 master or slave is the server (responder). One time slot is allocated at the maximum within the bandwidth that is allocated to the retry of the I/O data exchange mentioned above, and request and response are transmitted once, respectively. Because one of the bandwidths for retry of I/O data exchange is allocated as this bandwidth, when all of the time slots allocated for retry are used, C1 message can not be executed within the transmission cycle.

4.3.2.1.3 Estimation of cycle time

The transmission cycle of the fixed-width slot type T_{cycle} is calculated as the sum of the bandwidths described in 4.3.2.2, i.e.:

$$T_{cycle} = T_{sync} + T_{C2msg} + T_{io} + T_{retry} + T_{C1msg}$$

where

T_{sync} is the Sync band;
 T_{C2msg} is the C2 message band;
 T_{io} is the I/O data exchange band;
 T_{retry} is the I/O data exchange retry band;
 T_{C1msg} is the C1 message band.

An integral multiple of the number of time slots is allocated to the bandwidths. The formula shown above can be transformed by indicating the time slot with T_{slot} , the number of slave stations connected to the network with n , and the number of retry with n_r .

$$\begin{aligned} T_{cycle} &= T_{slot} + T_{slot} + n \times T_{slot} + n_r \times T_{slot} + T_{slot} \\ &= (n + n_r + 3) \times T_{slot} \end{aligned}$$

Time slot T_{slot} can be calculated as shown in the following formula by indicating the frame transmission time (identical to the instruction frame, answer frame, request frame, and response frame) with T_{tr} and the gap between frames with T_{gap} :

$$T_{slot} = \max(T_{tr\_c}(n) + T_{dly}(n) + T_{gap} + T_{tr\_r}(n) + T_{dly}(n) + T_{gap})$$

$$= 2 \times \max(T_{tr\_c}(n) + T_{dly}(n) + T_{gap})$$

T_{tr_c} is the instruction transmission time from C1 master to the slave n;

T_{tr_r} is the response transmission time from slave n to C1 master;

T_{gap} is the gap between the frames;

T_{dly} is the frame transmission delay time between C1 master and slave n.

4.3.2.2 Configurable time slot type

4.3.2.2.1 Overview

Figure 3 shows transmission sequence of configurable time slot type. In this type, the length of time slots that are allocated to execute exchange of command and response one by one between the master and the slave is differ for each slave. DLE manages the residual time of the transmission cycle by using the time slots configured for each slave by the DLMS user. Details of each transmission bandwidth are described in the following subclauses.

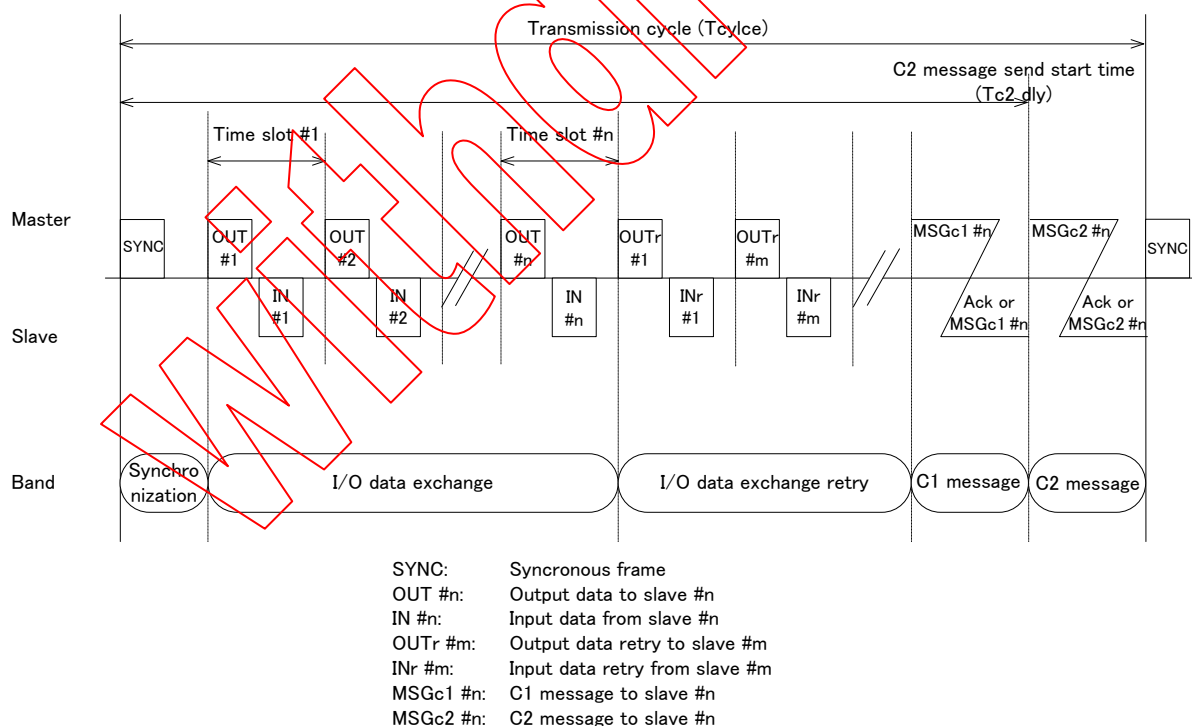


Figure 3 – Timing chart of configurable time slot type cyclic communication

4.3.2.2.2 Detailed description of communication phase

4.3.2.2.2.1 Synchronization

See 4.3.2.1.2.1.

4.3.2.2.2 IO data exchange

This is a bandwidth where C1 master executes I/O data exchange with all slaves connected to the network. The time from the end of Synchronization bandwidth in the head of the transmission cycle to the start of the C2 message is allocated for the bandwidth that aggregates this bandwidth, the succeeding I/O data exchange retry bandwidth, and C1 message bandwidth. C1 master and one slave station execute I/O data exchange once within one time slot.

C1 master registers the slave that fails I/O data exchange within this bandwidth into the retry list as a re-transmission target within the succeeding I/O data exchange retry bandwidth.

4.3.2.2.3 IO data exchange retry

This band is basically same as the case of fixed-width time slot (see 4.3.2.1.2.4). Subclause 4.3.2.2.2.3 describes the differences.

The time from the end of Synchronization bandwidth in the head of the transmission cycle to the start of the C2 message is allocated for the bandwidth that aggregates the I/O data exchange bandwidth, this bandwidth, and C1 message bandwidth. C1 master executes the retry for the slave registered in the retry list in the order of registration, and when the retry succeed, clears the registration. At the same time, C1 master compares the time required to complete the I/O data exchange with the slave and the residual time until the bandwidth ends (until C2 message starts), then executes the retry if the residual time is longer. If the residual time is shorter than the required time, C1 master ends this bandwidth.

C1 master executes the retry for the slave registered in the retry list in the order of registration, and when the retry succeed, clears the registration. When the bandwidth ends before executing the retries for all of the retry targets, C1 master quits retry.

In the case when the retry executed for a registered slave does not completed successfully, C1 master registers the slave again at the end of the retry list. C1 master repeats retry for the identical slave within the residual time of the bandwidth. When the retries for all of the retry targets within the retry list is executed, C1 master retrieves the slave from the retry list and then execute the retry again. C1 master ends the bandwidth when all of the slaves are cleared from the retry list.

4.3.2.2.4 C1 message

This is a bandwidth for a message transmission (C1 message transmission) where C1 master is the client (primary station) and C2 master or slave is the server (secondary station). Residual time from the end of the I/O data exchange retry bandwidth to the start of C2 message transmission is allocated to this bandwidth. C1 master executes the C1 message transmission within the allocated bandwidth. C1 master can repeat the transmission that consists of one request and one response as a pair within this bandwidth. However, C1 master can not execute C1 message transmission if there is no residual time enough for one transmission when the I/O data exchange retry bandwidth ends.

4.3.2.2.5 C2 message

This is a bandwidth for a message transmission (C2 message transmission) where C2 master is the client (primary station) and C1 master or slave is the server (secondary station). Time from the start of C2 message to the end of the transmission cycle is allocated to this bandwidth. C2 master executes the C2 message transmission within the allocated bandwidth. C2 master can repeat the transmission that consists of one request and one response as a pair within the bandwidth.

4.3.2.2.3 Estimation of cycle time

The operation of multiple slaves is synchronized with the command sent by the C1 master. To enable this, the transmission delay time of each slave is measured during initialization. The measured delay time is retained by the C1 master and each slave.

Based on the measured transmission delay time, the C1 master calculates the response monitoring time and the interrupt delay time for each slave to match the communication interrupt timing in the system.

The interrupt delay time is delivered with the synchronous frame (SYN frame in the figure). C1 master and each slave generates communication interrupt timing according to the interrupt delay time and the transmission delay time retained in the local station. As the result, communication interrupt occurs at the same time throughout the system.

By executing data reception processing simultaneously at all slaves at the cyclic event timing, the system can operate synchronously.

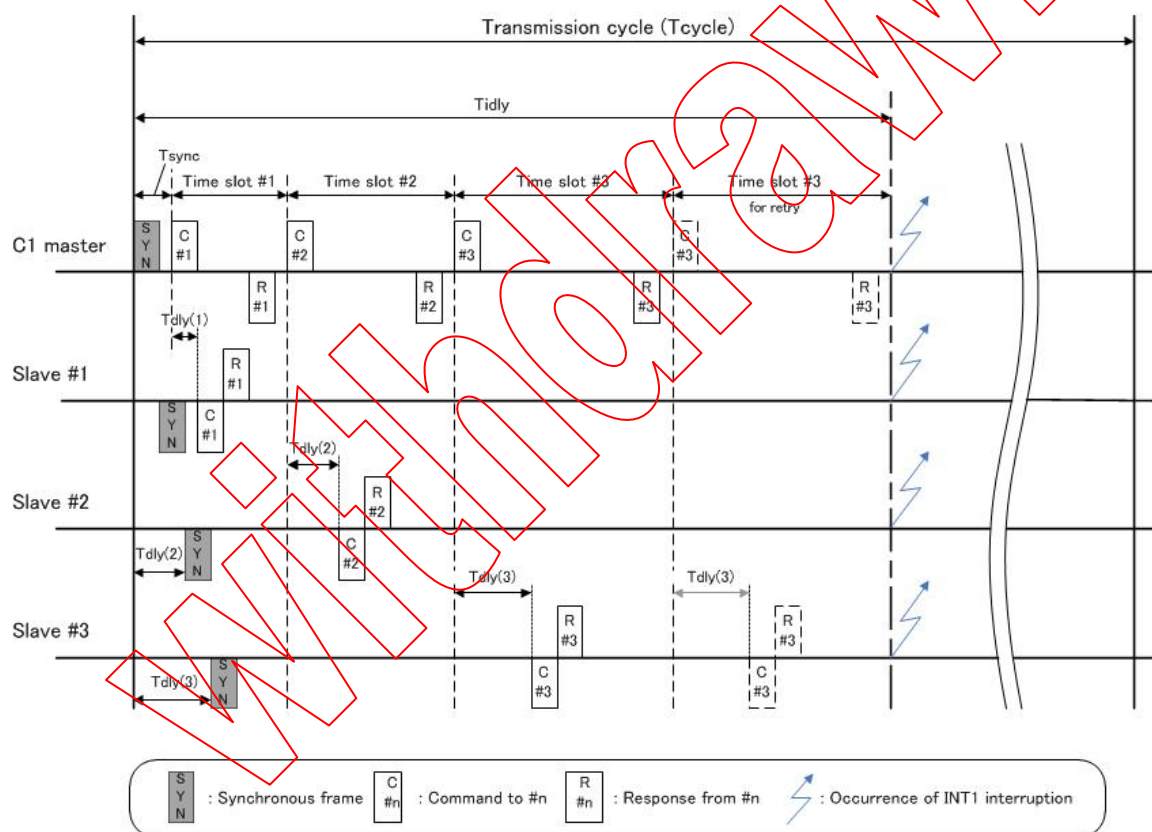


Figure 4 – Schematic Diagram of Communication Interrupt Occurrence

The transmission cycle of variable time slot type T_{cycle} is calculated as an aggregation of the bandwidth described in 4.3.2.3.2, as shown in the following formula:

$$T_{cycle} = T_{sync} + T_{io} + T_{retry} + T_{C1msg} + T_{C2msg}$$

where

- T_{sync} is the Sync band;
- T_{io} is the I/O data exchange band;
- T_{retry} is the I/O data exchange retry band;

T_{c1msg} is the C1 message band;
 T_{c2msg} is the C2 message band.

The calculation method for the bandwidths mentioned above is shown in the followings.

a) Sync band

Sync bandwidth T_{sync} is calculated as follows: where T_{tr_s} is the transmission time of synchronous frame, and T_{gap} is the gap between the frames:

$$T_{sync} = T_{tr\_s} + T_{gap}$$

b) I/O data exchange band

I/O data exchange bandwidth T_{io} is calculated as follows: where N is the number of slave connections, $T_{tr\_c}(n)$ is the instruction transmission time from C1 master to the slave of the number n , $T_{dly}(n)$ is the frame transmission delay time between C1 master and the slave of the number n , and T_{gap} is the gap between the frames:

$$\begin{aligned} T_{io} &= \sum_n \{T_{tr\_c}(n) + T_{dly}(n) + T_{gap} + T_{tr\_r}(n) + T_{dly}(n) + T_{gap}\} \\ &= \sum_n \{T_{tr\_c}(n) + T_{tr\_r}(n) + 2 \times T_{dly}(n)\} + 2 \times N \times T_{gap} \end{aligned}$$

c) I/O data exchange retry band

I/O data exchange bandwidth T_{retry} is calculated as follows: where N_r is the number of retry, $T_{tr\_c}(r)$ instruction transmission time from C1 master to the slave of the number r , $T_{dly}(r)$ is the frame transmission delay time between C1 master and the slave of the number r , and T_{gap} is the gap between the frames:

$$\begin{aligned} T_{retry} &= \sum_{ir} \{T_{tr\_c}(r) + T_{dly}(r) + T_{gap} + T_{tr\_r}(r) + T_{dly}(r) + T_{gap}\} \\ &= \sum_r \{T_{tr\_c}(r) + T_{tr\_r}(r) + 2 \times T_{dly}(r)\} + 2 \times N_r \times T_{gap} \end{aligned}$$

d) C1 message band

C1 message bandwidth T_{c1msg} is calculated as follows: $T_{tr\_c1c}(m_1)$ is the request transmission time from the primary station (C1 master) to the secondary station m_1 (m_1 is the station number of slave or C2 master that becomes the secondary station), $T_{tr\_c1r}(m_1)$ is the response transmission time from the secondary station to the primary station, $T_{dly}(m_1)$ is the transmission delay between the primary station and the secondary station, N_{c1msg} is the number of the C1 messages, and T_{gap} is the gap between the frames:

$$\begin{aligned} T_{C1msg} &= N_{c1msg} \times \{T_{tr\_c1c}(m_1) + T_{dly}(m_1) + T_{gap} + T_{tr\_c1r}(m_1) + T_{dly}(m_1) + T_{gap}\} \\ &= N_{c1msg} \times \{T_{tr\_c1c}(m_1) + T_{tr\_c1r}(m_1) + 2 \times T_{dly}(m_1) + 2 \times T_{gap}\} \end{aligned}$$

e) C2 message band

C2 message bandwidth T_{c2msg} is calculated as follows: $T_{tr\_c2c}(m_2)$ is the request transmission time from the primary station (C2 master) to the secondary station m_2 (m_2 is the station number of slave or C1 master that becomes the secondary station), $T_{tr\_c2r}(m_2)$ is the response transmission time from the secondary station to the primary station, $T_{dly}(m_2)$ is the transmission delay between the primary station and the secondary station, N_{c2msg} is the number of the C2 messages, and T_{gap} is the gap between the frames:

transmission delay between the primary station and the secondary station, N_{c2msg} is the number of the C2 messages, and T_{gap} is the gap between the frames:

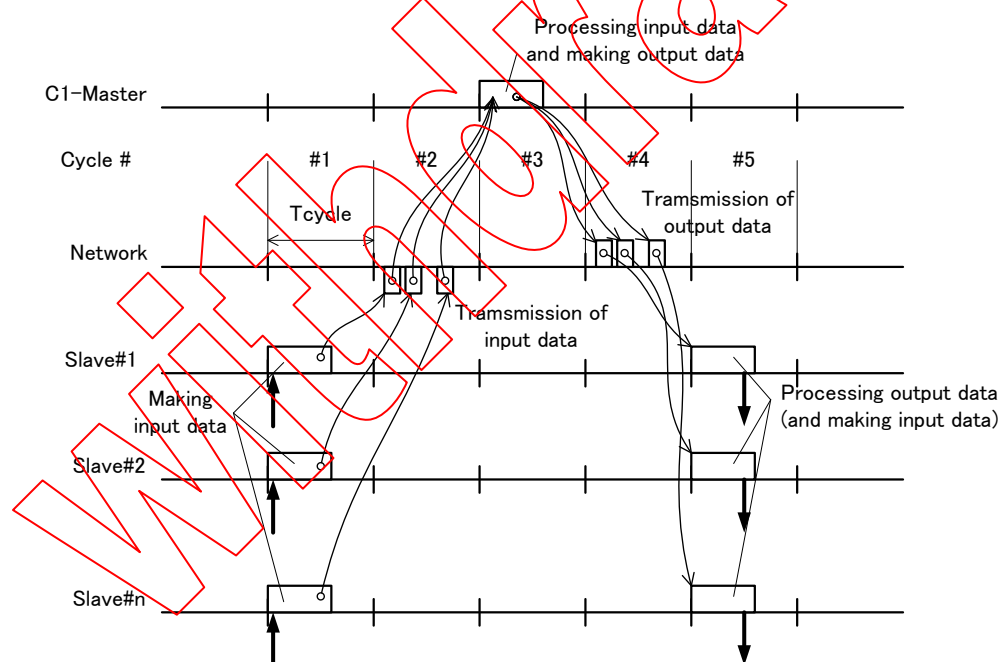
$$T_{c2msg} = N_{c2msg} \times \{T_{tr\_c2c}(m_2) + T_{dly}(m_2) + T_{gap} + T_{tr\_c2r}(m_2) + T_{dly}(m_2) + T_{gap}\}$$

$$= N_{c2msg} \times \{T_{tr\_c2c}(m_2) + T_{tr\_c2r}(m_2) + 2 \times T_{dly}(m_2) + 2 \times T_{gap}\}$$

4.3.2.3 Timing relationship between cyclic transmission and data processing

This subclause explains timing relationship between cyclic transmission and data processing by using Figure 5. In cycle #1, the slaves latch input and make the input data to be sent. The input data that the each slave made is transmitted to C1 master in cycle #2. Though it is received by C1 master, it is not processed by C1 master at this time. C1 master starts to process it at the top of the cycle #3. Therefore, the delay from the timing of slave's latched input to the timing of the master processing it is two transmission cycle.

Similarly, the output data that the C1 master made at cycle #3 is transmitted to all slaves, slave by slave, in cycle #4. Though it is received by each slave in cycle #4, it is not processed by the slave at this time. All slaves start to process it all together at the top of cycle #5. Therefore, the delay from the timing of master's making output data to the timing of the slave processing it is two transmission cycles, that is same as input data.



NOTE Output data and input data are transmitted in every cycle, but these drawings are omitted in this figure to explain easily. Data processing by C1 master and slaves in every cycle are also omitted.

Figure 5 – Timing relationship between cyclic transmission and data processing

4.3.3 Acyclic transmission mode

Acyclic transmission may be used in a system that does not require real-time communication or cyclical data exchange. In acyclic transmission mode, it is possible to execute the same transmission sequence as cyclic transmission mode without fixing the transmission cycle. Although C2 message communication is also possible, the DLS-user shall execute the arbitration of the transmission timing. In acyclic transmission mode, the data length is fixed at 64 octets.

Since acyclic transmission may not use the synchronous frame, slaves execute processing of the output data sent by the master and processing of the data to send the input data at its own timing. (Slaves do not operate simultaneously.)

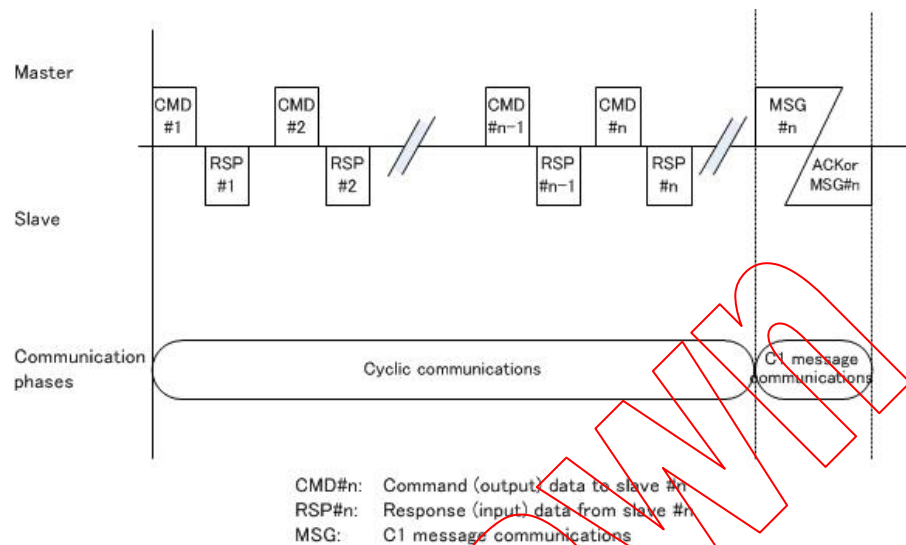


Figure 6 – Timing chart example of acyclic communication

4.4 Service assumed from PhL

4.4.1 General requirement

There are two types of Ph service which DLE required. One is defined in IEC 61158-2, Type 24 and the other is defined in ISO/IEC 8802-3, Clause 6.

Both PHY requires the following interface elements;

- Transmit Machine
- Receive Machine
- Serializer
- Deserializer

4.4.2 DL_Symbols

The PhL Interface Data Units present at the DLL-PhL interface shall be DL_symbols. DL_symbol shall have one of the following values:

- a) ZERO corresponds to a binary "0";
- b) ONE corresponds to a binary "1".

4.4.3 Assumed primitives of PhS

The PhS is assumed to provide the following two categories of primitives to the Type 24 DL-protocol.

- a) Service primitives for transmitting and receiving frames to / from other peer DLEs.
- b) Service primitives that provide information needed by the local DLE to perform the media access functions.

The assumed primitives of PhS are grouped into these two categories:

- c) Transfer of Data to the corresponding DLE

- 1) PLS_DATA request
- 2) PLS_DATA indication
- d) Indication from the local PhL
 - 3) PLS_CARRIER indication
 - 4) PLS_SIGNAL indication
 - 5) PLS_DATA_VALID indication

4.5 Local parameters, variable, counters, timers

4.5.1 Overview

This specification uses DLS-user request parameters P(...) and local variables V(...) as a means of clarifying the effect of certain actions and the conditions under which those actions are valid, local timers T(...) as a means of monitoring actions of the distributed DLS-provider and of ensuring a local DLE response to the absence of those actions. It also uses local queues Q(...) as a means of ordering certain activities, of clarifying the effects of certain actions, and of clarifying the conditions under which those activities are valid.

Unless otherwise specified, at the moment of their creation or of DLE activation:

- a) all variables shall be initialized to their default value, or to their minimum permitted value if no default is specified;
- b) all timers shall be initialized to inactive;
- c) all queues shall be initialized to empty.

DL-management may change the values of configuration variables.

4.5.2 Variables, parameters, counters and timers to support DLE function

4.5.2.1 V(MA), P(MA)

This variable is used by the CTC to record station address of this station. This variable shall be implemented by all stations. Its range is 1 to $2^{16}-1$. When the station adopts short format DLPDU, the lower 8 bits of this variable is effective.

4.5.2.2 V(Tcycle), P(Tcycle)

This variable is used by the CTC to record transmission period of cyclic communication. This variable shall be implemented by all stations. The time that a set value indicates depends on V(Tunit). Its range is 1 000 to 64 000.

4.5.2.3 V(Nmax_slaves), P(Nmax_slaves)

This variable is used by the CTC to record the number of connectable slave stations. Its range is 1 to 62.

4.5.2.4 V(Cyc_sel), P(Cyc_sel)

This variable is used by the DLM to record the selection of transmission mode, which is cyclic or acyclic. The value is listed at Table 5.

Table 5 – List of the values of variable Cyc_sel

Value	Symbol	Description
0	CMode_Cyclic	Cyclic transmission mode
1	CMode_Acyclic	Acyclic transmission mode

4.5.2.5 V(Nmax_dly_cnt), P(Nmax_dly_cnt)

This variable is used by the DLM to record maximum-measurement-count, which limits the number of delay measurement execution. This variable is implemented only by the C1 master adopts configurable time slot. Its default value is 2. Its range is 2 to 31.

4.5.2.6 V(IO_sz), P(IO_sz)

This variable is used by the CTC to hold and designate the data size of send and receive frame, which is transferred in I/O data exchange band. Its range is 8 to 64. When CTC adopts fixed-width time slot, its value shall be same for all stations.

4.5.2.7 V(Pkt_sz), P(Pkt_sz)

This variable is used by message segmentation machine to record the message packet size of cyclic transmission. Its range is 4 to 500. When CTC adopts fixed-width time slot, its value shall be equal to V(IO_sz).

4.5.2.8 V(Nmax_retry), P(Nmax_retry)

This variable is used by the CTC to record maximum-retry-count, which limits the number of retries in the I/O data exchange retry band. This variable is implemented only by the C1 master. Its default value is 0, meaning retry are not permitted. Its range is 0 to 62.

4.5.2.9 V(Tslot), P(Tslot)

This variable is used by the CTC to hold and designate the value of the timeout time for I/O data exchange to each station. This variable shall be implemented by C1 master and C2 master. Its range is 0 to less than V(Tcycle). The time that a set value indicates depends on V(Tunit). When CTC adopts fixed-width time slot, its value shall be same for all stations.

4.5.2.10 V(Tunit), P(Tunit)

This variable is used by the CTC to record the unit of a set value of the variable concerning time, when the CTC adopts configurable time slot. Table 6 shows its range. This variable shall be implemented only by the CTC which adopts configurable time slot. CTC which adopts fixed-width time slot shall not this variable, and shall use 250 ns as time unit for all variables concerning time.

Table 6 – List of the values of variable Tunit

Value	Definition	Tcycle
0	10 ns	31,25 µs to 500 µs (See NOTE)
1	100 ns	More than 500 µs to 4 ms
2	1 µs	More than 4 ms to 64 ms
NOTE Value 0 is default.		

4.5.2.11 V(Tidly), P(Tidly)

This variable is used by the CTC to record the timing of event, which is issued periodically to synchronize DLS-user. This variable shall be implemented by all stations, which adopt configurable time slot. The value is delay time from the start of cyclic transmission. Its range is 0 to less than V(Tcycle). The time that a set value indicates depends on V(Tunit).

4.5.2.12 V(Tc2_dly), P(Tc2_dly)

This variable is used by the CTC to record the timing to start C2 message communication. This variable shall be implemented by C1 master and C2 master, which adopt configurable time slot.

time slot. The value is delay time from the end of cyclic transmission. Its range is 0 to less than V(Tcycle). The time that a set value indicates depends on V(Tunit).

4.5.2.13 V(Tmsg), P(Tmsg)

This variable is used by the CTC to record the time period for message communication. This variable shall be implemented by C1 master and C2 master. Its range is 0 to less than V(Tcycle). The time that a set value indicates depends on V(Tunit). When CTC adopts fixed-width time slot, its value shall be same for all stations.

4.5.2.14 V(Twrpt)

This variable is used by the SRC to record the time period for transmission delay measurement. This variable shall be implemented by C2 master and slave. Its range is V(Tslot) x 3 to less than 64 ms. The default value is 500 µs. The time that a set value indicates depends on V(Tunit).

4.5.2.15 V(IO_MAP), P(IO_MAP)

This variable is used by the DLM and CTC to record the information of the slaves and C2 master which to be connected in the network. See IEC 61158-3-24, 5.3.2.2.13 for the details.

4.5.2.16 V(Sts_STI), P(Sts_STI)

This variable is used by the DLM to hold the connection status of the stations which to be connected in the network. See IEC 61158-3-24, 5.3.3.2.2.1 for the details.

4.5.2.17 V(Sts_Err), P(Sts_Err)

This variable is used by the DLM to hold the error factor which occurred in the DLE.

4.5.2.18 V(Fc2msg)

This variable is used by the CTC to hold the presence of C2 message communication bandwidth in cyclic transmission mode. This variable shall be implemented by C1 master and C2 master. Its value is 0 or 1. The value shall be set to 1 when C1 message communication bandwidth is assigned, and set to 0 when it is not assigned.

4.5.2.19 V(Nslave)

This variable is used by the CTC to hold and designate slave number, which is being processed in the current time slot. This variable shall be implemented by C1 master and C2 master. Its range is 0 to V(Nmax_slaves). The value is reset to zero at the start of each cycle of cyclic transmission. And it is incremented when I/O data exchange to a slave is executed.

4.5.2.20 V(Nretry)

This variable is used by the CTC to hold and designate the element of retry list, which is being processed in the current time slot. The value is reset to zero at the start of each cycle of cyclic transmission. And it is incremented when I/O data exchange to a slave is fault, and decremented when I/O data exchange retry is executed.

4.5.2.21 V(Nrest_slot)

This variable is used by the CTC to hold and designate the number of rest time slot within the end of this cycle. Its range is 0 to V(Nmax_slave). This variable shall be implemented by C1 master, which adopt fixed-width time slot. The value is decremented in the range of V(Nmax_retry) to 0.

4.5.2.22 V(Ndly_cnt)

This variable is used by the DLM to hold and designate the count of executed delay measurement. This variable shall be implemented by C1 master, which adopt configurable time slot. The value is reset to zero at the start of each cycle of cyclic transmission, and incremented when delay measurement is executed. Its range is 0 to V(Nmax_dly_cnt).

4.5.2.23 V(PDUType)

This variable is used by the CTC and DLM to hold and designate the selection of DLPDU type, which is basic format DLPDU or short format DLPDU. When the DLE adopts each of them, it may not implement this variable. The value is listed at Table 7.

Table 7 – List of the values of variable PDUType

Value	Symbol	Description
0	PDUBasic	Basic format DLPDU
1	PDUShort	Short format DLPDU

4.5.2.24 V(SlotType)

This variable is used by the CTC and DLM to hold and designate the selection of time slot type, which is fixed-width or configurable. When the DLE adopts each of them, it may not implement this variable. The value is listed at Table 8.

Table 8 – List of the values of variable SlotType

Value	Symbol	Description
0	TSTFixed	Fixed-width time slot
1	TSTConfig	Configurable time slot

4.5.2.25 V(Nms_1), V(Nms_2)

This variable is used by the CTC to hold the number of segmentations to be sent in the message communication using basic format DLPDU. The suffix “_1” and “_2” show the bandwidth of message communication, and indicate C1 message communication and C2 message communication respectively. This variable shall be implemented by all stations which execute message communication. The value is reset to zero at the first segment of each message. And, it is incremented by one every time CTC received acknowledge of one segment normally from peer station. Its range is 0 to 127.

4.5.2.26 V(Nmr_1), V(Nmr_2)

This variable is used by the CTC to hold the number of segments to be received in message communication using basic format DLPDU. The suffix “_1” and “_2” show the bandwidth of message communication, and indicate C1 message communication and C2 message communication respectively. This variable shall be implemented by all stations which execute message communication. The value is reset to zero at the first segment of each message. And it is incremented when one segment is received from peer station. Its range is 0 to 127.

4.5.2.27 V(Fmp_1), V(Fmp_2)

This variable is used by the CTC to hold and designate the flag of the polling request in message communication using basic format DLPDU. The suffix “_1” and “_2” show the bandwidth of message communication, and indicate C1 message communication and C2 message communication respectively. This variable shall be implemented by all stations

which execute message communication. Its range is 0 or 1. The value 1 means the polling request and 0 (default) means the other.

4.5.2.28 V(Fmf_1), V(Fmf_2)

This variable is used by the CTC to hold and designate the flag of the last segment in message communication using basic format DLPDU. The suffix “_1” and “_2” show the bandwidth of message communication, and indicate C1 message communication and C2 message communication respectively. This variable shall be implemented by all stations, which execute message communication. Its range is 0 or 1. The value is reset to zero at the first segment of each message, and set one when the last segment of the message is sent or received.

4.5.2.29 V(Ten)

This variable is used by the DLM to hold the timestamp of delay measurement end when the DLE adopts configurable time slot. The DLE shall implement this variable only when the DLE adopts configurable time slot.

4.5.2.30 V(Tdly)

This variable is used by the DLM to hold the transmission delay measured in CompDly state of DLM when the DLE adopts configurable time slot. The DLE shall implement this variable only when the DLE adopts configurable time slot.

4.5.2.31 V(Tmax_dly)

This variable is used by the DLM to hold the transmission delay measured in CompDly state of DLM when the DLE adopts configurable time slot. The DLE shall implement this variable only when the DLE adopts configurable time slot.

4.5.2.32 V(Tst)

This variable is used by the DLM to hold the timestamp of delay measurement start time when the DLE adopts configurable time slot. The DLE shall implement this variable only when the DLE adopts configurable time slot.

4.5.2.33 T(Tcycle)

T(Tcycle) is used by the CTC to measure the cyclic transmission period. The value is decremented in the range of V(Tcycle) to 0.

4.5.2.34 T(Tslot)

T(Tslot) is used by the CTC to measure the time elapsed since last sending a frame. The value is decremented in the range of V(Tslot) to 0.

4.5.2.35 T(Tmsg)

T(Tmsg) is used by the CTC to measure the time period of message communication band. The value is decremented in the range of V(Tmsg) to 0.

4.5.2.36 T(Twrpt)

T(Twrpt) is used by the SRC to watch repeat function. The value is decremented in the range of V(Twrpt) to 0.

4.5.2.37 Q(MSGc1s), Q(MSGc2s)

The queue buffer is implemented at the interface between CTC and MSM to transfer the send message. CTC enqueues the message to be sent, then MSM dequeues the message to build DLPDU and send it.

4.5.2.38 Q(MSGc1r), Q(MSGc2r)

The queue buffer is implemented at the interface between CTC and Message segmentation protocol machine to transfer the received message. MSM builds the message from the received DLPDU and enqueues it, then CTC dequeues the message to transfer it to the DLS-user.

5 DLPDU structure

5.1 Overview

5.1.1 Transfer syntax for bit sequences

For transmission across Type 24 DL a bit sequence is reordered into a sequence of octets. Hexadecimal notation is used for octets as specified in ISO/IEC 9899. Let $b = b_0 \dots b_{n-1}$ be a bit sequence. Denote k a non-negative integer such that $8(k-1) \leq n < 8k$. Then b is transferred in k octets assembled as shown in Table 9. The bits b_i , $i > n$ of the highest numbered octet shall be ignored.

Table 9 – Transfer syntax for bit sequences

Octet number	1	2	k
	$b_7 \dots b_0$	$b_{15} \dots b_8$	$b_{8k-1} \dots b_{8k-8}$

When the DLE implemented over the PHY defined in IEC 61158-2, Type 24, octet 1 is transmitted first and octet k is transmitted last. Hence the bit sequence is transferred as follows across the network:

$b_0, b_1, \dots, b_7, b_8, \dots, b_{15}, \dots$

5.1.2 Data type encodings

Data of basic data type Unsigned_n has values in the non-negative integers. The value range is $0, \dots, 2^n - 1$. The data is represented as bit sequences of length n . The bit sequence

$b = b_0 \dots b_{n-1}$

is assigned the value

$$\text{Unsigned}(b) = b_{n-1} \times 2^{n-1} + \dots + b_1 \times 2^1 + b_0 \times 2^0$$

The bit sequence starts on the left with the least significant octet.

EXAMPLE The value $266 = 0x10A$ with data type Unsigned_{16} is transferred in two octets, first $0x0A$ and then $0x01$.

Table 10 – Bit order

Octet number	1	2	3	4	5	6	7	8
Unsigned8	b ₇ ..b ₀							
Unsigned16	b ₇ ..b ₀	b ₁₅ ..b ₈						
Unsigned32	b ₇ ..b ₀	b ₁₅ ..b ₈	b ₂₃ ..b ₁₆	b ₃₁ ..b ₂₄				
Unsigned64	b ₇ ..b ₀	b ₁₅ ..b ₈	b ₂₃ ..b ₁₆	b ₃₁ ..b ₂₄	b ₃₉ ..b ₃₂	b ₄₇ ..b ₄₀	b ₅₅ ..b ₄₈	b ₆₃ ..b ₅₆

The Unsigned n data types are transferred as specified in Table 10. Unsigned data types as Unsigned1 to Unsigned7 and Unsigned 9 to Unsigned15 will be used too. In this case the next element will start at the first free bit position as denoted in 5.1.1.

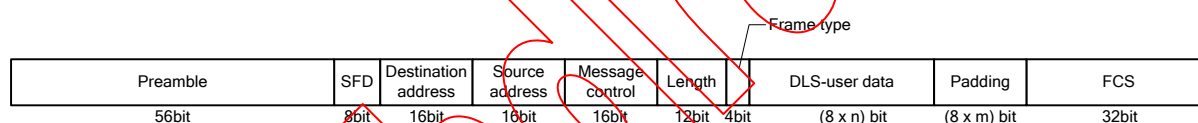
5.1.3 Frame format

There are two types of frame format. One is basic format and the other is short format that based on ISO/IEC 13239:2002 (HDLC).

5.2 Basic format DLPDU structure

5.2.1 General

Figure 7 shows the structure of basic frame format.

**Figure 7 – Basic format DLPDU structure**

5.2.1.1 Preamble

The preamble field is identical to Clause 3 of ISO/IEC 8802-3:2000. The preamble field is a 56-bit field that is used to allow the physical signaling part circuitry to reach its steady state synchronization with the receiving frame timing.

The preamble pattern is:

“10101010 10101010 10101010 10101010 10101010 10101010 10101010.”

5.2.1.2 Start frame delimiter (SFD)

The Start Frame Delimiter (SFD) is identical to Clause 3 of ISO/IEC 8802-3:2000. The SFD field is the sequence of bit pattern “10101011”. It immediately follows the preamble pattern and indicates the start of a frame.

5.2.1.3 Destination address (DA)

Destination address shall contain the node address of the destination DLE.

The higher 8 bits of a 16-bit address is used as an extended address and the lower 8 bits is used as a station address (see Table 11).

For both station addresses and extension address, the usable addresses are specified in Table 12 and Table 13.

Table 11 – Destination and Source address format

Octet number	Size	Contents
1	Unsigned8	Station address
2	Unsigned8	Extended address

Table 12 – Station address

Station address	Contents
0x00	Reserved
0x01	C1 master
0x02	C2 master
0x03 to 0xEF	Slave, Gateway
0xF0 to 0xFE	Reserved
0xFF	Broadcast address

Table 13 – Extended address

Extended address	Contents
0x00 to 0xFEh	Device address for the node that has multiple device, or remote address for gateway node
0xFF	Broadcast address ^a
^a Only synchronous frame may use broadcast address.	

5.2.1.4 Source address (SA)

Source address shall contain the node address of the source DLE. See 5.2.1.3 for its format and its range.

5.2.1.5 Message control

Message control field is used for send data with acknowledge service. This field is effective only when Frame type which follows this field is Message frame. This field shall be zero except Message frame.

This field has two formats. One is Information transfer format and the other is supervisory format (see Table 14 and Table 15). Each field shall have the same function as the field with the same name in ISO/IEC 13239:2000 (HDLC).

NOTE In HDLC and this specification, the order of transmitting the bit is reverse.

Table 14 – Message control field format (Information transfer format)

Octet number	Size	Symbol	Contents
1	Unsigned7	N(R)	Transmitting receive sequence number
	Unsigned1	P/F	Poll bit – primary transmissions Final bit – secondary transmission
2	Unsigned7	N(S)	Transmitting send sequence number

Octet number	Size	Symbol	Contents
	Unsigned1	-	Reserved (0) ^a
^a This bit shall be zero.			

Table 15 – Message control field format (Supervisory format)

Octet number	Size	Symbol	Contents
1	Unsigned7	N(R)	Transmitting receive sequence number
	Unsigned1	-	Reserved (1) ^a
2	Unsigned4	-	Reserved (0) ^b
	Unsigned2	S	Supervisory function bits
	Unsigned1	-	Reserved (0) ^b
	Unsigned1	-	Reserved (1) ^a
^a This bit shall be one.			
^b This bits shall be zero.			

Table 16 – The list of Supervisory function bits

Value	Symbol	Description	Note
0	RR	Receive ready (RR) command or RR response	
1	REJ	Reject (REJ) command or REJ response	
2	RNR	Receive not ready (RNR) response	
3	-	Reserved	

5.2.1.6 Type and length field

Frame type and Data length field consists of a higher 4-bit area where the frame type is set and a lower 12-bit area where the data length is set (see Table 17).

The frame type is used for identifying the contents of a frame and also for identifying the type of the protocol for message communication. Table 18 shows the definition of frame type. The data length indicates the size of the data stored in a frame in terms of the number of octets.

Table 17 – Frame type and Data length format

Octet number	Size	Contents
1	Unsigned12	Data length (lower 8 bits)
2		Data length (higher 4 bits)
	Unsigned4	Frame type

Table 18 – The list of Frame type

Value	Symbol	Description
0	–	Reserved
1	FT_SYNC	Synchronous Frame
2	FT_IO	Output data and Input data frame
3	FT_DLST	Delay measurement start frame
4	FT_DLMS	Delay measurement frame
5	FT_MTKN	Message token frame
6	FT_STS	Status frame
7	FT_CINF	Cyclic information frame
8 to 11	–	Reserved
12	FT_MSG	Message frame
13 to 15	–	Reserved

5.2.1.7 DLS-user data field

The data format varies according to the frame type. With message frames, if the application data cannot be set in one frame, it is possible to set and send the data in multiple frames using message control.

5.2.1.8 Field check sequence field (FCS)

A frame check sequence (FCS) uses 32-bit CRC-CCITT. FCS is calculated in the range from the destination address to the end of the data except the FCS itself.

5.2.2 Synchronous frame

C1 master uses this frame to synchronize slaves and C2 master. Only C1 master may send this frame. C1 master shall set the station address as the broadcast address (0xFF), and the slaves and the C2 master shall receive this frame.

When slave and C2 master receive this frame, they shall refresh the local clock with the time calculated by adding the transmission delay measured in advance (notified with delay measurement frame) to the current time stored this frame.

Table 19 and Table 20 show detailed the data format of this frame.

Table 19 – Data format of Synchronous frame

Octet number	Size	Contents
1 to 4	Unsigned32	Timestamp
5 to 6	Unsigned16	Cyclic event delay time
7 to 8	Unsigned16	Reserved

Table 20 – The field list of Synchronous frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Timestamp	Time stamp of C1 master at the frame is sent	0 to $2^{32}-1$	–	The unit is defined according to the setting of the variable V(Tunit).
Cyclic event delay time	Delay time from the current time stored in this frame to the time when the cyclic event is indicated	0 to $2^{16}-1$	0	The unit is defined according to the setting of the variable V(Tunit).

5.2.3 Output data or Input data frame

C1 master uses this frame for the output data to be sent to slaves, and slaves use this frame for the input data to be sent to C1 master, within I/O data exchange bandwidth of cyclic transmission mode. C2 master may only receive this frame and shall not send this frame.

Either of the destination address or the source address of this frame must be C1 master because this frame is exchanged between dataC1 master and slave. The data length must not be changed during normal operation.

Table 21 and Table 22 show the data format of this frame.

Table 21 – Data format of Output data or Input data frame

Octet number	Size	Contents
1 to n	Unsigned8n	Output data or Input data
(n+1) to (n+m)	Unsigned8m	Padding

Table 22 – The field list of Output data or Input data frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Output data or Input data	Output data from C1 master to slave or input data from slave to C1 master	0 to maximum value that can be represented with the octet length of the specified data length	–	
Padding	Area adjusted to become multiple in 32 bits in data length	Don't care	0	

5.2.4 Delay measurement start frame

C1 master uses this frame to specify the targeted station of the delay measurement to measure the transmission delay from C1 master to each slave or C2 master. Only C1 master transmits this frame. After the station receives this frame, the station returns the receipt frame till the number of times that specified with this frame.

Table 23 and Table 24 show detailed the data format of this frame.

Table 23 – Data format of Delay measurement start frame

Octet number	Size	Contents
1 to 2	Unsigned16	Measurement number
3 to 4	Unsigned16	Reserved

Table 24 – The field list of Delay measurement start frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Measurement number	Number of times for sending the transmission delay measurement frame	1 to 32	1	

5.2.5 Delay measurement frame

C1 master uses this frame to measure the transmission delay and to notify the slaves and C2 master of the result. Only C1 master transmits this frame. C1 master shall send this frame to the station to which the delay measurement start frame is sent, and send this frame till the times specified with the delay measurement start frame. C1 master shall notify of the result of the measurement by using this frame.

Slave and C2 master that received delay measurement start frame shall receive and return this frame. They shall stop returning the receipt frame after receiving this frame till the number of times notified with the delay measurement start frame.

Table 25 and Table 26 show detailed the data format of this frame.

Table 25 – Data format of Delay measurement frame

Octet number	Size	Contents
1 to 4	Unsigned32	Timestamp
5 to 6	Unsigned16	Transmission delay
7 to 8	Unsigned16	Reserved

Table 26 – The field list of Delay measurement frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Transmission delay	Time from sending a frame of C1 master to reception of slave or C2 master of it.	0 to $2^{16}-1$	–	The unit is defined according to the setting of the time unit. The default unit is 10 ns.

5.2.6 Message token frame

C1 master sends this frame to notify C2 master of the permission of start C2 message communication before C2 message communication start time. C1 master shall send this frame only when C1 master exchanges the command data/response data with all slaves and C1 message communication ends before C2 message communication start time. However, C1 master shall not send this frame when the time from the current time of the local clock to the start time of C2 message communication is shorter than the transmission delay between C1 master and the C2 master.

C2 master that receives this frame may start C2 message communication unless C2 message communication start time has come.

Only C1 master may send this frame. The destination and source addresses are fixed because only C2 master may receive this frame. This frame contains no data.

5.2.7 Status frame

C1 master uses this frame to inquire the status of slaves and C2 master. The station that received this frame from C1 master shall send this frame to notify of the current status. Slaves and C2 master shall return this frame also when receiving a cycle information frame contains their own address as the destination. Slave and C2 master may return this frame to request C1 master to execute the transmission delay measurement even when they receive the other frame than the synchronous frame from C1 master.

Broadcast address or multicast address shall not be specified as the destination of this frame.

Table 27 to Table 30 show detailed the data format of this frame.

Table 27 – Data format of Status frame

Octet number	Size	Contents
1 to 2	Unsigned16	Status
3 to 4	Unsigned16	Repeater status

Table 28 – The field list of Status frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Status	Current value of the DLE status	(See Table 29)	–	Refreshed by slave or C2 master
Repeater status	Current value of repeater status	(See Table 30)	–	Refreshed by slave or C2 master

Table 29 – The list of the DLE status

Status code	Description
0x0000	Station not exist
0x0023	Station address duplicated
0x0024	Waiting for the delay measurement request by DLS-user
0x0025	Waiting for delay measurement start indication from C1 master
0x0026	Measuring transmission delay
0x0027	Waiting for cyclic information frame from C1 master
0x0050	Operating in cyclic transmission mode
0x0060	Operating in acyclic transmission mode

Table 30 – The list of Repeater status

Send status			
bit	Symbol	Description	Initial
0	–	Reserved	0
1	MII_RXTXE	Send request detected while receiving data from PhL	0
2	MII_TXRXE	Receive data from PhL detected while sending data to PhL	0
3	MII_RXRXE	Receive data from PhL detected while receiving data from PhL	0
4 to 15	–	Reserved	0

5.2.8 Cycle Information frame

C1 master uses this frame to notify slave and C2 master of the transmission mode. Only C1 master may send this frame.

C1 master may broadcast this frame or send it to slaves or C2 master individually. Slaves and C2 master shall return a status frame when they receive this frame that contains their own address as the destination.

Table 31 and Table 32 show detailed the data format of this frame.

Table 31 – Data format of Delay measurement frame

Octet number	Size	Contents
1 to 2	Unsigned16	Transmission cycle
3 to 4	Unsigned16	C2 message delay
5 to 6	Unsigned16	Maximum delay
7	Unsigned8	Communication mode
8	Unsigned8	Time unit

Table 32 – The field list of Cycle Information frame

Field	Contents	Maximum and minimum value	Note
Transmission cycle	Transmission cycle of the cyclic transmission mode	3 125 to 64 000	a)
C2 message delay	Delay time from the current time stored in the synchronous frame to the time of C2 message communication start	0 to $2^{16}-1$	
Maximum delay	Maximum value among the transmission delay measured by C1 master.	0 to $2^{16}-1$	a)
Communication mode	Selection of transmission mode to be executed after initialization	0: Cyclic 1: Acyclic	
Time unit	Selection code of time unit	0 : 10 ns 1 : 100 ns 2 : 1 µs	b)

- a) The unit is defined by the value of the time unit field in this frame.
- b) When the transmission cycle T_{cycle} is $31,25 \mu s \leq T_{MCYC} \leq 500 \mu s$, set to 10 ns.
- In the case of $500 \mu s < T_{MCYC} \leq 4 ms$, set to 100 ns.
- When $4 ms < T_{MCYC} \leq 64 ms$, set to 1 μs .

5.2.9 Message frame

This frame is used for message transmission. All stations may send this frame. When the DLSDU that requested to send is beyond the size that may contained within one frame, the DLSDU shall be divided by using the message control field in this frame.

Table 33 and Table 34 show detailed the data format of this frame.

Table 33 – Data format of Message frame

Octet number	Size	Contents
1 to n	Unsigned8n	Message data
(n+1) to (n+m)	Unsigned8m	Padding

Table 34 – The field list of Message frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Message data	Arbitrary data except output data or input data	0 to maximum value that can be represented with the octet length of the specified data length	–	
Padding	Area adjusted to become multiple in 32 bits in data length	Don't care	0	

5.3 Short format DLPDU structure

5.3.1 General

The short format DLPDU is shown in Figure 8. Transmission sequence shall be from left to right as shown in Figure 8, i.e. station address first, followed by control, DLS-user data and finally CRC.

Preamble	Start flag	Station address	Control	DLS-user data	CRC	End flag
16 bit	8 bit	8 bit	8 bit	(8 x n) bit	16 bit	8 bit

Figure 8 – Short format DLPDU structure

5.3.1.1 Preamble

The preamble field is identical to ISO/IEC 13239:2002 (HDLC). The preamble field is a 16-bits field that is used to allow the physical signaling part circuitry to reach its steady state synchronization with the receiving frame timing.

The preamble pattern is:

“10101010 10101010.”

5.3.1.2 Start flag

The start flag is identical to ISO/IEC 13239:2002 (HDLC). This field is the sequence of bit pattern “10101011”. It immediately follows the preamble pattern and indicates the start of a frame.

Due to bit-stuffing, this bit sequence is prevented from occurring inside the DLSDU sequence. The DLE shall only accept a received signal burst as a DLPDU after verifying this sequence and shall remove this sequence before transferring the DLSDU sequence to the DLS-user.

5.3.1.3 Station address field

Table 35 shows the range of the station address field.

Table 35 – Range of Station address field

Station Address	Contents
0x00	Reserved
0x01	C1 master
0x02	C2 master
0x03 to 0xDE	Slaves
0xDF	Not connected (default)
0xE0 to 0xFE	Reserved
0xFF	Broadcast address

5.3.1.4 Control field (CTL)

Control field is used to identify the frame type. This field has two formats. One is I/O data exchange format and the other is Message format. Table 36 to Table 38 show detailed this field.

Table 36 – Control field format (I/O data exchange format)

Octet number	Size	Symbol	Contents
1	Unsigned4	CMD	Input data or Output data flag; 1: Input data (response) 3: Output data (command)
	Unsigned4	-	Reserved (0) ^a

^a This bit shall be zero.

Table 37 – Control field format (Message format)

Octet number	Size	Symbol	Contents
1	Unsigned4	S(n)	Sequence number
	Unsigned1	-	Reserved (1) ^a
	Unsigned1	C1/C2	Primary node flag
	Unsigned1	END	End flag
	Unsigned1	S/D	Sync / data flag

^a This bit shall be one.

Table 38 – The field list of Message format

Symbol	Description
S(n)	Transmitting send or receive sequence number.
C1/C2	0: C1 master 1: C2 master
END	When S/D is 0, 0: Data transfer from primary node to secondary node 1: Data transfer from secondary node to primary node When S/D is 1, 0: Following data exists 1: This data is last data
S/D	0: Handshake frame 1: Data frame

5.3.1.5 DLS-user data field

The length of the DLS-user data field is from 8 octets to 64 octets.

5.3.1.6 CRC field

A frame check sequence (FCS) using a 16-bit CRC-CCITT is used. CRC is calculated based on the following formula.

$$P(x) = X^{16} + X^{12} + X^5 + 1$$

5.3.1.7 End flag

The sequence of symbols in this field is identical to the start flag (see 5.3.1.2).

5.3.2 Synchronous frame

C1 master uses this frame to synchronize slaves and C2 master. Only C1 master may send this frame. C1 master shall set the station address to the broadcast address (0xFF), and slaves and C2 master shall receive this frame. When they receive this frame, they shall check the CRC field contained in this frame, and then issue a cyclic event if the result of the check has no error.

Table 39 and Table 40 show detailed the data format of this frame.

Table 39 – Data format of Synchronous frame

Octet number	Size	Contents
1 to 2	Unsigned16	Transmission cycle
3 to 4	Unsigned16	Time slot width
5 to 16 or 31	-	Reserved

Table 40 – The field list of Sync frame

Field	Contents	Maximum and minimum value	Note
Transmission cycle	Transmission cycle notified C2 master	0 to $2^{16}-1$	The unit is 0,25 us
Time slot width	Time slot	0 to $2^{16}-1$	The unit is 0,25 us

5.3.3 Output data or Input data frame

5.3.3.1 Output data frame

C1 master uses this frame for the output data to be sent to slave within I/O data exchange bandwidth of cyclic transmission mode. C2 master only may receive this frame. The length of the output data shall be 16 or 31 octets.

Table 41 and Table 42 show detailed the data format of this frame.

Table 41 – Data format of Output data frame

Octet number	Size	Contents
1 to 16 or 31	Unsigned8n	Output data

Table 42 – The field list of Output data frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Output data	Output data from C1 master to slave	0 to Maximum value according to the data length	–	

5.3.3.2 Input data frame

Slaves use this frame for the input data to be sent to C1 master within I/O data exchange bandwidth of cyclic transmission mode. C2 master only may receive this frame. The length of the input data shall be 16 or 31 octets.

Table 43 and Table 44 show detailed the data format of this frame.

Table 43 – Data format of Input data frame

Octet number	Size	Contents
1 to 16 or 31	Unsigned8n	Input data

Table 44 – The field list of Input data frame

Field	Contents	Maximum and minimum value	Recommended value	Note
Input data	Input data from slave to C1 master	0 to Maximum value according to the data length	–	

5.3.4 Message frame

This frame is used for message transmission. All stations may send this frame. When the DLSDU that requested to send is beyond the size that may contained within one frame, the DLSDU shall be divided by using the message control field in this frame.

6 DLE element procedure

6.1 Overview

In following subclause, the operation of CTC and SRC is described. Though DL-management is a component of DLE, it is described in the next clause.

6.2 Cyclic transmission control sublayer

6.2.1 General

CTC provides the following functions.

- Control of communication sequence and communication band (C1 master)
- Monitoring of all I/O data exchanged between C1 master and slaves (C2 master)
- Sending response as a server (Slave)
- Message communication in cyclic communication
- Sporadic data exchange

6.2.2 DLS-user interface

6.2.2.1 Primitive definitions

The primitives exchanged with the DLS-user between CTC are shown below. Table 45 is for the case that issued by DLS-user and Table 46 is for the case that issued by CTC.

Table 45 – The primitives and parameters for DLS-user interface issued by DLS-user

Primitive	Source	Parameter	Function
DL-WRITE-DATA.req	DLS-user	SAP_ID, DLS-user-data	Send data writing request
DL-READ-DATA.req	DLS-user	SAP_ID	Receive data reading request
DL-SDA.req	DLS-user	SAP_ID, Node_ID, Length, DLS-user-data	Send data request with transmission confirmation
DL-SDN.req	DLS-user	SAP_ID, Node_ID, Length, DLS-user-data	Send data request without transmission confirmation
DL_GET_STATUS.req	DLS-user	Sts_ID	DL parameter referring request

Table 46 – The primitives and parameters for DLS-user interface issued by CTC

Primitive	Source	Parameter
DL-WRITE-DATA.cnf	CTC	Result
DL-READ-DATA.cnf	CTC	Result, DLS-user-data
DL-SDA.ind	CTC	Node_ID, Length, DLS-user-data
DL-SDA.cnf	CTC	Result
DL-SDN.ind	CTC	Node_ID, Length, DLS-user-data
DL-SDN.cnf	CTC	Result

Primitive	Source	Parameter
DL_GET_STATUS.cnf	CTC	Result, Cur_Status
DL_EVENT.ind	CTC	Event_ID

6.2.2.2 Overview of the interactions

See IEC 61158-3-24, 4.3.

6.2.2.3 Detailed definitions of the primitives and parameters

See IEC 61158-3-24, 4.4.

6.2.3 Protocol machines in CTC

6.2.3.1 Overview

There are three protocol machines in CTC, which are cyclic transmission protocol machine, message segmentation protocol machine, and acyclic transmission protocol machine.

The cyclic communication protocol machine has two kinds of protocol machines corresponding to the adopted frame format. One is “fixed-width time slot type” whose transmission sequence is composed of same-width time slot, and the other is “configurable time slot type” whose transmission sequence for each station may be different time slot. In addition, each of two protocol machines of “fixed-width time slot type” and “fixed-width time slot type” has three kinds of protocol machines corresponding to the station type (the C1 master, the C2 master, and the slave).

The cyclic communication protocol machine has two protocol machine, sender and receiver.

The message communication protocol machine works only while the cyclic transmission protocol machine is active.

6.2.3.2 Cyclic transmission protocol machine

6.2.3.2.1 Protocol machine for cyclic communication consists of fixed-width time slot

6.2.3.2.1.1 C1 master

Figure 9 and Table 47 show the state diagram and the state table of C1 master that adopts fixed-width time slot.