BRITISH STANDARD

BS EN 61158-4-3:2008

Industrial communication networks — Fieldbus specifications —

Part 4-3: Data-link layer protocol specification — Type 3 elements

ICS 25.040.40; 35.100.20

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British Standards

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National foreword

This British Standard is the UK implementation of EN 61158-4-3:2008. It is identical with IEC 61158-4-3:2007. Together with all of the other sections of BS EN 61158-4, it supersedes BS EN 61158-4:2004 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee AMT/7, Industrial communications — Process measurement and control, including Fieldbus.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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February 2008

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English version

Industrial communication networks - Fieldbus specifications - Part 4-3: Data-link layer protocol specification - Type 3 elements

(IEC 61158-4-3:2007)

Réseaux de communication industriels - Spécifications des bus de terrain - Partie 4-3: Spécification des protocoles des couches de liaison de données - Eléments de type 3 (CEI 61158-4-3:2007)

Industrielle Kommunikationsnetze - Feldbusse - Teil 4-3: Protokollspezifikation des Data Link Layer (Sicherungsschicht) - Typ 3-Elemente (IEC 61158-4-3:2007)

This European Standard was approved by CENELEC on 2008-02-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

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Foreword

The text of document 65C/474/FDIS, future edition 1 of IEC 61158-4-3, prepared by SC 65C, Industrial networks, of IEC TC 65, Industrial-process measurement, control and automation, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61158-4-3 on 2008-02-01.

This and the other parts of the EN 61158-4 series supersede EN 61158-4:2004.

With respect to EN 61158-4:2004 the following changes were made:

– deletion of Type 6 fieldbus, and the placeholder for a Type 5 fieldbus data-link layer, for lack of market relevance;

– addition of new fieldbus types;

– partition into multiple parts numbered 4-1, 4-2, …, 4-19.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2008-11-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2011-02-01

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 EN 61784 series. Use of the various protocol types in other combinations may require permission from their respective intellectual-property-right holders.

IEC and CENELEC draw attention to the fact that it is claimed that compliance with this standard may involve the use of patents as follows, where the [xx] notation indicates the holder of the patent right:

Type 3 and possibly other types:

DE 36 43 979 C2	[SI]	Deterministisches Zugriffsverfahren nach dem Tokenprinzip für eine Datenübertragung
DE 36 43 979 A1	[SI]	Deterministisches Zugriffsverfahren nach dem Tokenprinzip für eine Datenübertragung

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

The holders of these patent rights have assured IEC that they are willing to negotiate licences 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 are registered with IEC. Information may be obtained from:

[SI]: SIEMENS AG
Ludwig Winkel
Siemensallee 84
D-76181 Karlsruhe
Germany

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

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61158-4-3:2007 was approved by CENELEC as a European Standard without any modification.

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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/TR 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.

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Part 4-3: Data-link layer protocol specification – Type 3 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 a pre-selected “master” subset of data-link entities in a cyclic asynchronous manner, sequentially to each of those data-link entities. Other data-link entities communicate only as permitted and delegated by those master data-link entities.

For a given master, its communications with other data-link entities can be cyclic, or acyclic with prioritized access, or a combination of the two.

This protocol provides a means of sharing the available communication resources in a fair manner. There are provisions for time synchronization and for isochronous operation.

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 data-link service provider;

b) 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.

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

IEC 61158-2 (Ed.4.0), *Digital data communications for measurement and control – Fieldbus for use in industrial control systems – Part 2: Physical layer specification and service definition*

IEC 61158-3-3, *Digital data communications for measurement and control – Fieldbus for use in industrial control systems – Part 3-3: Data link service definition – Type 3 elements*

ISO/IEC 2022, *Information technology – Character code structure and extension techniques*

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

ISO 1177, *Information processing – Character structure for start/stop and synchronous character oriented transmission*

3 Terms, definitions, symbols and abbreviations

For the purposes of this standard, the following terms, definitions, symbols and abbreviations 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 called-DL-address [7498-3]

3.1.2 calling-DL-address [7498-3]

3.1.3 centralized multi-end-point-connection [7498-1]

3.1.4 correspondent (N)-entities [7498-1]
correspondent DL-entities (N=2)
correspondent Ph-entities (N=1)

3.1.5 demultiplexing [7498-1]

3.1.6 DL-address [7498-3]

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3.1.7 DL-address-mapping [7498-1]

3.1.8 DL-connection [7498-1]

3.1.9 DL-connection-end-point [7498-1]

3.1.10 DL-connection-end-point-identifier [7498-1]

3.1.11 DL-connection-mode transmission [7498-1]

3.1.12 DL-connectionless-mode transmission [7498-1]

3.1.13 DL-data-sink [7498-1]

3.1.14 DL-data-source [7498-1]

3.1.15 DL-duplex-transmission [7498-1]

3.1.16 DL-facility [7498-1]

3.1.17 DL-local-view [7498-3]

3.1.18 DL-name [7498-3]

3.1.19 DL-protocol [7498-1]

3.1.20 DL-protocol-connection-identifier [7498-1]

3.1.21 DL-protocol-control-information [7498-1]

3.1.22 DL-protocol-data-unit [7498-1]

3.1.23 DL-protocol-version-identifier [7498-1]

3.1.24 DL-relay [7498-1]

3.1.25 DL-service-connection-identifier [7498-1]

3.1.26 DL-service-data-unit [7498-1]

3.1.27 DL-simplex-transmission [7498-1]

3.1.28 DL-subsystem [7498-1]

3.1.29 DL-user-data [7498-1]

3.1.30 flow control [7498-1]

3.1.31 layer-management [7498-1]

3.1.32 multiplexing [7498-3]

3.1.33 naming-(addressing)-authority [7498-3]

3.1.34 naming-(addressing)-domain [7498-3]

3.1.35 naming-(addressing)-subdomain [7498-3]

3.1.36 (N)-entity [7498-1]
DL-entity
Ph-entity

3.1.37 (N)-interface-data-unit [7498-1]
DL-service-data-unit (N=2)
Ph-interface-data-unit (N=1)

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3.1.38 (N)-layer [7498-1]
DL-layer (N=2)
Ph-layer (N=1)

3.1.39 (N)-service [7498-1]
DL-service (N=2)
Ph-service (N=1)

3.1.40 (N)-service-access-point [7498-1]
DL-service-access-point (N=2)
Ph-service-access-point (N=1)

3.1.41 (N)-service-access-point-address [7498-1]
DL-service-access-point-address (N=2)
Ph-service-access-point-address (N=1)

3.1.42 peer-entities [7498-1]

3.1.43 Ph-interface-control-information [7498-1]

3.1.44 Ph-interface-data [7498-1]

3.1.45 primitive name [7498-3]

3.1.46 reassembling [7498-1]

3.1.47 recombining [7498-1]

3.1.48 reset [7498-1]

3.1.49 responding-DL-address [7498-3]

3.1.50 routing [7498-1]

3.1.51 segmenting [7498-1]

3.1.52 sequencing [7498-1]

3.1.53 splitting [7498-1]

3.1.54 synonymous name [7498-3]

3.1.55 systems-management [7498-1]

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 acceptor

3.2.2 asymmetrical service

3.2.3 confirm (primitive);
requestor.deliver (primitive)

3.2.4 deliver (primitive)

3.2.5 DL-confirmed-facility

3.2.6 DL-facility

3.2.7 DL-local-view

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3.2.8 DL-mandatory-facility

3.2.9 DL-non-confirmed-facility

3.2.10 DL-provider-initiated-facility

3.2.11 DL-provider-optional-facility

3.2.12 DL-service-primitive; primitive

3.2.13 DL-service-provider

3.2.14 DL-service-user

3.2.15 DL-user-optional-facility

3.2.16 indication (primitive) acceptor.deliver (primitive)

3.2.17 multi-peer

3.2.18 request (primitive); requestor.submit (primitive)

3.2.19 requestor

3.2.20 response (primitive); acceptor.submit (primitive)

3.2.21 submit (primitive)

3.2.22 symmetrical service

3.3 Common terms and definitions

NOTE Many definitions are common to more than one protocol Type; they are not necessarily used by all protocol Types.

3.3.1
DL-segment, link, local link
single DL-subnetwork in which any of the connected DLEs may communicate directly, without any intervening DL-relaying, whenever all of those DLEs that are participating in an instance of communication are simultaneously attentive to the DL-subnetwork during the period(s) of attempted communication

3.3.2
DLSAP
distinctive point at which DL-services are provided by a single DL-entity to a single higher-layer entity

NOTE This definition, derived from ISO/IEC 7498-1, is repeated here to facilitate understanding of the critical distinction between DLSAPs and their DL-addresses. (See Figure 1.)

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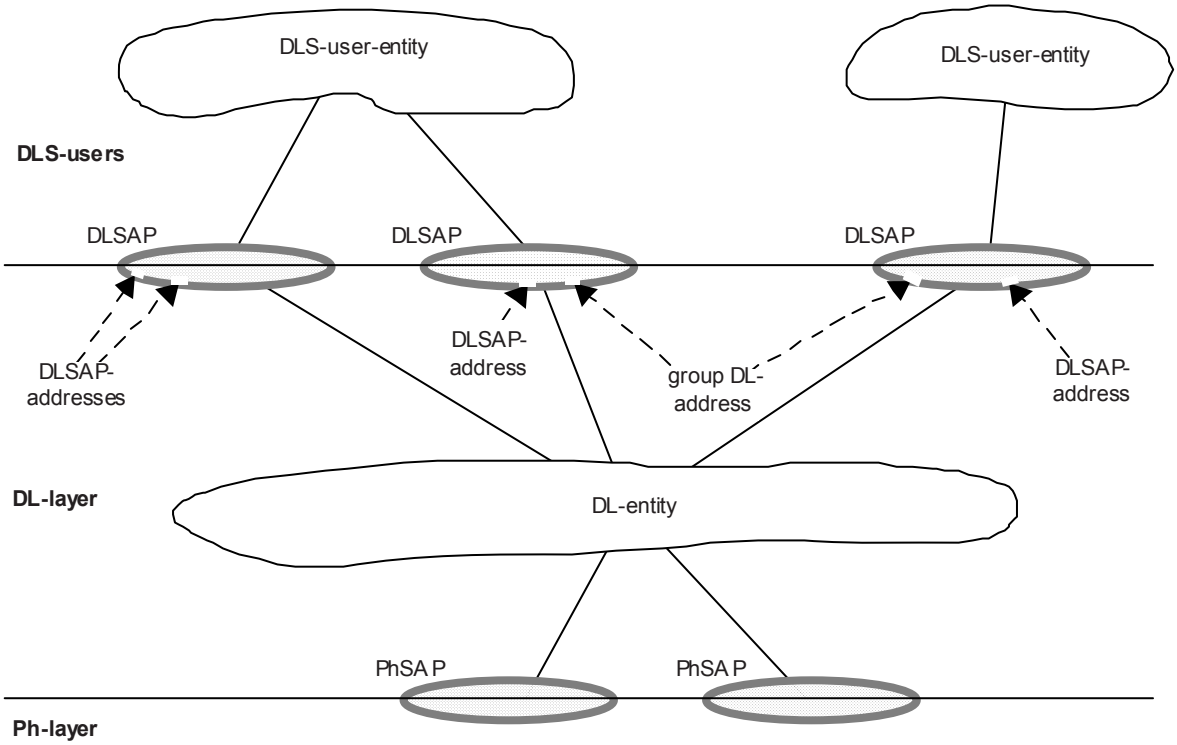

NOTE 1 DLSAPs and PhSAPs are depicted as ovals spanning the boundary between two adjacent layers.

NOTE 2 DL-addresses are depicted as designating small gaps (points of access) in the DLL portion of a DLSAP.

NOTE 3 A single DL-entity may have multiple DLSAP-addresses and group DL-addresses associated with a single DLSAP.

Figure 1 – Relationships of DLSAPs, DLSAP-addresses and group DL-addresses

3.3.3
DL(SAP)-address
either an individual DLSAP-address, designating a single DLSAP of a single DLS-user, or a group DL-address potentially designating multiple DLSAPs, each of a single DLS-user.

NOTE This terminology is chosen because ISO/IEC 7498-3 does not permit the use of the term DLSAP-address to designate more than a single DLSAP at a single DLS-user

3.3.4
(individual) DLSAP-address
DL-address that designates only one DLSAP within the extended link

NOTE A single DL-entity may have multiple DLSAP-addresses associated with a single DLSAP.

3.3.5
extended link
DL-subnetwork, consisting of the maximal set of links interconnected by DL-relays, sharing a single DL-name (DL-address) space, in which any of the connected DL-entities may communicate, one with another, either directly or with the assistance of one or more of those intervening DL-relay entities

NOTE An extended link may be composed of just a single link.

3.3.6
frame
denigrated synonym for DLPDU

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3.3.7
group DL-address
DL-address that potentially designates more than one DLSAP within the extended link. A single DL-entity may have multiple group DL-addresses associated with a single DLSAP. A single DL-entity also may have a single group DL-address associated with more than one DLSAP

3.3.8
node
single DL-entity as it appears on one local link

3.3.9
receiving DLS-user
DL-service user that acts as a recipient of DL-user-data

NOTE A DL-service user can be concurrently both a sending and receiving DLS-user.

3.3.10
sending DLS-user
DL-service user that acts as a source of DL-user-data

3.4 Additional Type 3 definitions

3.4.1
acknowledge DLPDU
reply DLPDU that contains no DLSDU

3.4.2
address extension
DLSAP address or region/segment address

3.4.3
bit time
time to transmit one bit

3.4.4
confirmed message exchange
complete data transfer with request and acknowledgement or response DLPDU

3.4.5
controller_type
hardware class of the communications entity

3.4.6
current master
token holder

3.4.7
data DLPDU
DLPDU that carries a DLSDU from a local DLS-user to a remote DLS-user

3.4.8
DL_status
status that specifies the result of the execution of the associated request

3.4.9
GAP
range of station (DLE) DL-addresses from this station (TS) to its successor (NS) in the logical token ring, excluding stations above HSA

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3.4.10
GAP maintenance
registration of new Master and slave stations

3.4.11
isochronous mode
special operational mode that implies both a constant (isochronous) cycle with a fixed schedule of high and low priority messages, and the synchronization of the DLS-users with this constant (isochronous) cycle

3.4.12
local DLS-user
DLS-user that initiates the current service

3.4.13
message exchange
complete confirmed or unconfirmed data transfer

3.4.14
region/segment address
address extension that identifies a particular fieldbus subnetwork

NOTE This supports DL-routing between fieldbusses.

3.4.15
request data
DLSDU provided by the remote DLS-user to the local DLS-user

3.4.16
remote DLE
addressed DLE of a service request (that is, the intended receiving DLE of any resulting send/request DLPDU)

3.4.17
remote DLS-user
addressed DLS-user of a service request (that is, the intended receiver of any resulting indication primitive)

3.4.18
reply DLPDU
DLPDU transmitted from a remote DLE to the initiating (local) DLE, and possibly other DLEs

NOTE When the remote DLE is a Publisher, the reply DLPDU also can be sent to several remote DLEs.

3.4.19
response DLPDU
reply DLPDU that carries a DLSDU from a remote DLS-user to local DLS-user

3.4.20
send data
DLSDU provided by a local DLS-user to a remote DLS-user

3.4.21
send/request DLPDU
DLPDU that carries either a request for data or a DLSDU or both from a local DLS-user to a remote DLS-user

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3.4.22
time master
device which is able to send clock synchronization DLPDUs

NOTE Link devices have time master functionality.

3.4.23
time receiver
device which is able to be time synchronized by a time Master

3.4.24
token holder
Master station that controls bus access

3.4.25
token passing
medium access method, in which the right to transmit is passed from master station to master station in a logical ring

3.5 Common symbols and abbreviations

3.5.1 Data units

3.5.1.1	**DLPDU**	DL-protocol data unit
3.5.1.2	**DLSDU**	DL-service data unit
3.5.1.3	**PhIDU**	Ph-interface data unit
3.5.1.4	**PhPDU**	Ph-protocol data unit

3.5.2 Miscellaneous

3.5.2.1	**DL-**	data link layer (as a prefix)
3.5.2.2	**DLCEP**	DL-connection endpoint
3.5.2.3	**DLE**	DL-entity (the local active instance of the Data Link layer)
3.5.2.4	**DLL**	DL-layer
3.5.2.5	**DLM-**	DL-management (as a prefix)
3.5.2.6	**DLMS**	DL-management-service
3.5.2.7	**DLS**	DL-service
3.5.2.8	**DLSAP**	DL-service access point
3.5.2.9	**FIFO**	first-in first-out (queuing method)
3.5.2.10	**LLC**	logical link control
3.5.2.11	**MAC**	medium access control
3.5.2.12	**OSI**	open systems interconnection
3.5.2.13	**Ph-**	physical layer (as a prefix)
3.5.2.14	**PhE**	Ph-entity (the local active instance of the Physical layer)
3.5.2.15	**PhL**	Ph-layer

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3.5.2.16 PhS Ph-service

3.5.2.17 PhSAP Ph-service access point

3.5.2.18 QoS quality of service

3.6 Type 3 symbols and abbreviations

3.6.1 ACK acknowledge(ment) DLPDU

3.6.2 ASM active spare time message

3.6.3 ASP active spare time period

3.6.4 Bus ID bus identification, an address extension (region/DL-segment address) that identifies a particular bus as supporting routing between DL-segments

3.6.5 CRX character receive execution

3.6.6 CS clock synchronization

3.6.7 CTX character transmit execution

3.6.8 DA destination address of a DLPDU

3.6.9 DAE destination address extension(s) of a DLPDU, which convey D_SAP_index and/or destination bus ID

3.6.10 D_SAP destination service access point, the DLSAP associated with the remote DLS-user

3.6.11 D_SAP_index destination service access point index – that component of a DLSAP address which designates a DLSAP and remote DLS-user within the remote DLE

3.6.12 DXM data exchange multicast

3.6.13 ED end delimiter of a DLPDU

3.6.14 EOA END-OF-ACTIVITY

3.6.15 EOD END-OF-DATA

3.6.16 EODA END-OF-DATA-AND-ACTIVITY

3.6.17 EXT address extension bit of a DLPDU

3.6.18 FC frame control (frame type) field of a DLPDU

3.6.19 FCB frame count bit of a DLPDU (FC field) used to eliminate lost or duplicated DLPDUs

3.6.20 FCV frame count bit valid bit of a DLPDU, indicates whether the FCB is to be evaluated

3.6.21 FCS frame check sequence (synchronous) or frame checksum (asynchronous)

3.6.22 FLC fieldbus link control

3.6.23 G GAP update factor, the number of token rotations between GAP maintenance (update) cycles

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3.6.24 GAPL	GAP list containing the status of all stations in this station's GAP
3.6.25 IsoM	isochronous mode
3.6.26 Hd	Hamming distance, a measure of DLPDU integrity, the minimum number of bit errors that can cause acceptance of a spurious DLPDU
3.6.27 HSA	highest station address installed (configured) on this fieldbus
3.6.28 L	length of the information field, the part of a DLPDU that is checked by the FCS
3.6.29 LE	field giving the length of a DLPDU beyond the fixed part
3.6.30 LEr	field that repeats the length to increase DLPDU integrity
3.6.31 LMS	list of master stations
3.6.32 LR	local resource not available or not sufficient (DL/DLM_status of the service primitive)
3.6.33 LS	local service not activated at DL-service access point or local DLSAP not activated (DL/DLM_status of the service primitive)
3.6.34 lsb	least significant bit of a field or octet
3.6.35 max	the arithmetic maximum function
3.6.36 MCT	multicast
3.6.37 MP	message transfer message retry transfer periods
3.6.38 mr	number of retries
3.6.39 msb	most significant bit of a field or octet
3.6.40 MSRD	DLS: Send and Request Data with Multicast reply
3.6.41 mt	number of retries per token rotation
3.6.42 n	number of stations
3.6.43 NA	no acknowledgement/response (DL/DLM_status of the service primitive)
3.6.44 na	number of active stations
3.6.45 NIL	locally determined value
3.6.46 NO	not ok (DL/DLM_status of the service primitive)
3.6.47 np	number of passive stations
3.6.48 NR	no response DL-data acknowledgement negative and send data ok (DL_status of the service primitive)
3.6.49 NRZ	non-return-to-zero (PhL), an encoding technique where transitions occur only when successive data bits have different values
3.6.50 NS	next station, the station to which this master will pass the token

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3.6.51 OK service finished according to the rules (DL/DLM_status of the service primitive)

3.6.52 PhICI PhL Interface Control Information [ISO/IEC 7498-1]

3.6.53 PhPCI PhL Protocol Control Information [ISO/IEC 7498-1]

3.6.54 PON power on transition occurs at a station

3.6.55 PS previous station, the station which passes the token to this master station

3.6.56 PSP passive spare time period

3.6.57 RDH response DL-data high and no resource for send data (DL/DLM_status of the service primitive)

3.6.58 RDL response DL/DLM-data low and no resource for send data (DL/DLM_status of the service primitive)

3.6.59 Res reserved

3.6.60 RET retry

3.6.61 RR no resource for send data and no response DL-data available (negative acknowledgement) (DL/DLM_status of the service primitive)

3.6.62 RS no service, or no service activated at remote DLSAP (negative acknowledgement) (DL/DLM_status of the service primitive)

3.6.63 RSYS system message rate (in message transfer periods per second) at which confirmed DL-message exchanges are performed

3.6.64 SA source address of a DLPDU

3.6.65 SAE source address extension(s) of a DLPDU, which convey S_SAP_index and/or source bus ID

3.6.66 SC single character acknowledge DLPDU

3.6.67 SD1 to SD4 start delimiters of asynchronous DLPDU transmission

3.6.68 SDA Send Data with Acknowledge (DL-service)

3.6.69 SDA_H/L Send Data with Acknowledge high/low (DLPDU Function)

3.6.70 SDX start delimiter of asynchronous or synchronous DLPDU transmission

3.6.71 SDL1 to SDL5 start delimiters of synchronous DLPDU transmission

3.6.72 SDN Send Data with No Acknowledge (DL-service)

3.6.73 SDN_H/L Send Data with No Acknowledge high/low (DLPDU Function)

3.6.74 SM state machine

3.6.75 SOA START-OF-ACTIVITY

3.6.76 SRC send receive control

3.6.77 SRD Send and Request Data with Reply (DL-service)

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3.6.78 SRD_H/L Send and Request Data with Reply high/low (DLPDU Function)

3.6.79 SRU send receive unit

3.6.80 S_SAP source service access point, the DLSAP associated with the initiating local DLS-user

3.6.81 S_SAP_index source service access point index — a component of a DLSAP-address which designates that DLSAP within the DLE at which the transaction is being initiated

3.6.82 Stn station, a device implementing a DLE with a fieldbus DL-address

3.6.83 SYN synchronizing bits of a DLPDU (period of idle), which guarantees the specified DLPDU integrity and allows for receiver synchronization

3.6.84 TA/R time to transmit an acknowledgement/response DLPDU

3.6.85 TASM ASM message time

3.6.86 t_{BIT} bit time

3.6.87 TCSI clock synchronization interval time

3.6.88 T_{CT} isochronous cycle time

3.6.89 TGUD GAP update time

3.6.90 T_{ID} idle time

3.6.91 TIM timer state machine

3.6.92 T_{MP} message transfer period

3.6.93 TP token transfer period

3.6.94 TPSP passive spare time

3.6.95 TPTG post transmission gap time

3.6.96 TQUI quiet time

3.6.97 TRCT real isochronous cycle time

3.6.98 T_{RD} receive delay time

3.6.99 TRDY ready time

3.6.100 TRES spare time

3.6.101 T_{RR} real rotation time

3.6.102 TS this station

3.6.103 TS/R send/request DLPDU time

3.6.104 T_{SD} send delay time

3.6.105 TSDI station delay of initiator

3.6.106 TSDR station delay of responder

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3.6.107 TSET setup time

3.6.108 T_{SH} time shift

3.6.109 T_{SL} slot time

3.6.110 T_{SM} safety margin time

3.6.111 T_{SR} system reaction time

3.6.112 TSYN synchronization time

3.6.113 TSYNI synchronization interval time

3.6.114 T_{TC} token cycle time

3.6.115 T_{TD} transmission delay time

3.6.116 T_{TF} token DLPDU time

3.6.117 T_{TH} token holding time

3.6.118 T_{TO} timeout time

3.6.119 T_{TP} token transfer period

3.6.120 T_{TR} target rotation time

3.6.121 UART universal asynchronous receiver/transmitter

3.6.122 UC UART character

3.6.123 UE negative acknowledgement, remote user interface error (DL/DLM_status of the service primitive)

4 Common DL-protocol elements

4.1 Frame check sequence

4.1.1 General

Any reference to bit *K* of an octet is a reference to the bit whose weight in a one-octet unsigned integer is 2^K.

NOTE 1 This is sometimes referred to as “little endian” bit numbering.

As in other International Standards (see Note 2), DLPDU-level error detection is provided by calculating and appending a multi-bit frame check sequence (FCS) to the other DLPDU fields during transmission to form a "systematic code word"[1] of length ***n*** consisting of ***k*** DLPDU message bits followed by ***n - k*** redundant bits, and by calculating during reception that the message and concatenated FCS form a legal (*n*,*k*) code word. The mechanism for this checking is as follows:

NOTE 2 For example, ISO/IEC 3309, ISO/IEC 8802 and ISO/IEC 9314-2.

The generic form of the generator polynomial for this FCS construction is specified in equation (4) and the polynomial for the receiver’s expected residue is specified in equation

[1] W. W. Peterson and E. J. Weldon, Jr., *Error Correcting Codes* (2nd edition), MIT Press, Cambridge, 1972.

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(9). The specific polynomials for DL-protocol type 3 are specified in Table 1. An exemplary implementation is shown in Annex B.

Table 1 – FCS length, polynomials and constants by Type 3 synchronous

Item	Value
n-k	16
G(x)	$X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^6 + X^3 + X^2 + X + 1$ (see Notes 1, 2, 3)
R(x)	$X^{15} + X^{14} + X^{13} + X^9 + X^8 + X^7 + X^4 + X^2$ (see Note 4)

NOTE 1 Code words D(X) constructed from this G(X) polynomial have Hamming distance 4 for lengths ≤ 344 octets and Hamming distance 5 for lengths ≤ 15 octets.

NOTE 2 This G(X) polynomial is relatively prime to all, and is thus not compromised by any, of the polynomials commonly used in DCEs (modems): the differential encoding polynomial $1 + X^{-1}$ and all primitive scrambling polynomials of the form $1 + X^{-j} + X^{-k}$.

NOTE 3 This G(X) polynomial is the optimal 16-bit polynomial for burst error detection over DLPDUs of 300 octets or less when the statistics of the error burst have a Poisson distribution (as is the usual case).

NOTE 4 The remainder R(x) should be 1110 0011 1001 0100 (X^{15} to X^0, respectively) in the absence of errors.

4.1.2 At the sending DLE

The original message (that is, the DLPDU without an FCS), the FCS, and the composite message code word (the concatenated DLPDU and FCS) shall be regarded as vectors M(X), F(X), and D(X), of dimension *k*, *n* - *k*, and *n*, respectively, in an extension field over Base Galois Field(2). If the message bits are $m_1 \ldots m_k$ and the FCS bits are $f_{n-k-1} \ldots f_0$, where

$m_1 \ldots m_8$	form the first octet sent,
$m_{8N-7} \ldots m_{8N}$	form the *N*th octet sent,
$f_7 \ldots f_0$	form the last octet sent, and
m_1	is sent by the first PhL symbol(s) of the message and f_0 is sent by the last PhL symbol(s) of the message (not counting PhL framing information),

NOTE 1 This “as transmitted” ordering is critical to the error detection properties of the FCS.

then the message vector M(X) shall be regarded to be

$$M(X) = m_1X^{k-1} + m_2X^{k-2} + \ldots + m_{k-1}X^1 + m_k \quad (1)$$

and the FCS vector F(X) shall be regarded to be

$$F(X) = f_{n-k-1}X^{n-k-1} + \ldots + f_0 \quad (2)$$
$$= f_{15}X^{15} + \ldots + f_0$$

The composite vector D(X), for the complete DLPDU, shall be constructed as the concatenation of the message and FCS vectors

$$D(X) = M(X)\,X^{n-k} + F(X) \quad (3)$$
$$= m_1X^{n-1} + m_2X^{n-2} + \ldots + m_kX^{n-k} + f_{n-k-1}X^{n-k-1} + \ldots + f_0$$
$$= m_1X^{n-1} + m_2X^{n-2} + \ldots + m_kX^{16} + f_{15}X^{15} + \ldots + f_0$$

The DLPDU presented to the PhL shall consist of an octet sequence in the specified order.

The redundant check bits $f_{n-k-1} \ldots f_0$ of the FCS shall be the coefficients of the remainder F(X), after division by G(X), of $L(X)\,(X^k + 1) + M(X)\,X^{n-k}$

where G(X) is the degree *n-k* generator polynomial for the code words

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$$G(X) = X^{n-k} + g_{n-k-1}X^{n-k-1} + \ldots + 1 \quad (4)$$
$$= X^{16} + X^{12} + X^{11} + X^{10} + X^{8} + X^{6} + X^{3} + X^{2} + X + 1$$

and L(X) is the maximal weight (all ones) polynomial of degree *n-k-1*

$$L(X) = \frac{X^{n-k} + 1}{X + 1} = X^{n-k-1} + X^{n-k-2} + \ldots + X + 1 \quad (5)$$
$$= X^{15} + X^{14} + X^{13} + X^{12} + \ldots + X^{2} + X + 1$$

That is,

$$F(X) = L(X)\,(X^{k} + 1) + M(X)\,X^{n-k} \ \ (\text{modulo } G(X)) \quad (6)$$

NOTE 2 The L(X) terms are included in the computation to detect initial or terminal message truncation or extension by adding a length-dependent factor to the FCS.

NOTE 3 As a typical implementation when n-k = 16, the initial remainder of the division is preset to all ones. The transmitted message bit stream is multiplied by X^{n-k} and divided (modulo 2) by the generator polynomial G(X), specified in equation (4). The ones complement of the resulting remainder is transmitted as the (n-k)-bit FCS, with the coefficient of X^{n-k-1} transmitted first.

4.1.3 At the receiving DLE

The octet sequence indicated by the PhE shall be concatenated into the received DLPDU and FCS, and regarded as a vector V(X) of dimension ***u***

$$V(X) = v_1X^{u-1} + v_2X^{u-2} + \ldots + v_{u-1}X + v_u \quad (7)$$

NOTE 1 Because of errors **u** can be different than **n**, the dimension of the transmitted code vector.

A remainder R(X) shall be computed for V(X), the received DLPDU and FCS, by a method similar to that used by the sending DLE (see 4.1.2) in computing F(X)

$$R(X) = L(X)\,X^{u} + V(X)\,X^{n-k} \ \ (\text{modulo } G(X)) \quad (8)$$
$$= r_{n-k-1}X^{n-k-1} + \ldots + r_0$$

Define E(X) to be the error code vector of the additive (modulo-2) differences between the transmitted code vector D(X) and the received vector V(X) resulting from errors encountered (in the PhS provider and in bridges) between sending and receiving DLEs.

$$E(X) = D(X) + V(X) \quad (9)$$

If no error has occurred, so that E(X) = 0, then R(X) will equal a non-zero constant remainder polynomial

$$R_{ok}(X) = L(X)\,X^{n-k} \ \ (\text{modulo } G(X)) \quad (10)$$

whose value is independent of D(X). Unfortunately R(X) will also equal $R_{ok}(X)$ in those cases where E(X) is an exact non-zero multiple of G(X), in which case there are “undetectable” errors. In all other cases, R(X) will not equal $R_{ok}(X)$; such DLPDUs are erroneous and shall be discarded without further analysis.

NOTE 2 As a typical implementation, the initial remainder of the division is preset to all ones. The received bit stream is multiplied by X^{n-k} and divided (modulo 2) by the generator polynomial G(X), specified in equation (4).

5 Overview of the DL-protocol

NOTE Annex A specifies a number of finite state machines used by the DLE to provide its low-level and high-level protocol functions. The specification of Annex A is complementary to the textual specification in this and related clauses in the body of this standard. In case of conflict the requirements of Annex A take precedence.

5.1 General

From the requirements of the various application fields, for example, process control, factory automation, power distribution, building automation, primary process industry etc., the following characteristic features of the fieldbus data-link protocol are resulting (see Table 2).

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Table 2 – Characteristic features of the fieldbus data-link protocol

Feature	Description
Station types	Masters (active stations, with bus access control); Slaves (passive stations, without bus access control); preferably at most 32 masters, optionally up to 127, if the applications are not time critical
Station addressing	0 to 127 (127 = global addresses for broad-cast and multicast messages), address extension for region/DL-segment address and service access address (DLSAP), 6 bit each
Bus access	Hybrid: decentralized and central; "token-passing" between master stations and "Master-Slave" between Master and slave stations
Data transfer services	Send Data with/without Acknowledge Send and Request Data with Reply Send and Request Data with Multicast Reply Clock Synchronization
DLPDU length	max. 255 octets per DLPDU, 0 to 246 octets for each data unit without address extension
Transmission speed	Depending on network topology and cable lengths, for example, step-wise from 9,6 to 12000 kBit/s
Transmission characteristic	Half duplex, asynchronous and synchronous transmission
Data integrity asynchronous transmission	Messages with Hamming distance (Hd) = 4, sync slip detection, special sequence to avoid loss or duplication of data
Data integrity synchronous transmission	Hamming distance (Hd) = 4 for DLPDU lengths shorter than 255 octets and Hd = 5 for lengths shorter than 15 octets, special sequence to avoid loss or duplication of data

NOTE 1 The DLPDU format for asynchronous transmission is the format FT 1.2 (asynchronous transmission with start-stop synchronization) for Telecontrol Equipment and Systems, which is specified in IEC 60870-5-1.

NOTE 2 The DLPDU format for synchronous transmission is based on octet characters.

5.2 Overview of the medium access control and transmission protocol

The fieldbus data-link layer uses controlled medium access accomplished by a hybrid medium access method: a decentralized method according to the principle of **token-passing** is underlain by a central method according to the **master-slave** principle. Medium access control may be exercised by each master station (active station). The token-passing is characterized by the following features:

a) Token-passing allows fair media access for all token holders.

EXAMPLE: When four token holders produce the same amount of similar priority data they will share the media so that on average each of them can use 25% of the available message transfer time. With the token-passing procedure, rules exist to share the message transfer time between the token holders without discrimination of any of them. In case of usage of the whole of the available token holding time by one token holder in one token rotation this token holder is limited to one high priority message in the next token rotation after which it has to transfer the token immediately.

b) Token-passing guarantees short reaction time.

EXAMPLE: For urgent messages, a maximum delay is specified for delivery of the information. Thus, a configurable time (T_{TR}) specifies the target rotation time. Independent of the number of token holders and the amount of messages that have to be sent, at least one urgent message can be sent by each token holder. Thus, a short reaction time is guaranteed for one urgent message from each token holding station in each token holding period.

c) Token-passing allows flexible (re-)configuration.

EXAMPLE: When a token holder is switched on or off, it will be automatically included or excluded in the logical ring. In the next token rotation after detection and inclusion in the logical token ring, the new token holder has the same rights to send messages as the other token holders. The sharing of the bus message transfer time is organized automatically without changing of parameters of the other token holders.

Medium access control may be exercised by each master station (active station) if the station has the token. The token is passed from master station to master station in a logical ring and

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thus determines the instant, when a master station may access the medium. Controlled token passing is managed by each station knowing its predecessor (previous station, PS), the station from which it receives the token. Furthermore, each station knows its successor (next station, NS), that is, the station to which the token is transmitted, and its own address (This station, TS). Each master station determines the PS and NS addresses after the initialization of the operating parameters for the first time and then later dynamically according to the algorithm described in 5.3.2.4.

The Master-Slave principle is characterized by the following features:

Communication is always initiated by a master station which has the permission for medium access, the token. slave stations (passive stations) act neutrally in respect to medium access, that is, they do not transmit independently but only on request. If the logical ring consists of only one Master and several slave stations then it is a pure Master-Slave system.

The following error conditions, exceptions and operational states in the system are dealt with:

— multiple tokens,
— lost token,
— error in token passing,
— duplicate station addresses,
— stations with faulty transmitter or receiver,
— adding and removing stations during operation,
— any combinations of master and slave stations.

5.3 Transmission modes and DL-entity

5.3.1 Overview

The exchange of messages takes place confirmed or unconfirmed. A confirmed message exchange consists of a master station's send/request DLPDU and the associated acknowledgement or response DLPDU of a Master or a slave station. User data may be transmitted in the send/request DLPDU as well as in the response DLPDU. The acknowledgement DLPDU does not contain any user data (for DLPDU formats see clause 7).

An unconfirmed message exchange takes place only in case of token transmission and in case of the transmission of data without acknowledgement (for example, necessary for broadcast messages). In both modes of operation, there is no acknowledgement. In broadcast messages a master station (initiator) addresses all other stations at the same time by means of a global address (highest station address, all address bits are binary "1").

All stations except the respective token holder (initiator) shall in general monitor all requests. The stations acknowledge or respond only when they are addressed. The acknowledgement or response shall arrive within a predefined time, the slot time, otherwise the initiator repeats, depending on the predefined retry limit, the request if it is not a "first request" (see 6.4, FCB). A new request or a token shall not be issued by the initiator before the expiration of a waiting period after receiving an acknowledge or response, the idle time (see 5.5).

If the responder does not acknowledge or respond after a predefined number of retries (see Table 5), it is marked as "non-operational". If a responder is "non-operational", a later unsuccessful request will not be repeated.

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The modes of transmission operation define the sequence of the message transfer periods. Three modes are distinguished

1) Token handling.

2) Send operation.

3) Send and request operation.

5.3.2 Token procedures

5.3.2.1 Token circulation

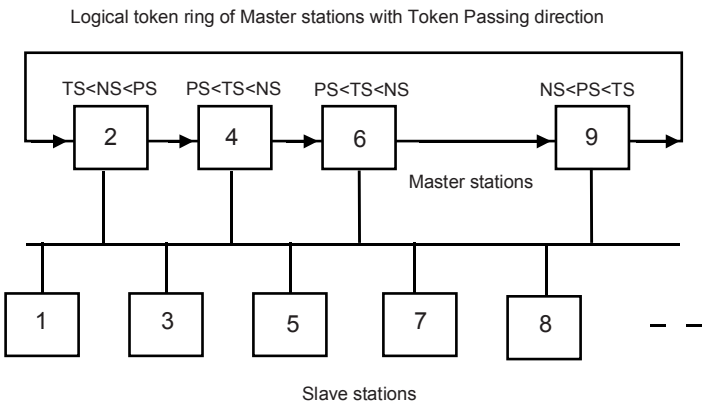
The token is passed from master station to master station in ascending numerical order of station addresses by means of the token DLPDU (see 7.4). To close the logical token ring, the station with the highest address passes the token to the station with the lowest address, see Figure 2.

5.3.2.2 Token reception

If a master station (TS) receives a token DLPDU addressed to itself from a station which is registered as Previous station (PS) in its list of master stations (LMS), it **owns the token** and may execute message transfer periods. The LMS is generated in a master station in the "Listen_Token" state (see 8.2.4) after power on and is updated and corrected, if necessary, later on upon each receipt of a token DLPDU.

If the token transmitter is not the registered PS, the addressee assumes an error and shall not accept the token. Only a subsequent retry of the same PS is accepted and results in the token receipt, because the token receiver shall assume now that the logical ring has changed. It replaces the originally recorded PS in its LMS by the new one.

Figure 2 shows the logical token-passing ring.



where

TS is this station (address);

PS is previous station (address);

NS is next station (address);

master stations are 2, 4, 6 and 9 (addresses as an example);

slave stations are 1, 3, 5, 7 and 8 (addresses as an example).

Figure 2 – Logical token-passing ring

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5.3.2.3 Token transmission

After the master station has finished its message transfer periods - contingent maintenance of the GAP station list (GAPL, see 5.3.2.4) included - it passes the token to its successor (NS) by transmitting the token DLPDU. The functionality of its transceiver is checked by simultaneous monitoring (see 8.2.11, "Pass_Token" state).

If, after transmitting the token DLPDU and after expiration of the synchronization time within the slot time (see 5.5), the token transmitter receives a valid DLPDU, that is, a DLPDU header without any errors, it assumes that its NS owns the token and executes message transfer periods. If the token transmitter receives an invalid DLPDU, it assumes that another master station is transmitting. In both cases it ceases monitoring the token passing and retires, that is, it enters the "Active_Idle" state (see 8.2.5).

If the token transmitter does not recognize any bus activity within the slot time, it repeats the token DLPDU and waits another slot time. It retires thereafter, if it recognizes bus activity within the second slot time. Otherwise, it repeats the token DLPDU to its NS for a last time. If, after this second retry, it recognizes bus activity within the slot time, it retires.

If, after the second retry, there is no bus activity, the token transmitter tries to pass the token to the next but one master station (NS of NS). It continues repeating this procedure until it has found a successor from its LMS. If it does not succeed, the token transmitter assumes that it is the only one left in the logical token ring and transmits the token to itself. If it finds a NS again in a later station registration, it tries again to pass the token.

5.3.2.4 Addition and removal of stations

Master and slave stations may be connected to or disconnected from the transmission medium at any moment. Each master station in the logical token ring is responsible for the addition of new stations in the range from the own station address (TS) to the next station (NS), excluding TS and NS. This address range is called GAP and is represented in the GAP List (GAPL), except the address range between Highest Station Address (HSA: 2 to 126) and 127, which does not belong to the GAP.

Each master station in the logical token ring examines its address range (all GAP addresses) after expiration of the GAP update timer (see 5.5.3.11) for changes concerning Master and slave stations. This is accomplished by examining **one** address per token receipt, using the "Request DL Status with Reply" request DLPDU (see Table 3, b7=1, Code-No 9: Format 7.1.1 a) and 7.1.2 a)).

Upon receiving the token, GAP maintenance starts immediately after all queued message transfer periods have been executed, if there is still transmission time available (see 5.3.2.6). Otherwise, GAP maintenance starts upon the next or the consecutive token receipts after the high priority message transfer periods and other low priority services invoked before the previous GAP maintenance have been performed (see 5.3.2.7). In realizations, care is necessary to ensure that GAP maintenance and low priority message transfer periods do not block each other.

GAP addresses are examined in ascending order, except the GAP which surpasses the HSA. For example, if the HSA and address 0 are not used by a master station, the master station with the highest address examines address 0 after checking the HSA.

If a station acknowledges positively with the DL status "Master station not ready to enter logical token ring" or "Slave station" (see Table 3, b7=0, Code-No 0, no SC, and Figure 20), it is accordingly marked in the GAPL and the next address is checked. If a station answers with the state "Master station ready to enter logical token ring", the token holder changes its GAPL and LMS and passes the token to the new NS. This station, which has newly been admitted to the logical token ring, has already built up its LMS, when it was in the "Listen_Token" state, so that it is able to determine its GAP range and its NS.

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If a station answers with the DL status "Master station in logical token ring", then the token holder does not change its GAP and passes the token to the NS given in the LMS. Thus the skipped master station may retire from the bus in case of permanent not receiving the token. In this case the master station shall enter the "Listen_Token" state. In this state it generates a new LMS and remains in this state until it is addressed once more by a "Request DL Status with Reply" transmitted by its predecessor (PS).

Stations which were registered in the GAPL and which do not respond to a "Request DL Status with Reply" are removed from the GAPL and are recorded as unused station addresses.

Due to performance requirements repeated requests of "Request DL Status with Reply" are not desired.

5.3.2.5 (Re)initialization of the logical token ring

Initialization is primarily a special case of updating the LMS and GAPL. If after power on (PON) of a master station a time-out is encountered in the "Listen_Token" state (no bus activity within Time-out Time T_{TO} (see 5.5)), then the master station shall claim the token ("Claim_Token" state) and start initialization.

When the entire fieldbus system is started, the master station with the lowest station address starts initialization. By transmitting two token DLPDUs addressed to itself (DA = SA = TS) it informs any other master stations (entering a NS into their LMS) that it is now the only station in the logical token ring. Then it transmits a "Request DL Status with Reply" DLPDU to each station in an incrementing address sequence, in order to register other stations. If a station responds with "Master station not ready to enter logical token ring" or with "Slave station" it is entered in the GAPL. The first master station, which answers with "Master station ready to enter logical token ring", is registered as NS in the LMS and thus closes the GAP range of the token holder. Then the token holder passes the token to its NS.

Reinitialization becomes necessary after loss of the token, which causes a time-out (no bus activity). In this case, an entire bus initialization sequence is not required, because LMS and GAPL already exist in the master stations. The time-out expires first in the master station with the lowest address. It takes the token and starts executing regular message transfer periods or passes the token to its NS.

5.3.2.6 Token rotation time

After receiving a token, the DL-entity may carry out high priority and low priority message transfer periods according to the token rotation time. The token rotation time is measured by using the token-rotation-timer. At the beginning the token-rotation-timer is loaded with the target rotation time T_{TR} and decremented with each bit time. The token-rotation-timer stops if the value zero is reached.

The token rotation time shall be measured according to the following rules:

— immediately after token reception the master station shall read the current value of the token-rotation-timer (token holding time T_{TH}) to calculate the real rotation time T_{RR} (difference between the target rotation time and the current value of token-rotation-timer) and shall start the token-rotation-timer with the value target rotation time (T_{TR})

— the T_{RR} represents always the token rotation time of the last token rotation (from the viewpoint of this station)

A system's minimum target rotation time depends on the number of master stations and thus on the token transfer period (T_{TP}) and the duration of high priority message transfer periods (high T_{MP}). The predefined target rotation time T_{TR} shall also contain sufficient time for low priority message transfer periods and a safety margin for potential retries.

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In order to keep within the system reaction time required by the field of application, the target rotation time T_{TR} of the token in the logical ring shall be specified.

The system reaction time is defined as the maximum time interval (worst case) between two consecutive high priority message transfer periods of a master station, measured at the DLS-user interface at maximum bus load.

In order to achieve a target rotation time as short as possible, it is recommended for the DLS-user (see IEC 61158-5-3), to declare only important data as high priority message transfer periods and to restrict their length (for example, ≤ 32 octets for the DLSDU, see 6.6).

If the transfer periods defined in 5.6 (equations (52) and (59) as well as (53) and (60)) are included and possible retries are taken into consideration, the operating parameter "target rotation time T_{TR}" (see 5.6 and Table 5), which is necessary for initialization (min T_{TR}), is calculated for the DLS-user as follows:

$$\min T_{TR} = na \times T_{TP} + (na + 1) \times \text{high } T_{MP} + k \times \text{low } T_{MP} + mt \times T_{RMP} \qquad (11)$$

where

- na is the number of master stations;
- k is the estimated number of low priority message transfer periods per token rotation;
- T_{TP} is the token transfer period (see 5.6.1.1 and 5.6.2.1);
- T_{MP} is the message transfer period, depending on DLPDU length (see 5.6.1.2 and 5.6.2.2);
- mt is the numbers of message retry transfer periods per token rotation;
- T_{RMP} is the message retry transfer period.

The first term contains one token transfer period per master station. The second term contains **one** high priority message transfer period for *N+1* master stations. The third term contains the estimated number of low priority message transfer periods per token rotation. The fourth term serves as a safety margin for potential retries. The maximum reaction time for high priority message transfer periods is guaranteed for all bus loads.

5.3.2.7 Message priorities

In the parameter service_class of the DL services the DLS-user (application layer) can choose between two priorities: low and high. The priority is passed to the DLE with the service request.

After token reception, each master station may always execute **one** high priority message transfer period including retries in the case of an error independently of the token holding time T_{TH}.

Further high or low priority message transfer periods may be executed according to the following rules if T_{TH} is still available (see 5.5.5).

— High or low priority messages may be carried out if the calculated real rotation time (T_{RR}) is less than the current value of the token-rotation-timer before the instant of execution of message sending.

— Once a high or low priority message transfer period is started, it is always completed, including any required retry (retries), even if the token-rotation-timer is less than or equal to the value of T_{RR} during the execution.

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— If there is no T_{TH} available (the T_{RR} is greater than the current value of the token-rotation-timer before the instant of execution of message sending) then the token shall be passed to NS immediately.

NOTE 1 The prolongation of the token holding time T_{TH} automatically results in a shortening of transmission time for message transfer periods at the next token receipt.

NOTE 2 For further explanation refer to Annex A and Annex C.

5.3.3 Send or send/request mode

In the send or send/request mode, single message transfer periods are conducted sporadically. The master station's DL-entity initiates this mode due to a local user's request upon receipt of the token. If there are several requests, this mode of operation may be continued until the maximum allowed token holding time expires.

5.4 Service assumed from the PhL

5.4.1 Asynchronous transmission

5.4.1.1 PhS transmission and reception services

The PhL data service includes two service primitives. A request primitive is used to request a service by the DL-entity; an indication primitive is used to indicate a reception to the DL-entity. The names of the respective primitives are as follows:

Ph-ASYN-DATA request

Ph-ASYN-DATA indication

The temporal relationship of the primitives is shown in Figure 3.

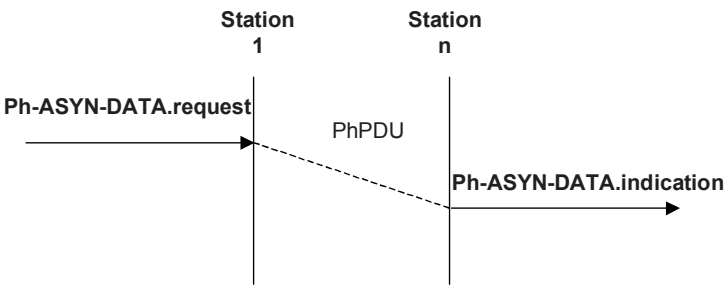

Figure 3 – PhL data service for asynchronous transmission

5.4.1.2 Detailed specification of the service and message exchange

This subclause describes in detail the service primitives and the related parameters in an abstract way. The parameters contain information needed by the PhL-entity.

Parameters of the primitives:

Ph-ASYN-DATA request (DL_symbol)

The parameter DL_symbol shall have one of the following values:

a) ZERO corresponds to a binary "0",

b) ONE corresponds to a binary "1",

c) SILENCE disables the transmitter when no valid DL symbol is to be transmitted.

The Ph-ASYN-DATA request primitive is passed from the DL-entity to the PhL-entity to request that the given symbol shall be sent to the fieldbus medium.

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The reception of this primitive shall cause the PhL-entity to attempt encoding and transmission of the DL-symbol.

The Ph-ASYN-DATA request is a primitive, which shall only be generated once per DL-symbol period (t_{BIT}). The PhL-entity may confirm this primitive with a locally defined confirmation primitive.

Ph-ASYN-DATA indication (DL_symbol)

The parameter DL_symbol shall have one of the following values:

— ZERO corresponds to a binary "0",

— ONE corresponds to a binary "1".

The Ph-ASYN-DATA indication primitive is passed from the PhL-entity to the DL-entity to indicate that a DL-symbol was received from the fieldbus medium.

The Ph-ASYN-DATA indication is a primitive, which shall only be generated once per received DL-symbol period (t_{BIT}).

5.4.2 Synchronous transmission

5.4.2.1 General

This subclause defines the assumed physical service (PhS) primitives and their constraints on use by the DLE.

NOTE Proper layering requires that an (N+1)-layer entity not be concerned with, and that an (N)-service interface not overly constrain, the means by which an (N)-layer provides its (N)-services. Thus the Ph-service interface does not require DLEs to be aware of internal details of the PhE (for example, preamble, postamble and DLPDU delimiter signal patterns, number of bits per baud), and should not prevent the PhE from using appropriate evolving technologies.

5.4.2.2 Assumed primitives of the PhS

The granularity of transmission in the fieldbus protocol is one octet. This is the granularity of PhS-user data and timing information exchanged at the PhL — DLL interface.

5.4.2.2.1 PhS characteristics reporting service

The PhS is assumed to provide the following service primitive to report essential PhS characteristics used in DLL transmission, reception, and scheduling activities:

Ph-CHARACTERISTICS indication (minimum-data-rate, framing-overhead)

where

minimum-data-rate — specifies the effective minimum rate of data conveyance in bits per second, including any timing tolerances, of any PhE on the local link.

NOTE 1 A PhE with a nominal data rate of 1 Mbit/s ± 0,01 % would specify a minimum data rate of 0,9999 Mbit/s.

framing-overhead — specifies the maximum number of bit periods, where
period = 1/data rate,
used in any transmission for PhPDUs which do not directly convey data (for example, PhPDUs conveying preamble, DLPDU delimiters, postamble, inter-DLPDU “silence”, and so on).

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NOTE 2 If the framing overhead is F and two DL message lengths are L_1 and L_2, then the time to send two immediately consecutive messages of lengths L_1 and L_2 will be at least as great as the time required to send one message of length $L_1 + F + L_2$.

If this framing-overhead is more than the DLEs configured per-DLPDU-PhL-overhead, V(PhLO), then the DLE shall report this discrepancy to DL-management and shall not issue Ph-DATA requests while the discrepancy exists.

NOTE 3 This restriction prohibits DLE transmission while this discrepancy exists. The DLEs local station management may remedy this discrepancy by reconfiguring V(PhLO) to a greater value.

5.4.2.2.2 PhS transmission and reception services

The PhS is assumed to provide the following service primitives for transmission and reception:

Ph-DATA request (class, data);

Ph-DATA indication (class, data);

Ph-DATA confirm (status)

where

class — specifies the Ph-interface-control-information (PhICI) component of the Ph-interface-data-unit (PhIDU). For a Ph-DATA request, its possible values are

START-OF-ACTIVITY — transmission of the PhPDUs which precede Ph-user data should commence;

DATA — the single-octet value of the associated data parameter should be transmitted as part of a continuous correctly-formed transmission;

END-OF-DATA-AND-ACTIVITY — the PhPDUs which terminate Ph-user data should be transmitted after the last preceding octet of Ph-user data, culminating in the cessation of active transmission;

For a Ph-DATA indication, its possible values are:

START-OF-ACTIVITY — reception of an apparent transmission from one or more PhEs has commenced;

DATA — the associated data parameter was received as part of a continuous correctly-formed reception;

END-OF-DATA — the ongoing continuous correctly formed reception of Ph-user data has concluded with correct reception of PhPDUs implying END-OF-DATA;

END-OF-ACTIVITY — the ongoing reception (of an apparent transmission from one or more PhEs) has concluded, with no further evidence of PhE transmission;

END-OF-DATA-AND-ACTIVITY — simultaneous occurrence of END-OF-DATA and END-OF-ACTIVITY;

data — specifies the Ph-interface-data (PhID) component of the PhIDU. It consists of one octet of Ph-user data to be transmitted (Ph-DATA request) or which was received successfully (Ph-DATA indication).

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status — specifies either success or the locally detected reason for inferring failure.

The Ph-DATA confirm primitive provides the critical physical timing feedback necessary to inhibit the DLE from starting a second transmission before the first is complete. The final Ph-DATA confirm of a transmission shall not be issued until the PhE has completed the current transmission.

5.4.2.3 Notification of PhS characteristics

The PhE has the responsibility for notifying the DLE of those characteristics of the PhS which are relevant to DLE operation. This notification is accomplished by the PhE by issuing a single Ph-CHARACTERISTICS indication primitive at each of the PhEs PhSAPs at PhE startup.

5.4.2.4 Transmission of Ph-user data

The PhE determines the timing of all transmissions. When a DLE has a DLPDU to transmit, and the DL-protocol gives that DLE the right to transmit, then the DLE shall send the DLPDU, including a concatenated FCS, by making a well-formed sequence of Ph-DATA requests, consisting of a single request specifying START-OF-ACTIVITY; followed by three to 300 consecutive requests, inclusive, specifying DATA; and concluded by a single request specifying END-OF-DATA-AND-ACTIVITY.

The PhE signals its completion of each Ph-DATA request, and its readiness to accept a new Ph-DATA request, with a Ph-DATA confirm primitive; the status parameter of the Ph-DATA confirm primitive conveys the success or failure of the associated Ph-DATA request. A second Ph-DATA request should not be issued until after the Ph-DATA confirm corresponding to the first request has been received from the PhE.

5.4.2.5 Reception of Ph-user data

The PhE reports a received transmission with a well-formed sequence of Ph-DATA indications, which shall consist of either

a) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA; followed by a single indication specifying END-OF-DATA; and concluded by a single indication specifying END-OF-ACTIVITY, or

b) a single indication specifying START-OF-ACTIVITY; followed by consecutive indications specifying DATA; followed by a single indication specifying END-OF-DATA-AND-ACTIVITY, or

c) a single indication specifying START-OF-ACTIVITY; optionally followed by one or more consecutive indications specifying DATA; and concluded by a single indication specifying END-OF-ACTIVITY.

NOTE This last sequence is indicative of an incomplete or incorrect reception. Detection of an error in the sequence of received PhPDUs, or in the PhEs reception process, disables further Ph-DATA indications with a class parameter specifying DATA, END-OF-DATA, or END-OF-DATA-AND-ACTIVITY until after both the end of the current period of activity and the start of a subsequent period of activity have been reported by Ph-DATA indications specifying END-OF-ACTIVITY and START-OF-ACTIVITY, respectively.

In the first two cases, the DLE concatenates the received data and then attempts to parse it into a DLPDU followed by a concatenated FCS. In the last case the DLE discards all reported data and reports the event to DL-management.

5.5 Operational elements

5.5.1 Overview

The following times T are measured in bits. A time t in seconds (s) shall therefore be divided by the bit time t_{BIT}.

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5.5.2 Bit time t_{BIT}

The bit time t_{BIT} is the time, which elapses during the transmission of one bit. It is equivalent to the reciprocal value of the data rate:

$$t_{BIT} = \frac{1}{\text{data rate}} \ [\text{s bit}^{-1}] \tag{12}$$

5.5.3 Asynchronous transmission

5.5.3.1 Synchronization time (T_{SYN})

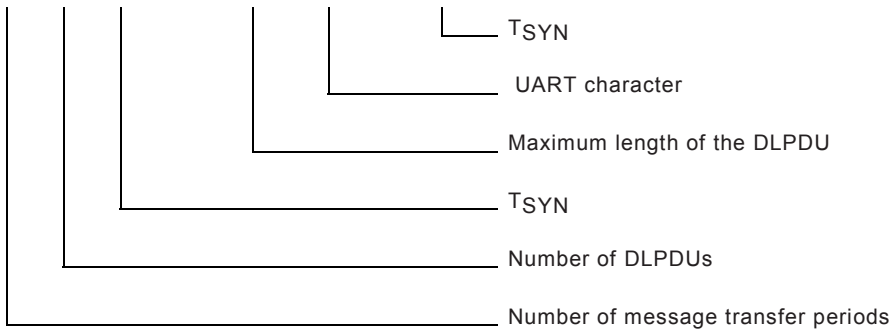
The synchronization time T_{SYN} is the minimum time interval during which each station shall receive idle state (idle = binary "1") from the transmission medium before it may accept the beginning of a send/request DLPDU or token DLPDU. The value of the synchronization time shall be set with:

$$T_{SYN} = 33 \text{ bit} \tag{13}$$

5.5.3.2 Synchronization interval time (T_{SYNI})

The synchronization interval time T_{SYNI} is the maximum allowed time interval between two consecutive synchronization times (T_{SYN}), in order to detect “permanent transmitters”. The value of the synchronization interval time shall be set with:

$$T_{SYNI} = 2 \times (2 \times (33 \text{ bit} + 255 \times 11 \text{ bit})) + 33 \text{ bit} = 11\,385 \text{ bit} \tag{14}$$



This value regards two complete message transfer periods, each of which consists of two DLPDUs of maximum length and the related synchronization times. A transmission disturbance is permitted in one of those synchronization times.

5.5.3.3 Station delay time (T_{SDx})

The station delay time T_{SDx} is the period of time which may elapse between the transmission or receipt of a DLPDUs last bit until the transmission or receipt of a following DLPDUs first bit (with respect to the transmission medium, that is, including line receiver and transmitter). The following three station delays are defined:

a) Station Delay of Initiator (station transmitting request or token DLPDU):

   TSDI

b) Minimum Station Delay of Responders (stations which acknowledge or respond):

   min T_{SDR}

c) Maximum Station Delay of Responders:

   max T_{SDR}

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5.5.3.4 Quiet time (T_{QUI})

When transposing the NRZ signals into a different signal coding, the transmitter fall time after switching off the transmitter (at the initiator) shall be taken into account if it is greater than T_{SDR}.

During this quiet time T_{QUI}, transmission and receipt of DLPDUs shall be disabled. This shall also be taken into account when using self-controlled repeaters, whose switching time shall be taken into consideration. The implementation shall ensure, that the following condition is fulfilled:

$$T_{QUI} < \min T_{SDR} \quad (15)$$

In order to fulfil this condition, it may be necessary to prolong min T_{SDR}.

5.5.3.5 Ready time (T_{RDY})

The ready time T_{RDY} is the time within which a master station shall be ready to receive an acknowledgement or response after transmitting a request. The implementation shall ensure, that the following condition is fulfilled:

$$T_{RDY} < \min T_{SDR} \quad (16)$$

In order to fulfil this condition it may be necessary to prolong min T_{SDR}.

When transposing NRZ signals into a different signal coding, the quiet time shall also be taken into consideration when switching off the transmitter. The receiver shall not be enabled before this time:

$$T_{QUI} < T_{RDY} \quad (17)$$

In order to fulfil this condition, it may be necessary to prolong T_{RDY} and thus min T_{SDR} accordingly.

5.5.3.6 Safety margin (T_{SM})

The following time interval is specified as safety margin T_{SM}:

$$T_{SM} = 2 \text{ bit} + 2 \times T_{SET} + T_{QUI} \quad (18)$$

T_{SET} is the set-up time, which expires from the occurrence of an event (for example, an interrupt on the last bit of a sent DLPDU or when synchronization time expires) until the necessary reaction is performed (for example, to start synchronization time or to enable the receiver).

5.5.3.7 Idle time (T_{IDx})

The idle time T_{IDx} is the time which expires at the initiator either after receipt of a DLPDUs last bit (measured at the line receiver) as idle = binary "1" **on the transmission medium**, until a new DLPDUs first bit is transmitted on the medium (including line transmitter) or between transmitting the last bit of a DLPDU which is not to be acknowledged and transmitting the first bit of the next DLPDU. The idle time shall be at least the synchronization time plus the safety margin T_{SM} (see Figure 4, Figure 5 and Figure 6 case a)).

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$$T_{IDx} \geq T_{SYN} + T_{SM} \quad (19)$$

At high data rates (see Figure 4, case b) and c) and Figure 5 case b)) the synchronization time is very short, hence the station delays become significant and shall be taken into consideration.

Two idle times are distinguished. After an acknowledgement, response or token DLPDU the idle time shall be calculated as follows:

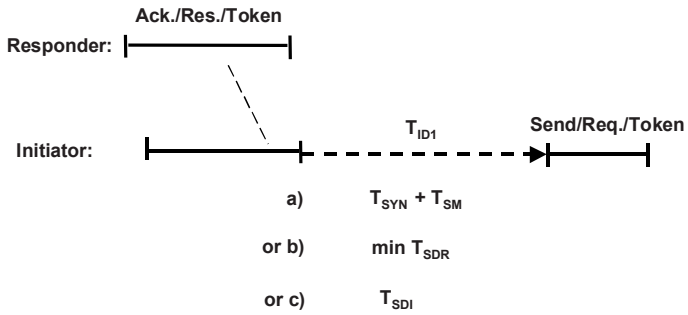

Figure 4 – Idle time T_{ID1}

$$T_{ID1} = \max((T_{SYN} + T_{SM}), (\min T_{SDR}), T_{SDI}) \quad (20)$$

Care shall be taken that the time to update the LMS is not greater than T_{ID1}. This can be accomplished by prolonging T_{SET} or min T_{SDR}. If the necessary prolongation cannot be reached with the range of value of T_{SET}, than the min T_{SDR} shall be made longer.

After a send DLPDU which is **not** to be acknowledged (SDN or CS), the idle time shall be calculated as shown in Figure 5 and equation 34.

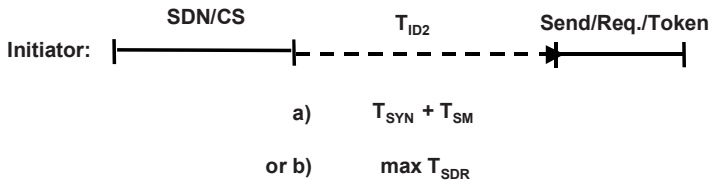

Figure 5 – Idle time T_{ID2} (SDN, CS)

$$T_{ID2} = \max((T_{SYN} + T_{SM}), (\max T_{SDR})) \quad (21)$$

Also, after a response DLPDU (MSRD) the idle time shall be calculated as shown in Figure 6 and equation 34.

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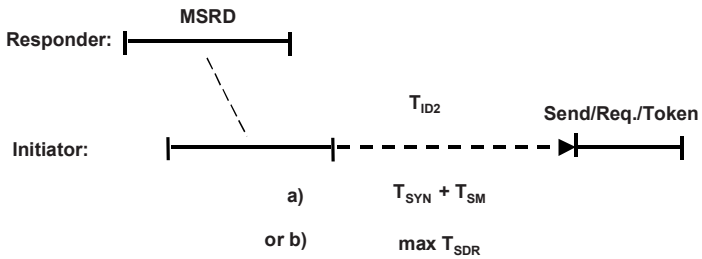

Figure 6 – Idle time T_{ID2} (MSRD)

5.5.3.8 Transmission delay time (T_{TD})

The transmission delay time T_{TD} is the maximum time, which elapses on the transmission medium between transmitter and receiver when a DLPDU is transmitted. When computing it, delay times of repeaters shall be considered, if necessary.

EXAMPLE for computing the transmission delay time: given a line length of 200 m without repeaters, t_{TD} is approximately 1 µs and thus at 500 kbit/s

T_{TD} = (1µs × 500 kbit/s) = 0,5 bit.

5.5.3.9 Slot time (T_{SL})

The slot time T_{SL} is the maximum time the initiator shall wait for the complete receipt of the first character (see 6.1.1, UART character, 1 UC = 11 bits) of the immediate acknowledgement or response DLPDU, after transmitting the last bit of a send/request DLPDU (including the line transmitter) (see Figure 7). Furthermore, T_{SL} is the maximum time the initiator waits for the token receiver's first UART character (1.UC) after transmitting a token DLPDU (see Figure 8). Theoretically, two slot times are distinguished. After a send/request DLPDU the slot time shall be calculated as follows:

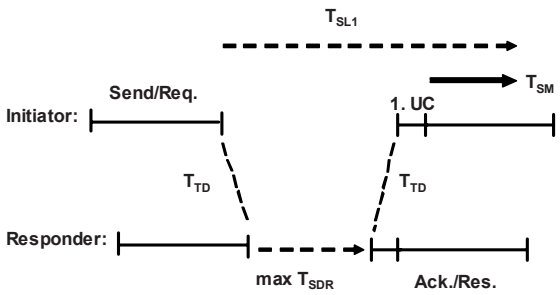

Figure 7 – Slot time T_{SL1}

$$T_{SL1} = 2 \times T_{TD} + \max T_{SDR} + 11 \text{ bit} + T_{SM} \quad (22)$$

After a token DLPDU the slot time shall be calculated as follows:

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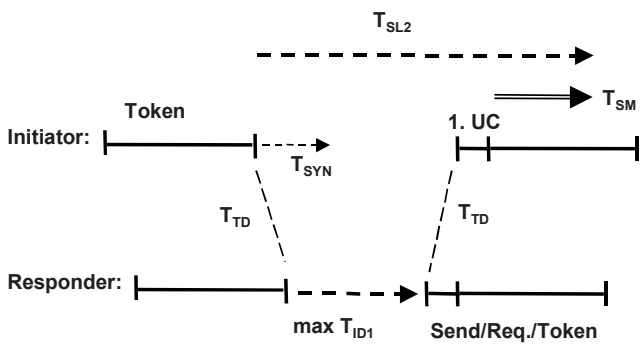

Figure 8 – Slot time T_{SL2}

$$T_{SL2} = 2 \times T_{TD} + \max T_{ID1} + 11 \text{ bit} + T_{SM} \quad (23)$$

In order to simplify the realization, only **one** slot time, the longer one, may be used in the system. This does not influence the system reaction time negatively, as the slot time is a pure monitoring time.

$$T_{SL} = \max (T_{SL1}, T_{SL2}) \quad (24)$$

5.5.3.10 Time-out time (T_{TO})

The time-out time T_{TO} serves to monitor the Master and slave stations' bus activity and idle time. Monitoring shall start either immediately after PON, in the "Listen_Token" or "Passive_Idle" state, or later after receiving the last bit of a DLPDU. It shall end after receiving the first bit of the following DLPDU. If the phase of no bus activity times out, the bus shall be regarded as inactive. (This is an error case, for example, due to a lost token DLPDU.) The time-out interval shall be set to:

$$T_{TO} = 6 \times T_{SL} + 2 \times n \times T_{SL} \quad (25)$$

For master stations: n = station address (0 to 126)

For slave stations: n = 130, independent of the station's address

The first term ensures that there is sufficient difference to the maximum permissible idle time between two DLPDUs. The second term ensures that not all master stations claim the token at the same moment after an error has occurred.

5.5.3.11 GAP update time (T_{GUD})

The GAP update time T_{GUD} serves for initializing GAP maintenance by the master station. After the first generation of the GAPL, update of the GAP image is cyclically initialized after every interval T_{GUD}. This initialization takes place at the next possible token receipt, if there is still token holding time available after the regular DLPDU transfer periods, or during later token holding phases. The GAP update time is a multiple of the target rotation time T_{TR} and shall be set to:

$$T_{GUD} = G \times T_{TR} \quad (\text{where } 1 \leq G \leq 100) \quad (26)$$

T_{TR} is the target rotation time (see 5.3.2.6).

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5.5.3.12 Isochronous mode

5.5.3.12.1 Isochronous cycle time (T_{CT})

The isochronous cycle time T_{CT} serves to supervise the isochronous cycle. The first cycle starts by sending the SYNCH DLPDU after reception of the token DLPDU.

5.5.3.12.2 IsoM synchronization DLPDU time (T_{SYNCH})

The isochronous mode synchronization DLPDU time describes the time, which is needed to send the SYNCH DLPDU at the start of a new IsoM cycle. The value of the IsoM synchronization message time shall be set with:

$$T_{SYNCH} = 13 \times 11 \text{ bit} = 143 \text{ bit} \quad (27)$$

UART character

Length of the SYNCH DLPDU

5.5.3.12.3 Active spare time DLPDU time (T_{ASM})

The active spare time DLPDU time describes the duration that is needed to send an active spare time (ASP) DLPDU.

$$T_{ASM} = T_{ID1} + (6 \times 11 \text{ bit}) \quad (28)$$

UART character

Length of the ASP DLPDU

5.5.3.12.4 Real isochronous cycle time (T_{RCT})

The real isochronous cycle time is the read value of the isochronous-cycle-timer.

5.5.3.12.5 Spare time (T_{RES})

Within the isochronous cycle the token is passed by the IsoM Master after the transmission of all high priority messages and the number of configured low priority messages. After receiving the next token addressed to the IsoM Master, the station read the isochronous cycle timer (T_{RCT}) in order to calculate the remaining time before the next SYNCH DLPDU is to be sent.

$$T_{RES} = T_{CT} - T_{RCT} \quad (29)$$

Within the spare time, at least one active spare time DLPDU shall be sent. For further active spare time, DLPDUs shall be valid.

$$T_{RES} > T_{ASM} + T_{ID1} \quad (30)$$

5.5.3.12.6 Passive spare time (T_{PSP})

The passive spare time denotes the part of isochronous cycle where the IsoM Master shows no bus activities. It shall be less than the minimum time-out time T_{TO} under consideration of possible delays in the stations and during transmission. The passive spare time is defined as follow:

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$$T_{PSP} < 6 \times T_{SL} - T_{SM} - 2 \times T_{TD} \quad (31)$$

$$T_{PSP} > T_{ID1} + T_{ASM} + \max T_{SDR} \quad (32)$$

5.5.3.12.7 Time shift (T_{SH})

The time shift is the difference between the measured cycle time and the calculated cycle time when the passive-spare-timer expires.

$$T_{SH} = T_{RCT} - T_{CT} \quad (33)$$

5.5.3.13 Send delay time (T_{SD})

The send delay time is the time that elapses between the receiving of a DL-CS-TIME-EVENT.request primitive at the DLE of the time master and the DLPDUs last bit of a resulting TE DLPDU (see 7.7) transmitted by the time master.

5.5.3.14 Receive delay time (T_{RD})

The receive delay time is the time that elapses at a time receiver between the receiving of the last bit of a TE DLPDU (see 7.7) and the receiving of a DLPDUs last bit of a CV DLPDU (see 7.8).

5.5.3.15 Clock synchronization interval time (T_{CSI})

The clock synchronization interval time is used to monitor the synchronization sequences within the DLE.

5.5.4 Synchronous transmission

5.5.4.1 Synchronization time (T_{SYN})

The synchronization time is the minimum time interval during which each station shall receive no activity from the transmission medium before it may accept the beginning of a send/request DLPDU or token DLPDU.

The synchronization time shall correspond to the post-transmission gap time (T_{PTG}) that is defined in 9.2.8 of IEC 61158-2. Its value shall be set to at least 4 bit and may be increased by the DLMS-user up to 32 bit.

$$T_{SYN} = T_{PTG} = T_{QUI} \quad (34)$$

$$T_{SYN} = 4 \text{ to } 32 \text{ bit} \quad (35)$$

5.5.4.2 Synchronization interval time (T_{SYNI})

The synchronization interval time T_{SYNI} is the maximum allowed time interval between two consecutive synchronization times (T_{SYN}), in order to detect "permanent transmitters".

The value of T_{SYNI} shall be set as follows:

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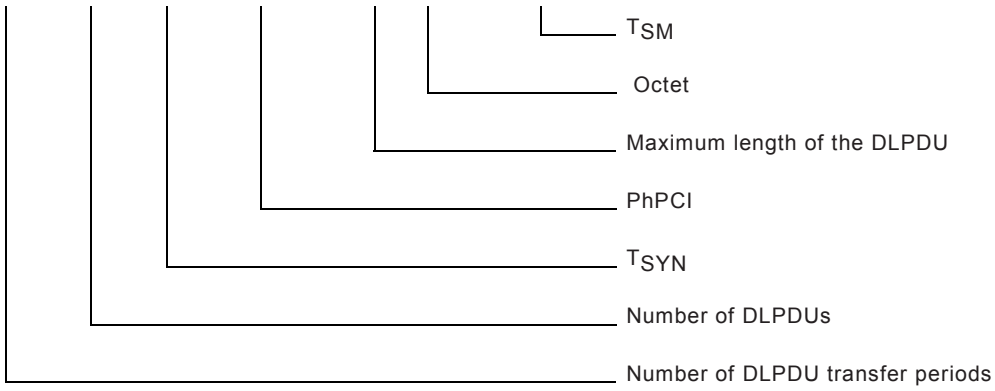
$$T_{SYNI} = 2 \times (2 \times (32 \text{ bit} + 80 \text{ bit} + 255 \times 8 \text{ bit})) + 64 \text{ bit} = 8\,672 \text{ bit} \quad (36)$$



This value regards two complete message sequences, each of which consists of two DLPDUs of maximum length and the associated maximum PhL Protocol Control Information (PhPCI: Preamble, Start Delimiter, End Delimiter) and the maximum synchronization time (post-transmission gap). A transmission disturbance is permitted in one of those synchronization times.

5.5.4.3 Station delay time (T_{SDx})

The station delay time T_{SDx} is the period of time, which may elapse between the transmission or receipt of a DLPDUs last octet until the transmission or receipt of a following DLPDUs first octet (with respect to the transmission medium, that is, including line receiver and transmitter). The following three station delays are defined:

a) Station Delay of Initiator (station transmitting request or token DLPDU)

T_{SDI}

b) Minimum Station Delay of Responders (station that acknowledges or responds)

min T_{SDR}

c) Maximum Station Delay of Responders

max T_{SDR}

5.5.4.4 Quiet time (T_{QUI})

The transmitter fall time or repeater switch time corresponds to the post-transmission gap time (T_{SYN}). The following shall apply:

$$T_{QUI} = T_{PTG} = T_{SYN} \quad (37)$$

5.5.4.5 Ready time (T_{RDY})

The ready time T_{RDY} is the time within which a Master station shall be ready to receive an acknowledgement or response after transmitting a request. The implementation shall ensure, that the following condition is fulfilled:

$$T_{RDY} < \min T_{SDR} \quad (38)$$

In order to fulfil this condition it may be necessary to prolong min T_{SDR}.

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During the quiet time T_{QUI}, transmission and receipt of DLPDUs shall be disabled. The implementation shall ensure, that the following condition is fulfilled:

$$T_{QUI} = T_{PTG} = T_{SYN} < T_{RDY} \quad (39)$$

In order to fulfil this condition the min T_{SDR} shall be increased according to equation (38) if necessary.

5.5.4.6 Safety margin (T_{SM})

The safety margin T_{SM} is defined as the time interval:

$$T_{SM} = 2 \text{ bit} + 2 \times T_{SET} \quad (40)$$

T_{SET} is the set-up time, which expires from the occurrence of an event (for example, an interrupt on the last octet of a sent DLPDU or on synchronization time expiration) until the execution of the necessary reaction.

5.5.4.7 Idle time (T_{IDx})

The idle time T_{IDx} is the time which expires at the initiator after a Ph-DATA indication primitive until sending of a new DLPDU with Ph-DATA request primitive or after passing a Ph-DATA request primitive with a Ph-DATA confirm primitive to transmit a DLPDU which is not to be acknowledged until passing a new Ph-DATA request primitive for transmitting the next DLPDU. The idle time shall be at least the synchronization time plus the safety margin T_{SM}.

$$T_{IDx} \geq T_{SYN} + T_{SM} \quad (41)$$

Two idle times are distinguished (see description of idle time in 5.5.3.7, Figure 4, Figure 5, and Figure 6). After an acknowledgement, response or token DLPDU the idle time shall be calculated as follows:

$$T_{ID1} = \max((T_{SYN} + T_{SM}), (\min T_{SDR}), T_{SDI}) \quad (42)$$

Care shall be taken that the time to update the LMS is not greater than T_{ID1}. This can be accomplished by prolonging T_{SET} or min T_{SDR}. If the necessary prolongation cannot be reached with the range of value of T_{SET}, then the min T_{SDR} shall be made longer.

After a send DLPDU, which is not to be acknowledged (SDN, CS), the idle time shall be calculated as follows:

$$T_{ID2} = \max((T_{SYN} + T_{SM}), (\max T_{SDR})) \quad (43)$$

5.5.4.8 Transmission delay time (T_{TD})

The transmission delay time T_{TD} is the maximum time, which elapses on the transmission medium between transmitter and receiver when a DLPDU is transmitted. When computing it, delay times of repeaters shall be considered if necessary. It shall also conform to any restrictions placed on it in IEC 61158-2, where it is called “propagation delay”.

5.5.4.9 Slot time (T_{SL})

The slot time T_{SL} is the maximum time the initiator shall wait after passing a Ph-DATA request primitive for transmitting a request DLPDU from the Ph-DATA confirm primitive until receiving

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the first Ph-DATA indication primitive as an indication of receiving the immediate acknowledgement or response (see Figure 9). Furthermore, T_{SL} is the maximum time the initiator shall wait for a Ph-DATA indication primitive after the token DLPDU as reaction to receiving the first DLPDU octet from the token receiver. Theoretically, two slot times are distinguished (see Figure 10). After a send/request DLPDU the following slot time shall be calculated:

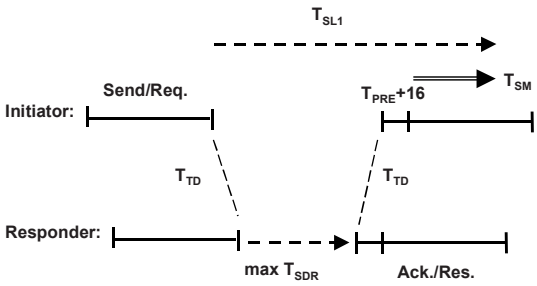

Figure 9 – Slot time T_{SL1}

$$T_{SL1} = 2 \times T_{TD} + \max T_{SDR} + T_{PRE} + 16 \text{ bit} + T_{SM} \quad (44)$$

After a token DLPDU the following slot time shall be calculated:

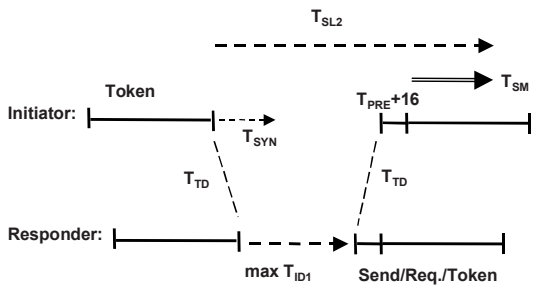

Figure 10 – Slot time T_{SL2}

$$T_{SL2} = 2 \times T_{TD} + \max T_{ID1} + T_{PRE} + 16 \text{ bit} + T_{SM} \quad (45)$$

where T_{PRE} is Preamble period (see IEC 61158-2)

In order to simplify the realization, only the longer slot time may be used in the system. This does not influence the system reaction time negatively, as the slot time is merely a monitoring time.

$$T_{SL} = \max (T_{SL1}, T_{SL2}) \quad (46)$$

5.5.4.10 Time-out time (T_{TO})

The time-out time T_{TO} serves to monitor the Master and Slave stations' bus activity and idle time. Monitoring shall start either immediately after PON, in the "Listen_Token" or "Passive_Idle" state, or later after the reception of a Ph-DATA indication primitive. It shall end upon receipt of a Ph-DATA indication primitive for reception of the first octet of a following DLPDU. If the phase of no bus activity times out, the bus shall be regarded as inactive. (This is an error case, for example, due to a lost token DLPDU.). The time-out time shall be set to the following value:

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$$T_{TO} = 6 \times T_{SL} + 2 \times n \times T_{SL} \quad (47)$$

For Master stations: n = station address (0 to 126)

For Slave stations: n = 130, independent of their station address

5.5.4.11 GAP update time (T_{GUD})

5.5.3.11 shall apply.

5.5.4.12 Isochronous Mode

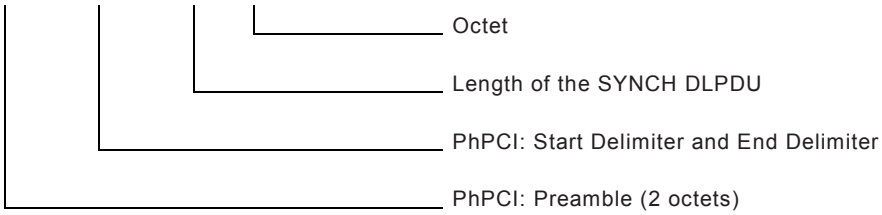
5.5.4.12.1 Isochronous cycle time (T_{CT})

5.5.3.12.1 shall apply.

5.5.4.12.2 IsoM synchronization DLPDU time (T_{SYNCH})

The isochronous mode synchronization DLPDU time describes the time, which is needed in order to send the SYNCH DLPDU at the start of a new IsoM cycle. The value of the IsoM synchronization message time shall be set with:

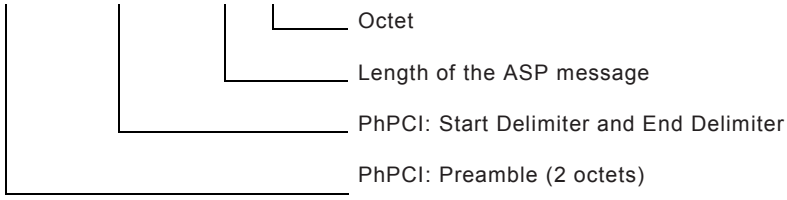
$$T_{SYNCH} = 16 \text{ bit} + 16 \text{ bit} + 13 \times 8 \text{ bit} = 136 \text{ bit} \quad (48)$$



5.5.4.12.3 Active spare time DLPDU time (T_{ASM})

The active spare time DLPDU time describes the duration that is needed to send an active spare time (ASP) DLPDU.

$$T_{ASM} = T_{PTG} + 16 \text{ bit} + 16 \text{ bit} + (6 \times 8 \text{ bit}) \quad (49)$$



5.5.4.12.4 Real isochronous cycle time (T_{RCT})

0 shall apply.

5.5.4.12.5 Spare time (T_{RES})

5.5.3.12.5 shall apply.

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5.5.4.12.6 Passive spare time (T_{PSP})

The passive spare time denotes the part of isochronous cycle where the IsoM Master shows no bus activities. It shall be less than the minimum time-out time T_{TO} under consideration of possible delays in the stations and during transmission. The passive spare time is defined as follow:

$$T_{PSP} < 6 \times T_{SL} - T_{SM} - 2 \times T_{TD} \quad (50)$$

$$T_{PSP} > T_{ID1} + T_{ASM} + \max T_{SDR} \quad (51)$$

5.5.4.12.7 Time shift (T_{SH})

5.5.3.12.7 shall apply.

5.5.4.13 Send delay time (T_{SD})

The send delay time is the time that elapses between a passed DL-CS-TIME-EVENT request primitive to the DLE of the time master and the DLPDUs last octet of a resulting TE DLPDU (see 7.7) transmitted by the time master.

5.5.4.14 Receive delay time (T_{RD})

The receive delay time is the time that elapses by a time receiver between the receiving of a DLPDUs last octet of a TE DLPDU (see 7.7) and the last octet of a CV DLPDU (see 7.8).

5.5.4.15 Clock synchronization interval time (T_{CSI})

Subclause 5.5.3.15 shall apply.

5.5.5 Timers and counters

5.5.5.1 Asynchronous transmission

5.5.5.1.1 Timers

In order to measure the token rotation time and to realize the supervisory times the following timers shall be implemented:

token-rotation-timer, idle-timer, slot-timer, time-out-timer, syn-interval-timer, GAP-update-timer, isochronous-cycle-timer, passive-spare-timer, send-delay-timer and receive-delay-timer.

token-rotation-timer: When a Master station receives the token, this timer is loaded with the target rotation time T_{TR} and decremented each bit time. When the station again receives the token, the timer value, the remaining time or token holding time T_{TH}, is read and the timer reloaded with T_{TR}. The real rotation time T_{RR} results from the difference T_{TR} - T_{TH}.

The token-rotation-timer can be read out at every moment, representing always the value of the actual token rotation. Low priority message transfer periods may be processed if at the instant of processing the real token rotation time is less than the value of the actual token rotation.

idle-timer: This timer monitors the idle state (binary "1"), the synchronization time, immediately on the bus line. The synchronization time preceding each request is necessary for unambiguous receiver synchronization. The idle-timer of Slave stations and Master stations "without token" is loaded with T_{SYN} after the transmission or receipt of a DLPDUs.

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last bit and then decremented each bit time. The receiver shall be enabled immediately after the timer has expired. The timer of a Master station "with token" is loaded according to the data transmission service with T_{ID1} or T_{ID2} (see 5.5.3). A new request or token DLPDU may only be transmitted after expiration of the timer. When the signalling level is binary "0", the timer is always reloaded.

slot-timer: This timer in a Master station monitors after a request or token pass whether the receiving station responds or becomes active within the predefined time T_{SL}, the slot time. After transmission of a DLPDUs last bit this timer is loaded with T_{SL} and decremented each bit time as soon as the receiver is enabled. If the timer expires before a DLPDUs first bit is received, an error has occurred. Then a retry or a new message transfer period shall be initiated.

time-out-timer: This timer monitors bus activity in Master and Slave stations. After the transmission or receipt of a DLPDUs last bit the timer is loaded with a multiple of the slot time (see 5.5.3) and decremented each bit time as long as no new DLPDU is received. If the timer expires, a fatal error has occurred, which for the Master station causes a (re)initialization. The DLMS-user of the Slave and Master station receives a time-out notification.

syn-interval-timer: Master and Slave stations use this timer to monitor the transmission medium whether a receiver synchronizing (T_{SYN}, idle state, idle = binary "1") occurs within T_{SYNI}. Each time the receiver is synchronized, the timer is loaded with T_{SYNI} (see 5.5.3). From the beginning of a DLPDU (first start bit) the timer is decremented each bit time as long as no new T_{SYN} is detected. If the timer expires, an error has occurred on the transmission medium, for example, stuck at "0" or permanent "0" / "1" edges. The DLMS-user is notified accordingly.

GAP-update-timer: Only Master stations need this timer. Its expiration indicates the moment for GAP maintenance. After a complete GAP check, which may last several token rotations (segmented; see 5.3.2.4), the timer is loaded with a multiple (G) of the target rotation time T_{TR} (see 5.3.2.6).

NOTE For ease of implementation, this timer can be implemented as a counter, decremented at each token receipt.

isochronous-cycle-timer: The timer supervises the isochronous cycle. It is loaded with value equal to 0 at the starting point of the isochronous mode (after receiving the first token) and increments every bit time. The timer is readable at any time. The timer is started either by loading with the value equal to 0 at the first beginning of the isochronous cycle or after expiration of the passive-spare-timer. In cases the timer is started too late, it is loaded with the value of the time difference between the real isochronous cycle time of the last cycle and the isochronous cycle time.

passive-spare- timer: This timer monitors the idle time before sending a SYNCH message. It shall be set according to the time difference between T_{CT} and the current value of the isochronous-cycle-timer T_{RCT} at the end of the last ASP message if the difference is greater than 0. The transmission of the last bit of the last ASP message in an isochronous cycle starts this timer. In the isochronous mode after expiration of the passive-spare-timer, a SYNCH message shall be sent and a synch notification event shall be sent to the DLMS-user.

send-delay-timer: When the time master receives a DL-CS-TIME-EVENT request primitive from the local DLS-user, this timer is started with the value = $2 \times T_{CSI}$ and decremented each bit time. The timer is stopped after confirmation of the transmission of the last portion of a TE DLPDU (see 7.7). The value of send delay time is calculated as the difference between the start value ($2 \times T_{CSI}$) and the read send-delay-timer value. The calculated send delay time is passed to the local DLS-user. In case the timer has expired, the DLS-user is notified of a clock synchronization sequence violation.

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receive-delay-timer: When the time receiver receives the DLPDUs last bit of a TE DLPDU (see 7.7), this timer is started with the value = $2 \times T_{CSI}$ and decremented each bit time. The timer is stopped after the receiving the last bit of a CV DLPDU (see 7.8). The value of the receive delay time is calculated as difference between the start value ($2 \times T_{CSI}$) and the read receive-delay-timer value. The calculated receive delay time is passed to the local DLS-user. In case the timer expired a clock synchronization sequence violation is notified to the DLS-user.

When a Master station enters the "Listen_Token" state, the idle-timer is loaded with T_{SYN}, the time-out-timer with T_{TO}, the syn-interval-timer with T_{SYNI} and the other timers are cleared. When a Slave station enters the "Passive_Idle" state, the time-out-timer is loaded with T_{TO} and the syn-interval-timer with T_{SYNI}.

5.5.5.1.2 Counters

For installation and maintenance the following pairs of counters (DL-variables) may be used:

For Master stations:

— counter for transmitted DLPDUs (DLPDU_sent_count), except for the SDN and Request DL Status with Reply services

— counter for transmitted DLPDU retries (Retry_count)

Additional counters may be provided for each individual remote station:

— counter for transmitted DLPDUs (DLPDU_sent_count_sr), except for the SDN and Request DL Status with Reply services and for token DLPDUs

— counter for transmitted DLPDUs with no response or erroneous response (Error_count), except for the SDN and Request DL Status with Reply services and for token DLPDUs

For Slave and Master stations:

— counter for received valid start delimiters (SD_count)

— counter for received invalid start delimiters (SD_error_count)

When a station enters the "Listen_Token" or "Passive_Idle" state, the counters are cleared and enabled. If a counter reaches its maximum, counting of this counter as well as of the related comparative counter is stopped. When clearing a counter the related comparative counter is also cleared and they are enabled again. The DLMS-user may access these counters using the Set/Read Value services.

5.5.5.2 Synchronous transmission

5.5.5.2.1 Timers

As explained in 5.5.5.1.1, the following timers shall be implemented to measure the token rotation time and to realize the monitor timers:

Token-rotation-timer, idle-timer, slot-timer, time-out-timer, syn-interval-timer, GAP-update-timer, isochronous-cycle-timer, passive-spare-timer, send-delay-timer and receive-delay-timer.

token-rotation-timer: The functionality of this timer is as defined in 5.5.5.1.1.

idle-timer: This timer monitors the idle state $T_{PTG} = T_{SYN} = T_{QUI}$ on the bus line. The idle-timer in the Master station with the token is loaded with T_{ID1} or T_{ID2} depending on the data transmission service (see 5.5.4). The timer is decremented every bit time, when after a Ph-DATA request primitive (PhICI specifying END-OF-DATA-AND-ACTIVITY) either the [illegible]

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confirm primitive at the transmitter or the Ph-DATA indication primitive (PhICI specifying either END-OF-ACTIVITY or END-OF-DATA-AND-ACTIVITY) at the receiver is transferred. A new request or a new token DLPDU may be transmitted only after expiration of the timer.

slot-timer: After a request from or a token transfer by a Master station, this timer of the Master station monitors whether the receiving station responds or becomes active within the defined slot time T_{SL}. The timer is initialized with T_{SL} and is decremented every bit time after each transmission of a DLPDU. This DLPDU transmission is indicated by a Ph-DATA confirm primitive after transfer of a Ph-DATA request primitive (PhICI specifying END-OF-DATA-AND-ACTIVITY). If the timer expires before a DLPDU has been received, as indicated by a Ph-DATA indication primitive (PhICI specifying START-OF-ACTIVITY), an error has occurred. As a result of that, a retry or a new message transfer period is initiated.

time-out-timer: This timer monitors bus activity in Master and Slave stations. After transfer of the last Ph-DATA request primitive with PhICI specifying END-OF-DATA-AND-ACTIVITY and return of the corresponding Ph-DATA confirm primitive, or after receiving a Ph-DATA indication primitive with PhICI specifying either END-OF-ACTIVITY or END-OF-DATA-AND-ACTIVITY, the timer is loaded with a multiple of the slot time (see 5.5.4) and is decremented every bit time as long as no Ph-DATA indication primitive with PhICI specifying START-OF-ACTIVITY has been received. If the timer expires, a fatal error has occurred, which for the Master station causes a (re)initialization. The DLMS-user of the Slave or Master station respectively receives a time-out notification.

syn-interval-timer: Master and Slave stations use this timer to monitor the transmission medium for "permanent transmitters". After every Ph-DATA indication primitive with PhICI specifying START-OF-ACTIVITY, the timer is loaded with the value T_{SYNI} (see 5.5.4) and decremented every bit time, as long as no Ph-DATA indication primitive with PhICI specifying either END-OF-ACTIVITY or END-OF-DATA-AND-ACTIVITY has been received. If the timer expires, an error of the transmission medium has occurred. The DLMS-user receives a corresponding notification.

GAP-update-timer: This timer operates in the same way as described in 5.5.5.1.1.

isochronous-cycle-timer: The functionality of this timer is as defined in 5.5.5.1.1.

passive-spare- timer: This timer monitors the idle time before sending a SYNCH message. It shall be set according to the time difference between T_{CT} and the current value of the isochronous-cycle-timer T_{RCT} at the end of the last ASP message if the difference is greater than 0. The transmission of the last bit of the last ASP message in an isochronous cycle starts this timer. In the isochronous mode after expiration of the passive-spare-timer, a SYNCH message shall be sent and a synch notification event shall be sent to the DLMS-user.

send-delay-timer: When the time master receives a DL-CS-TIME-EVENT request primitive from the local DLS-user, this timer is started with the value = $2 \times T_{CSI}$ and decremented each bit time. The timer is stopped after confirmation of the transmission of the last portion of a TE DLPDU (see 7.7). The value of send delay time is calculated as the difference between the start value ($2 \times T_{CSI}$) and the read send-delay-timer value. The calculated send delay time is passed to the local DLS-user. In case the timer has expired, the DLS-user is notified of a clock synchronization sequence violation.

receive-delay-timer: When the time receiver receives the DLPDUs last bit of a TE DLPDU (see 7.7) indicated by a Ph-DATA indication primitive (PhICI specifying either END-OF-ACTIVITY or END-OF-DATA-AND-ACTIVITY) has been received, this timer is started with the value = $2 \times T_{CSI}$ and decremented each bit time. The timer is stopped after the receiving of the DLPDUs last bit of a CV DLPDU (see 7.8) indicated by a Ph-DATA indication primitive (PhICI specifying either END-OF-ACTIVITY or END-OF-DATA-AND-ACTIVITY) has been received. The value of the receive delay time is calculated as difference between the start value ($2 \times T_{CSI}$) and the read receive-delay-timer value. The calculated receive delay time is passed to the

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