

INTERNATIONAL STANDARD

IEC
61158-4

Third edition
2003-05

**Digital data communications
for measurement and control –
Fieldbus for use in industrial
control systems –**

**Part 4:
Data link protocol specification**

<https://standards.iteh.ai>
Document Preview

<https://standards.iteh.ai>
IEC 61158-4:2003

<https://standards.iteh.ai/catalog/standards/iec/2cf5f060-797d-4bb3-a6c6-1a4efdd6cca0/iec-61158-4-2003>



Reference number
IEC 61158-4:2003(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site** (www.iec.ch)

- **Catalogue of IEC publications**

The on-line catalogue on the IEC web site (http://www.iec.ch/searchpub/cur_fut.htm) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.

- **IEC Just Published**

This summary of recently issued publications (http://www.iec.ch/online_news/justpub/jp_entry.htm) is also available by email. Please contact the Customer Service Centre (see below) for further information.

- **Customer Service Centre**

If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

Email: custserv@iec.ch
Tel: +41 22 919 02 11
Fax: +41 22 919 03 00

INTERNATIONAL STANDARD

IEC 61158-4

Third edition
2003-05

Digital data communications for measurement and control – Fieldbus for use in industrial control systems –

Part 4: Data link protocol specification

(<https://standards.iteh.ai>)
Document Preview

IEC 61158-4:2003

<https://standards.iteh.ai/catalog/standards/iec/2cf51060-797d-4bb3-a6c6-1a4efdd6cca0/iec-61158-4-2003>

© IEC 2003 – Copyright - all rights reserved

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 the publisher.

International Electrotechnical Commission, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch



Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE **XH**

For price, see current catalogue

CONTENTS

| | |
|---|-----|
| FOREWORD..... | 24 |
| 0 Introduction..... | 27 |
| 0.1 General..... | 27 |
| 0.2 Nomenclature for references within this standard..... | 27 |
| 1 Scope and object..... | 29 |
| 1.1 Overview..... | 29 |
| 1.2 Specifications..... | 30 |
| 1.3 Procedures..... | 32 |
| 1.4 Applicability..... | 32 |
| 1.5 Conformance..... | 32 |
| 2 Normative references..... | 32 |
| 3 Terms and definitions..... | 33 |
| 3.1 Reference model terms and definitions..... | 33 |
| 3.2 Service convention terms and definitions..... | 35 |
| 3.3 Common terms and definitions..... | 36 |
| 3.4 Type 1: Additional terms and definitions..... | 39 |
| 3.5 Type 2: Additional terms and definitions..... | 45 |
| 3.6 Type 3: Additional terms and definitions..... | 52 |
| 3.7 Type 4: Additional terms and definitions..... | 54 |
| 3.8 Type 5: Additional terms and definitions..... | 55 |
| 3.9 Type 6: Additional terms and definitions..... | 55 |
| 3.10 Type 7: Additional terms and definitions..... | 65 |
| 3.11 Type 8: Additional terms and definitions..... | 67 |
| 4 Symbols and abbreviations..... | 69 |
| 4.1 Common symbols and abbreviations..... | 69 |
| 4.2 Type 1: Additional symbols and abbreviations..... | 69 |
| 4.3 Type 2: Additional symbols and abbreviations..... | 73 |
| 4.4 Type 3: Additional symbols and abbreviations..... | 74 |
| 4.5 Type 4: Additional symbols and abbreviations..... | 78 |
| 4.6 Type 5: Additional symbols and abbreviations..... | 79 |
| 4.7 Type 6: Additional symbols and abbreviations..... | 79 |
| 4.8 Type 7: Additional symbols and abbreviations..... | 80 |
| 4.9 Type 8: Additional symbols and abbreviations..... | 81 |
| 5 DL-protocol elements common to multiple DL-protocol Types..... | 84 |
| 5.1 Frame check sequence..... | 84 |
| 6 Type 1: Overview of the DL-protocol..... | 88 |
| 6.1 Three-level model of the DLL..... | 88 |
| 6.2 Service provided by the DLL..... | 91 |
| 6.3 Structure and definition of DL-addresses..... | 97 |
| 6.4 Service assumed from the PhL..... | 109 |
| 6.5 Functions of the DLL..... | 112 |
| 6.6 Functional classes..... | 114 |
| 6.7 Local parameters, variables, counters, timers and queues..... | 116 |

| | | |
|------|--|-----|
| 7 | Type 1: General structure and encoding of PhIDUs and DLPDUs, and related elements of procedure | 130 |
| 7.1 | PhIDU structure and encoding | 130 |
| 7.2 | Common DLPDU structure, encoding and elements of procedure | 130 |
| 8 | Type 1: DLPDU-specific structure, encoding and elements of procedure..... | 139 |
| 8.1 | Establish Connection (EC) DLPDU | 141 |
| 8.2 | Disconnect Connection (DC) DLPDU | 143 |
| 8.3 | Reset Connection (RC) DLPDU | 146 |
| 8.4 | Compel Acknowledgement (CA) DLPDU | 147 |
| 8.5 | Compel Data (CD) DLPDU | 154 |
| 8.6 | Exchange Data (ED) DLPDU | 162 |
| 8.7 | Data (DT) DLPDU..... | 170 |
| 8.8 | Status Response (SR) DLPDU | 178 |
| 8.9 | Compel Time (CT) DLPDU | 181 |
| 8.10 | Time Distribution (TD) DLPDU..... | 182 |
| 8.11 | Round-Trip-Delay Query (RQ) DLPDU | 184 |
| 8.12 | Round-Trip-Delay Reply (RR) DLPDU | 186 |
| 8.13 | Probe Node DL-address (PN) DLPDU..... | 188 |
| 8.14 | Probe Response (PR) DLPDU | 191 |
| 8.15 | Pass Token (PT) DLPDU..... | 192 |
| 8.16 | Execute Sequence (ES) DLPDU | 201 |
| 8.17 | Return Token (RT) DLPDU | 208 |
| 8.18 | Request Interval (RI) DLPDU..... | 209 |
| 8.19 | Claim LAS (CL) DLPDU..... | 210 |
| 8.20 | Transfer LAS (TL) DLPDU | 212 |
| 8.21 | Wakeup (WK) DLPDU..... | 216 |
| 8.22 | Idle (IDLE) DLPDU | 217 |
| 8.23 | Spare DLPDUs | 218 |
| 8.24 | Reserved (not to be used) DLPDUs | 220 |
| 9 | Type 1: DLPDU-parameter structure and encoding | 221 |
| 9.1 | Structure and encoding of EC-PARAMETERS | 221 |
| 9.2 | Structure and encoding of DC-PARAMETERS | 226 |
| 9.3 | Structure and encoding of RC-PARAMETERS | 226 |
| 9.4 | Structure and encoding of SD-Parameters..... | 228 |
| 9.5 | Structure and encoding of SR-parameters | 235 |
| 9.6 | Structure and encoding of TD-parameters | 237 |
| 9.7 | Structure and encoding of RQ-parameters..... | 239 |
| 9.8 | Structure and encoding of RR-parameters | 240 |
| 9.9 | Structure and encoding of PN-parameters | 240 |
| 9.10 | Structure and encoding of DD-parameters | 242 |
| 10 | Type 1: DL-service elements of procedure | 243 |
| 10.1 | Operation of the DL(SAP)-address, buffer and queue management services | 243 |
| 10.2 | Operation of the connection-mode services | 247 |
| 10.3 | Operation of the connectionless-mode services..... | 288 |
| 10.4 | Operation of the scheduling guidance services | 300 |

| | | |
|-------|---|-----|
| 11 | Type 1: DL-support subprotocol | 310 |
| 11.1 | Scope | 310 |
| 11.2 | Overview of LAS operation | 310 |
| 11.3 | DL-support subprotocol definition | 311 |
| 11.4 | Elements of Procedures for receiving SPDUs | 345 |
| 12 | Type 1: Other DLE elements of procedure..... | 347 |
| 12.1 | DLE initialization | 347 |
| 12.2 | LAS behavior and operation | 351 |
| 12.3 | DL-support operation..... | 358 |
| 12.4 | DL-bridge elements of procedure and bridge sub-protocol..... | 363 |
| 12.5 | DL-management-information | 393 |
| 12.6 | Implementation profiles | 398 |
| 13 | Type 1: PICS proforma..... | 404 |
| 13.1 | Introduction | 404 |
| 13.2 | Scope..... | 404 |
| 13.3 | Normative references | 404 |
| 13.4 | Definitions | 404 |
| 13.5 | Abbreviations | 404 |
| 13.6 | Conformance..... | 405 |
| 13.7 | Instructions | 405 |
| 13.8 | Identification..... | 406 |
| 13.9 | Implementation profile | 407 |
| 13.10 | Major low-level capabilities..... | 411 |
| 13.11 | Major high-level capabilities | 425 |
| 14 | Type 2: Overview of the DL-protocol | 434 |
| 14.1 | General..... | 434 |
| 14.2 | Services provided by the DL..... | 436 |
| 14.3 | Structure and definition of DL-addresses | 437 |
| 14.4 | Services assumed from the PhL | 439 |
| 14.5 | Functional classes..... | 441 |
| 15 | Type 2: General structure and encoding of PhIDUs and DLPDUs and related elements of procedure | 442 |
| 15.1 | Overview | 442 |
| 15.2 | Media access procedure..... | 442 |
| 15.3 | DLPDU structure and encoding | 445 |
| 15.4 | Lpacket components..... | 447 |
| 15.5 | DLPDU procedures..... | 449 |
| 15.6 | Summary of DLL support services and objects | 450 |
| 16 | Type 2: Specific DLPDU structure, encoding and procedures..... | 453 |
| 16.1 | Modeling language | 453 |
| 16.2 | DLS user services | 455 |
| 16.3 | Generic Tag Lpacket | 461 |
| 16.4 | Moderator Lpacket | 461 |
| 16.5 | Time distribution Lpacket..... | 463 |
| 16.6 | UCMM Lpacket..... | 465 |
| 16.7 | Keeper UCMM Lpacket..... | 465 |
| 16.8 | TUI Lpacket..... | 466 |

| | | |
|-------|---|-----|
| 16.9 | Link parameters Lpacket and tMinus Lpacket | 467 |
| 16.10 | I'm alive Lpacket | 469 |
| 16.11 | Ping Lpackets..... | 470 |
| 16.12 | WAMI Lpacket | 472 |
| 16.13 | Debug Lpacket | 472 |
| 17 | Type 2: Objects for station management | 474 |
| 17.1 | General | 474 |
| 17.2 | ControlNet object | 475 |
| 17.3 | Keeper object..... | 485 |
| 17.4 | Scheduling object..... | 508 |
| 17.5 | TCP/IP interface object | 517 |
| 17.6 | Ethernet link object..... | 524 |
| 18 | Type 2: Other DLE elements of procedure | 529 |
| 18.1 | Network Attachment Monitor (NAM)..... | 529 |
| 18.2 | Calculating link parameters | 536 |
| 19 | Type 2: Detailed specification of DL components | 544 |
| 19.1 | General | 544 |
| 19.2 | Access Control Machine (ACM) | 544 |
| 19.3 | TxLLC..... | 561 |
| 19.4 | RxLLC..... | 565 |
| 19.5 | Transmit Machine (TxM)..... | 568 |
| 19.6 | Receive Machine (RxM)..... | 571 |
| 19.7 | Serializer..... | 577 |
| 19.8 | Deserializer | 578 |
| 19.9 | DLL management..... | 579 |
| 20 | Type 3: Overview of the DL-protocol..... | 582 |
| 20.1 | General | 582 |
| 20.2 | Overview of the medium access control and transmission protocol | 582 |
| 20.3 | Transmission modes and DL-entity..... | 583 |
| 20.4 | Service assumed from the PhL | 588 |
| 20.5 | Operational elements | 590 |
| 20.6 | Cycle and system reaction times | 605 |
| 21 | Type 3: General structure and encoding of DLPDUs, and related elements of procedure | 609 |
| 21.1 | DLPDU granularity..... | 609 |
| 21.2 | Length octet (LE, LEr) | 610 |
| 21.3 | Address octet | 610 |
| 21.4 | Control octet (FC)..... | 613 |
| 21.5 | DLPDU content error detection..... | 616 |
| 21.6 | DATA_UNIT | 617 |
| 21.7 | Error control procedures..... | 618 |
| 22 | Type 3: DLPDU-specific structure, encoding and elements of procedure..... | 619 |
| 22.1 | DLPDUs of fixed length with no data field..... | 619 |
| 22.2 | DLPDUs of fixed length with data field..... | 621 |
| 22.3 | DLPDUs with variable data field length..... | 622 |
| 22.4 | Token DLPDU | 624 |

| | | |
|------|---|-----|
| 22.5 | ASP DLPDU | 625 |
| 22.6 | SYNCH DLPDU | 625 |
| 22.7 | Time Event (TE) DLPDU | 625 |
| 22.8 | Clock Value (CV) DLPDU | 625 |
| 22.9 | Transmission procedures | 626 |
| 23 | Type 3: Other DLE elements of procedure | 629 |
| 23.1 | DL-entity initialization | 629 |
| 23.2 | States of the media access control of the DL-entity | 629 |
| 23.3 | Clock synchronization protocol | 635 |
| 24 | Type 4: Data Link Protocol Definition | 640 |
| 24.1 | Overview of the DL-protocol | 640 |
| 24.2 | General structure and encoding of PhIDUs and DLPDUs, and related elements of procedure | 651 |
| 24.3 | DLPDU-specific structure, encoding and elements of procedure | 657 |
| 24.4 | DL-service elements of procedure | 661 |
| 24.5 | Route mechanism | 664 |
| 24.6 | Link-access system | 668 |
| 24.7 | Local variables, counters and queues | 668 |
| 25 | Type 5: <placeholder for the Type 5 DL-protocol definition> | 671 |
| 26 | Type 6: Connection-oriented DL-protocol and related matters | 673 |
| 26.1 | Connection mode data transfer using TDMA principles | 673 |
| 26.2 | Bus access and data transmission | 673 |
| 26.3 | Overview of bus synchronization | 675 |
| 26.4 | Connection mode data transfer | 678 |
| 26.5 | DLM-connectionless service | 706 |
| 26.6 | Other real-time services | 720 |
| 26.7 | Bridge architecture and operation | 724 |
| 26.8 | Bus configuration | 726 |
| 26.9 | Conformance | 736 |
| 27 | Type 6: MAC elements of procedure | 738 |
| 27.1 | Procedures related to bus startup and bus operation | 738 |
| 27.2 | Medium access control (MAC) | 743 |
| 28 | Type 7: Overview of the DL-protocol | 746 |
| 28.1 | Overall description of medium allocation | 746 |
| 28.2 | Types of entities | 748 |
| 28.3 | Addressing | 751 |
| 28.4 | Flow control | 757 |
| 28.5 | Graphical representation | 759 |
| 29 | Type 7: General structure and encoding of PhIDUs and DLPDUs and related elements of procedure | 760 |
| 29.1 | DLPDU formats and components | 760 |
| 29.2 | Description of each DLPDU component | 760 |
| 29.3 | PhIDU structure and encoding | 762 |
| 29.4 | Common DLPDU structure, encoding and elements of procedure | 763 |
| 29.5 | Valid DLPDU types | 763 |
| 29.6 | DLL timers | 765 |

| | | |
|-------|---|-----|
| 30 | Type 7: DLPDU-specific structure, encoding and element of procedure..... | 771 |
| 30.1 | General | 771 |
| 30.2 | Buffer read | 771 |
| 30.3 | Buffer write..... | 771 |
| 30.4 | Buffer transfer | 771 |
| 30.5 | Specified explicit request..... | 772 |
| 30.6 | Free explicit request..... | 778 |
| 30.7 | Messaging..... | 781 |
| 30.8 | Acknowledged messaging | 786 |
| 30.9 | Numbering of acknowledged messages..... | 790 |
| 30.10 | Behavior with mismatched parameters | 792 |
| 31 | Type 7: DL-service elements of procedure, interfaces and conformance..... | 795 |
| 31.1 | General | 795 |
| 31.2 | Producer/consumer entity..... | 795 |
| 31.3 | Protocol elements by service..... | 798 |
| 31.4 | Bus arbitrator operation..... | 806 |
| 31.5 | Bridges..... | 813 |
| 31.6 | Interfaces | 820 |
| 31.7 | Conformance..... | 822 |
| 32 | Type 8: DL-protocol | 825 |
| 32.1 | Overview | 825 |
| 32.2 | DL-service Interface (DLI) | 825 |
| 32.3 | Peripherals data link (PDL)..... | 829 |
| 32.4 | Basic Link Layer (BLL)..... | 864 |
| 32.5 | Medium Access Control (MAC)..... | 880 |
| 32.6 | Peripherals network management for layer 2 (PNM2)..... | 912 |
| 32.7 | Parameters and monitoring times of the DLL..... | 920 |
| | Annex A (informative) – Types 1, 2, 3 (synchronous), 5 (first FCS), 6, 7 and 8: Exemplary FCS implementations..... | 926 |
| | Annex B (informative) – Type 1: Formal protocol finite state machines..... | 928 |
| B.1 | Basic reception and transmission FSMs | 928 |
| B.2 | FSMs for DLCs..... | 940 |
| B.3 | FSMs for scheduling..... | 946 |
| B.4 | FSMs for bridges..... | 946 |
| | Annex C (informative) – Type 1: DLPDU and DL-addressing short-form summaries..... | 947 |
| C.1 | Fields used in short-form summaries | 947 |
| C.2 | DLPDU short-form summary grouped by function | 949 |
| C.3 | DLPDU short-form summary in alphabetic order of DLPDU names | 951 |
| C.4 | DLPDU short-form summary in alphabetic order of DLPDU acronyms..... | 952 |
| C.5 | DLPDU FC code-point assignment matrix – overview and detail | 953 |
| C.6 | SD-parameters (status and data-description parameters) of CA, CD, ED and DT DLPDUs..... | 956 |
| C.7 | EC parameters of EC DLPDUs | 959 |
| C.8 | Parameters of DC and RC DLPDUs..... | 961 |
| C.9 | Parameters of TD, RQ and RR DLPDUs | 963 |
| C.10 | Parameters of PN, PT, ES and RI DLPDUs | 965 |
| C.11 | Addressing summary extracted from figures and tables of 6.3 | 967 |

| | |
|--|------|
| Annex D (informative) – Type 2: Indicators and Switches..... | 971 |
| D.1 Purpose..... | 971 |
| D.2 General indicator requirements..... | 971 |
| D.3 Common indicator requirements..... | 971 |
| D.4 Module status indicator..... | 972 |
| D.5 Network status indicators..... | 972 |
| D.6 Switches..... | 975 |
| Annex E (normative) – Type 3: DL-Protocol state machines..... | 977 |
| E.1 Overall structure..... | 977 |
| E.2 Variation of state machines in different devices..... | 979 |
| E.3 DL Data Resource..... | 979 |
| E.4 FLC / DLM..... | 984 |
| E.5 MAC..... | 1009 |
| E.6 SRU..... | 1038 |
| Annex F (informative) – Type 3: Exemplary token procedure and message transfer periods..... | 1056 |
| F.1 Procedure of token passing..... | 1056 |
| F.2 Examples for token passing procedure..... | 1057 |
| F.3 Examples for message transfer periods – asynchronous transmission..... | 1061 |
| F.4 Examples for message transfer periods – synchronous transmission..... | 1062 |
| Annex G (informative) – Type 7: Object Modeling..... | 1063 |
| G.1 Modeling of the IDENTIFIER object..... | 1063 |
| G.2 Description of the IDENTIFIER object attributes..... | 1064 |
| G.3 Modeling of the QUEUE object..... | 1068 |
| G.4 Description of the QUEUE object attributes..... | 1068 |
| G.5 Modeling of the BUFFER object..... | 1069 |
| G.6 Description of the BUFFER object attributes..... | 1069 |
| Annex H (informative) – Type 7: Topology of multi-segment DL-subnetwork..... | 1070 |
| H.1 Introduction..... | 1070 |
| H.2 Global specification..... | 1070 |
| H.3 Local specification..... | 1071 |
| H.4 Properties..... | 1071 |
| H.5 Methods..... | 1072 |
| Annex I (informative) – Type 7: Management of transmission errors..... | 1075 |
| I.1 Transmission of RP_DAT_XX..... | 1075 |
| I.2 Transmission of a free RP_RQ(1/2)..... | 1075 |
| I.3 Transmission of the specified RP_RQ1..... | 1076 |
| I.4 Transmission of RP_MSG_NOACK..... | 1077 |
| I.5 Transmission of RP_MSG_ACK..... | 1079 |
| Annex J (informative) – Type 8: Implementation possibilities of definite PNM2 functions..... | 1082 |
| J.1 Acquiring the current configuration..... | 1082 |
| J.2 Comparing the acquired and stored configurations prior to a DL-subnetwork error..... | 1085 |
| BIBLIOGRAPHY..... | 1092 |
| INDEX..... | 1094 |

| | |
|---|-----|
| Figure 1 – Relationship of IEC 61158-4 to other fieldbus layers and to users of the fieldbus Data Link service | 27 |
| Figure 2 – Relationships of DLSAPs, DLSAP-addresses and group DL-addresses | 38 |
| Figure 3 – Relationships of DLCEPs and DLCEP-addresses to DLSAPs, DLSAP-addresses and group DL-addresses | 40 |
| Figure 4 – Basic Structure of a DL-address | 98 |
| Figure 5 – Basic Structure of a Sublink Selector | 98 |
| Figure 6 – DL-address Alternative Structures | 99 |
| Figure 7 – Basic Structure of MAC-addresses | 109 |
| Figure 8 – Representation of a DL-address as a MAC-address | 109 |
| Figure 9 – Linear relationships of sending and receiving DLCEP sequence-number variables | 122 |
| Figure 10 – DL-address alternative structures | 133 |
| Figure 11 – SHORT DL-address field – alternative implicit structures | 133 |
| Figure 12 – NODE DL-address field – implicit structure | 134 |
| Figure 13 – State transition diagram for a DLCEP | 247 |
| Figure 14 – Projection of the sending and receiving DLCEP sequence-number variables of Figure 9 onto the cyclic sequence-number parameters of CA, CD, DT, ED and RC DLPDUs, with consequent determination of required actions | 264 |
| Figure 15 – State transitions of a DLE | 347 |
| Figure 16 – Bridged network topology | 364 |
| Figure 17 – Spanning tree representation | 365 |
| Figure 18 – DLSDU transit delay, DLPDU lifetime and bridge forwarding delay | 369 |
| Figure 19 – Forwarding and delivering a received DLPDU | 373 |
| Figure 20 – Forwarding a locally-originated DLPDU | 374 |
| Figure 21 – Republishing a DLSDU received from another link | 375 |
| Figure 22 – Bridge architecture | 376 |
| Figure 23 – Replacement for [IL] Fig 3-2 Bridge ports | 385 |
| Figure 24 – Replacement for [IL] Fig 3-3 Bridge architecture | 386 |
| Figure 25 – Data Link Layer internal architecture | 435 |
| Figure 26 – Basic Structure of a MAC ID address | 437 |
| Figure 27 – Basic Structure of a Generic tag address | 437 |
| Figure 28 – Basic Structure of a Fixed tag address | 438 |
| Figure 29 – M_symbols and Manchester encoding at 5 MHz (informative) | 439 |
| Figure 30 – NUT structure | 443 |
| Figure 31 – Media access during scheduled time | 443 |
| Figure 32 – Media access during unscheduled time | 444 |
| Figure 33 – DLPDU format | 445 |
| Figure 34 – Aborting a DLPDU during transmission | 446 |
| Figure 35 – Lpacket format | 447 |
| Figure 36 – Generic tag Lpacket format | 448 |
| Figure 37 – Fixed tag Lpacket format | 448 |
| Figure 38 – goodness parameter of TimeDist_Lpacket | 463 |
| Figure 39 – Example I'm alive processing algorithm | 470 |
| Figure 40 – Keeper CRC algorithm | 491 |
| Figure 41 – Keeper object power-up state diagram | 503 |

| | |
|--|-----|
| Figure 42 – Keeper object operating state diagram | 504 |
| Figure 43 – Synchronized network change processing | 507 |
| Figure 44 – State transition diagram for TCP/IP interface object | 524 |
| Figure 45 – NAM state machine | 530 |
| Figure 46 – Logical Token Passing ring | 585 |
| Figure 47 – PhL data service for asynchronous transmission | 589 |
| Figure 48 – Idle time T_{ID1} | 592 |
| Figure 49 – Idle time T_{ID2} (SDN, CS) | 592 |
| Figure 50 – Idle time T_{ID2} (MSRD) | 593 |
| Figure 51 – Slot time T_{SL1} | 593 |
| Figure 52 – Slot time T_{SL2} | 594 |
| Figure 53 – Slot time T_{SL1} | 599 |
| Figure 54 – Slot time T_{SL2} | 599 |
| Figure 55 – Token transfer period | 605 |
| Figure 56 – Message transfer period | 606 |
| Figure 57 – UART character | 609 |
| Figure 58 – Octet structure | 610 |
| Figure 59 – Length octet coding | 610 |
| Figure 60 – Address octet coding | 610 |
| Figure 61 – DAE/SAE octet in the DLPDU | 611 |
| Figure 62 – Address extension octet | 612 |
| Figure 63 – FC octet coding for send/request DLPDUs | 613 |
| Figure 64 – FC octet coding for acknowledgement or response DLPDUs | 613 |
| Figure 65 – FCS octet coding | 616 |
| Figure 66 – Data field | 617 |
| Figure 67 – Ident user data | 617 |
| Figure 68 – DLPDUs of fixed length with no data field | 619 |
| Figure 69 – DLPDUs of fixed length with no data field | 620 |
| Figure 70 – DLPDUs of fixed length with data field | 621 |
| Figure 71 – DLPDUs of fixed length with data field | 622 |
| Figure 72 – DLPDUs with variable data field length | 623 |
| Figure 73 – DLPDUs with variable data field length | 624 |
| Figure 74 – Token DLPDU | 624 |
| Figure 75 – Token DLPDU | 625 |
| Figure 76 – Send/request DLPDU of fixed length with no data | 626 |
| Figure 77 – Token DLPDU and send/request DLPDU of fixed length with data | 626 |
| Figure 78 – Send/request DLPDU with variable data field length | 627 |
| Figure 79 – Send/request DLPDU of fixed length with no data | 627 |
| Figure 80 – Token DLPDU and send/request DLPDU of fixed length with data | 628 |
| Figure 81 – Send/request DLPDU with variable data field length | 628 |
| Figure 82 – DL-state-diagram | 630 |
| Figure 83 – Overview of clock synchronization | 636 |
| Figure 84 – Time master state machine | 637 |
| Figure 85 – Time receiver state machine | 638 |
| Figure 86 – Clock synchronization | 639 |

| | |
|---|-----|
| Figure 87 – Relationship of PhE, DLE and DLS-user..... | 640 |
| Figure 88 – DLE state diagram for confirmed and unconfirmed, unacknowledged DLPDUs . | 642 |
| Figure 89 – DLE state diagram for confirmed acknowledged DLPDUs..... | 643 |
| Figure 90 – DLE state diagram for unconfirmed acknowledged DLPDUs..... | 644 |
| Figure 91 – Full duplex DLE receive state diagram..... | 645 |
| Figure 92 – Full duplex DLE transmit state diagram..... | 645 |
| Figure 93 – Link access example..... | 648 |
| Figure 94 – Simple P-NET-route format..... | 654 |
| Figure 95 – Extended P-NET-route format..... | 654 |
| Figure 96 – Complex P-NET-route format..... | 655 |
| Figure 97 – Immediate P-NET-route format..... | 655 |
| Figure 98 – Control-status format..... | 656 |
| Figure 99 – Data-field-format..... | 657 |
| Figure 100 – Source / destination designator..... | 665 |
| Figure 101 – Simple P-NET-route generation..... | 666 |
| Figure 102 – Extended P-NET-route generation..... | 666 |
| Figure 103 – Complex P-NET-route generation..... | 667 |
| Figure 104 – Simple DL-route generation..... | 667 |
| Figure 105 – Extended DL-route generation..... | 667 |
| Figure 106 – Complex DL-route generation..... | 668 |
| Figure 107 – Connection mode operation using TDMA..... | 673 |
| Figure 108 – Fundamental access concepts..... | 674 |
| Figure 109 – EXAMPLE: Architecture of a synchronizer showing one upper port bridge-DLE synchronizing multiple lower port bridge-DLEs..... | 676 |
| Figure 110 – EXAMPLE: Architecture of a forwarding bridge showing one upper port bridge-DLE synchronizing exactly one lower port bridge-DLE..... | 676 |
| Figure 111 – EXAMPLE: Lower-port bridge DLE..... | 677 |
| Figure 112 – EXAMPLE: Bridged network using forwarding bridges..... | 678 |
| Figure 113 – Operation of the SCAN channel-class and its associated primitives..... | 679 |
| Figure 114 – Operation of the ExSCAN channel-class and its associated primitives..... | 681 |
| Figure 115 – Operation of the GPA channel class and its associated primitives..... | 683 |
| Figure 116 – Data Transfer on the GPC channel-class and its associated primitives..... | 687 |
| Figure 117 – Transfer DLPDU composition on a UNITARY channel..... | 691 |
| Figure 118 – Initial-grain DLPDU composition..... | 693 |
| Figure 119 – Initial-grain header composition..... | 694 |
| Figure 120 – Middle-grain DLPDU composition..... | 695 |
| Figure 121 – Middle-grain header composition..... | 696 |
| Figure 122 – Final-grain DLPDU composition..... | 696 |
| Figure 123 – Final-grain header composition..... | 697 |
| Figure 124 – DL-status-header and DL-status DLPDU..... | 698 |
| Figure 125 – DLPDU transmission format for 1 WAY or 2 WAY transmission method..... | 704 |
| Figure 126 – EXAMPLE: Three level real network with two superimposed virtual networks . | 705 |
| Figure 127 – Operation of DLM-connectionless service and its primitives..... | 706 |
| Figure 128 – DLM-connectionless DLPDU composition and encoding..... | 708 |
| Figure 129 – Node DLMSDU composition and encoding..... | 712 |
| Figure 130 – Node-check DLMSDU composition and encoding..... | 715 |

Figure 131 – Configuration-status parameter composition..... 716

Figure 132 – DLM-connectionless DL-addresses, symbols and their relationships 717

Figure 133 – General form and encoding of DLM-connectionless DL-addresses 717

Figure 134 – Architecture of a forwarding bridge..... 724

Figure 135 – EXAMPLE: Forwarding through a bridge by slot matching 724

Figure 136 – Channel-mode composition and encoding 730

Figure 137 – Half-forwarding-port mode composition and encoding 732

Figure 138 – Configuration-status field composition 733

Figure 139 – Bus-config field composition and encoding 739

Figure 140 – General description of medium allocation 747

Figure 141 – Internal structure of a producer/consumer entity..... 748

Figure 142 – Associated buffers and queues 750

Figure 143 – Internal structure of a bus arbitrator 751

Figure 144 – Polling BA Table 751

Figure 145 – Addressing scheme 752

Figure 146 – Address partitioning 754

Figure 147 – Structure of an individual physical address..... 755

Figure 148 – Structure of an individual logical address 755

Figure 149 – Structure of restricted physical group address..... 755

Figure 150 – Structure of restricted logical group address 756

Figure 151 – Structure of a generalized group address..... 756

Figure 152 – Summary of address structure..... 757

Figure 153 – Example of an evaluation net 759

Figure 154 – Basic DLPDU structure..... 760

Figure 155 – DLPDU transmission / reception order..... 760

Figure 156 – Identifier DLPDU..... 764

Figure 157 – Variable response DLPDU..... 764

Figure 158 – Request response DLPDU..... 764

Figure 159 – Message response DLPDU..... 765

Figure 160 – Acknowledgement response DLPDU 765

Figure 161 – End of message transaction response DLPDU 765

Figure 162 – Buffer reading service interactions 771

Figure 163 – Buffer writing service interactions..... 771

Figure 164 – Buffer transfer service interactions 772

Figure 165 – Buffer transfer DLPDU sequence..... 772

Figure 166 – Interactions within the specified explicit request for buffer transfer service in the aperiodic window..... 774

Figure 167 – Interactions within the specified explicit request for buffer transfer service in the periodic window 775

Figure 168 – DLPDU sequence for an explicit request for a transfer 776

Figure 169 – Evaluation network for a buffer transfer specified explicit request with (RQ_INHIBITED = False)..... 777

Figure 170 – Evaluation network for a buffer transfer specified explicit request with (RQ_INHIBITED = True) 777

Figure 171 – Diagram of interactions within the free explicit request for buffer transfer service..... 779

Figure 172 – Evaluation network for a free explicit request 780