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Industrial networks — Single-drop digital communication interface

Part 3: Wireless extensions

National foreword

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European foreword

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Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 61131-1	-	Programmable controllers - Part 1: General information	EN 61131-1	-
IEC 61131-2	-	Industrial-process measurement and control - Programmable controllers - Part 2: Equipment requirements and tests	-	-
IEC 61131-9	2022	Programmable controllers - Part 9: Single-drop digital communication interface for small sensors and actuators (SDCI)	EN IEC 61131-9	2022
IEC 61158-1	-	Industrial communication networks - Fieldbus specifications - Part 1: Overview and guidance for the IEC 61158 and IEC 61784 series	EN IEC 61158-1	-
IEC 62657-2	-	Industrial communication networks - Wireless communication networks - Part 2: Coexistence management	EN 62657-2	-
ETSI EG 203 367	-	Short Range Devices (SRD) ETSI EG 203 367 "Guide to the application of harmonized standards covering articles 3.1b and 3.2 of the Directive 2014/53/EU (RED) to multi-ratio and combined ratio and non-radio equipment"	-	-
ETSI EN 300 328	-	Wideband transmission systems; Data transmission equipment operating in the 2,4 GHz ISM band and using wide band modulation techniques; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU"	-	-
ETSI EN 300 440	-	Short Range Devices (SRD); Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU	-	-

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FCC §15.247	-	Radio frequency devices; Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz	-
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**INDUSTRIAL NETWORKS –
SINGLE-DROP DIGITAL COMMUNICATION INTERFACE –****Part 3: Wireless extensions****FOREWORD**

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The text of this International Standard is based on the following documents:

Draft	Report on voting
65C/1268/FDIS	65C/1274/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61139 series, published under the general title *Industrial networks – Single-drop digital communication interface*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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

INTRODUCTION

The wired single-drop digital communication interface technology for small sensors and actuators (SDCI), commonly known as IO-Link™¹ is subject matter of the standard IEC 61131-9. It extends the traditional switching input and output interfaces as defined in IEC 61131-2 towards a point-to-point communication link using coded switching. This technology enables the cyclic exchange of digital input and output process data between a Master and its associated W-Devices (sensors, actuators, I/O terminals, etc.). The Master can be part of a fieldbus communication system or any stand-alone processing unit. The technology also enables the acyclic transfer of parameters to Devices and the propagation of diagnosis information from the Devices to the upper-level automation system (controller, host) via the Master/gateway.

This document provides the necessary changes and extensions to the basic IEC 61131-9 for wireless communication including the radio characteristic, air interface, frequencies, message/frame types, and pairing mechanism as well as the necessary configuration management and the changes of state machines compared to IEC 61131-9.

The main characteristics of the SDCI wireless technology are:

- The application interface for cyclic (Process Data) and acyclic data (On-request Data) is compatible to SDCI; from the user perspective, it is a transparent view on wireless Devices (W-Devices).
- A wireless Master (W-Master) can handle up to 5 transmission tracks in parallel, each W-Track can handle a maximum of 8 W-Devices, thus supporting up to 40 W-Devices per W-Master.
- Up to 3 W-Master can be placed in a cell, yielding a maximum of 120 W-Devices per W-Master cell.
- A scan service is available for discovery of yet unpaired W-Devices.
- A pairing service is provided to assign W-Devices to a W-Master, corresponding to a logical cable connection.
- Controlled roaming between multiple W-Master cells is supported by a dedicated handover mechanism.
- A minimum transmission cycle time of 5 ms can support high-speed wireless applications with a payload of up to 32 octets.
- SDCI wireless also supports mechanisms for low energy W-Devices.
- SDCI wireless utilizes in this version radios for the 2,4 GHz ISM band, divided to frequency channels with a spacing of 1 MHz.
- Frequency Hopping changes the frequency channels for each transmission as a measure against interference, yielding a residual failure probability (RFP) of 10^{-9} which is similar to a wired connection.
- Wireless coexistence with other wireless systems (e.g. WLAN) is achieved with a blocklisting mechanism.
- To comply with regulatory standards, transmission power is limited to ≤ 10 dBm (10 mW) EIRP, still yielding a range of up to 20 m in case of a W-Master cell with one W-Track. In case of more than one W-Track, 10 m can be achieved. These figures are dependent on the machine environment.
- Each transmission W-Track in a W-Master can use its own narrow-band transceiver and dedicated antenna or all of them can use a single shared transceiver and/or antenna.

¹ IO-Link™ is a trade name of the IO-Link Consortium. The IO-Link Consortium is a non-profit trade organization to support the IO-Link communication. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by IEC of the trade name holder or any of its products. Compliance to this document does not require use of the trade name. Use of the trade name IO-Link™ requires permission of the trade name holder, see <https://io-link.com/en>.

INDUSTRIAL NETWORKS – SINGLE-DROP DIGITAL COMMUNICATION INTERFACE –

Part 3: Wireless extensions

1 Scope

This part of IEC 61139 specifies a wireless single-drop digital communication interface (SDCI wireless).

This is an extension to the single-drop digital communication interface (SDCI) technology that is specified in IEC 61131-9.

This document specifies the wireless communication services and protocol (physical layer, data link layer and application layer in accordance with the ISO/OSI reference model) for W-Masters and W-Devices.

NOTE This document does not cover the integration into higher level systems such as fieldbuses.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61131-1, *Programmable controllers – Part 1: General information*

IEC 61131-2, *Programmable controllers – Part 2: Equipment requirements and tests*

IEC 61131-9:2022, *Programmable controllers – Part 9: Single-drop digital communication interface for small sensors and actuators (SDCI)*

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

IEC 62657-2, *Industrial networks – Coexistence of wireless systems – Part 2: Coexistence management*

ETSI EG 203 367, *Short Range Devices (SRD) ETSI EG 203 367 "Guide to the application of harmonized standards covering articles 3.1b and 3.2 of the Directive 2014/53/EU (RED) to multi-radio and combined radio and non-radio equipment*

ETSI EN 300 328, *Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU"*

ETSI EN 300 440, *Short Range Devices (SRD); ETSI EN 300 440 Radio equipment to be used in the 1 GHz to 40 GHz frequency range; Harmonized Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU*

FCC §15.247, *Radio frequency devices; Operation within the bands 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz*

3 Terms and definitions, abbreviated terms and conventions

For the purposes of this document, the terms and definitions given in IEC 61131-1 and IEC 61131-2 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1 Terms and definitions

3.1.1

Acknowledge

response information indicating the acceptance of a message

Note 1 to entry: Uppercase "Acknowledge" is used for SDCI wireless Acknowledge mechanism, while lowercase "acknowledge" is used in a generic manner.

3.1.2

Adaptive Hopping Table

mechanism that enables a change of the hopping table of a W-Track while the communication is already running (improvement of connection)

3.1.3

air interface

radio-based communication between the W-Master and the W-Devices

3.1.4

Alert Back Alive

indication from the W-Device, which informs the W-Master, a communication error has occurred

3.1.5

Application Layer

part of the protocol responsible for the transmission of process data objects and on-request data objects

3.1.6

blocklist

list of frequency channels not to be used for SDCI wireless communication within a W-Master

3.1.7

broadcast

mechanism to send a master command to all W-Devices in a W-Track

Note 1 to entry: A broadcast is restricted to specific Master commands according to Table C.2.

3.1.8

cell

logical grouping of 1 or up to 3 W-Masters with a dedicated coverage area

Note 1 to entry: This is often associated to a machine.

3.1.9

checksum

data integrity measures for each Pre-Downlink octets, downlink packet or uplink packet in the Physical Layer

3.1.10**ConfigSyncword**

data integrity measures for each pre-downlink, downlink or uplink in the physical layer

3.1.11**configuration frequency channels**

frequency channels reserved for configuration purposes

3.1.12**ConnectionParameter**

set of parameters containing the data that are necessary to establish wireless communication

Note 1 to entry: The parameters are transmitted via the pairing mechanism. These parameters are only changeable via a new pairing or re-pairing.

3.1.13**control interval**

time required to change the radio to receive mode, to transmit mode or to change frequencies

3.1.14**control octet**

header, indicating the structure and purpose of a W-Message

3.1.15**communication channel**

logical connection between W-Master and W-Device

Note 1 to entry: Four communication channels are defined: master command channel, process data channel, ISDU channel (for parameters), and diagnosis channel (for events).

3.1.16**communication error**

unexpected disturbance of the transmission

3.1.17**Cyclic Mode**

operation mode to achieve the required latency time

Note 1 to entry: Not occupied retries by process data are used for acyclic exchange of on-request Data. The configuration channels are not used.

3.1.18**data channel**

frequency channel used for (process) data exchange

3.1.19**DataSyncword**

syncword used for the data channels

Note 1 to entry: More detailed explanation is given in 5.3.4.

3.1.20**disconnected**

in a state where communication between a W Device and its W Master has been lost

3.1.21**Double Slot**

type of time slot required for the transmission of a Double Slot packet

Note 1 to entry: More detailed explanation is given in 4.5.4.

3.1.22

downlink

communication link from a W-Master to their associated W-Devices

3.1.23

event

instance of a change of conditions in a W-Device

Note 1 to entry: Uppercase "Event" is used for SDCI wireless Event mechanism, while lowercase "event" is used in a generic manner.

3.1.24

frequency band

range in the frequency spectrum that is assigned by regulatory organizations for use for specific applications or a group of applications

Note 1 to entry: The ITU as international regulatory organization assigns only radio communication services to a specific range in the frequency spectrum.

[SOURCE: IEC 62657-2:2022]

3.1.25

frequency channel

span of the frequency spectrum which is characterized by lower cut-off frequency and upper cut-off frequency or by center frequency and frequency bandwidth

[SOURCE: IEC 62657-2:2022]

3.1.26

frequency division multiple access

access method where users are allocated to individual frequency channels

3.1.27

FullDownLink packet

data structure of the regular downlink packet

3.1.28

Gaussian frequency shift keying

binary frequency shift modulation with gaussian filter limiting its spectral width

3.1.29

guard interval

time interval between successive uplinks to avoid collisions on air

3.1.30

header

first part of a message packet

Note 1 to entry: The header consists of preamble, Syncword, MasterID, track number, and Acknowledge.

3.1.31

IMA message

message from the W-Device, which informs the W-Master, that it is still functional

3.1.32

IMA time

user configured watchdog time in which the W-Device shall send an IMA message, if no other messages had been sent

3.1.33**InspectionLevel**

degree of verification for the W-Device identity during start-up

3.1.34**Indexed Service Data Unit**

data unit that is used for acyclic transmission of parameters which is segmented in multiple W-Frames

3.1.35**industrial, scientific and medical application**

ISM

operation of equipment or appliances designed to generate and use locally radio frequency energy for industrial, scientific, medical, domestic or similar purposes, excluding applications in the field of telecommunications

[SOURCE: ITU Radio Regulations, edition of 2020, Volume 1 – Art.1 §1.15]

3.1.36**ISM frequency band**

radio frequencies reserved for industrial, scientific, and medical use

3.1.37**link quality indication**

service for evaluation of the functionality and reliability of the W-Master and W-Device connections

3.1.38**MasterID**

Identification number of a particular W-Master

3.1.39**multicast**

transmission of the same message to a group of receivers, identified by their group address

Note 1 to entry: The term "multicast" is used even if the group includes all the receivers.

[SOURCE: IEC 61375-1:2012, 3.1.34]

3.1.40**negative Acknowledge**

indicator for a missing response message

EXAMPLE: a wrong CRC or no received DLink or ULink.

3.1.41**negotiation**

step within the pairing procedure for configuration of the ConnectionParameter

3.1.42**packet error probability**

probability that a received packet contains at least one bit error (inverted bit with respect to the corresponding bit sent)

Note 1 to entry: For the calculation see Annex K.

3.1.43**packet error ratio**

number of lost or incorrectly received packets divided by the total number of sent packets

3.1.44

pairing

procedure to log in a wireless device to an access point and subsequently creates a common link key that can be used as a basis for a trusted relationship or a secure connection

3.1.45

payload

data of a packet transmitted during communication that does not contain any control or protocol information in respect of the relevant layer

3.1.46

Port and Device Configuration Tool

configuration tool for a W-Master and W-Devices

3.1.47

PortCycle

IO update is performed in a cyclic manner, which is determined by the W-Port related cycle time, within which the IO data of the W-Device are read or written

3.1.48

preamble

fixed bit pattern used for bit synchronization and calibration of automatic gain control of a radio receiver

3.1.49

PreDownLink mechanism

PreDownLink

mechanism used to minimize the radio-on time to save power of low energy W-Devices

Note 1 to entry: The 2 octet payload is used for low energy W-Devices only.

Note 2 to entry: This document uses the term PreDownLink as a short form of the mechanism of PreDownLink.

3.1.50

residual failure probability

probability that the data cannot be transmitted within the set MaxRetry

3.1.51

received signal strength indication

estimated measure of power level that a W-Master (RSSI_M) or W-Device (RSSI_D) is receiving from its counterpart

3.1.52

roaming

feature that allows mobility to a predefined W-Device between multiple predefined W-Masters by handover disconnect and handover connect procedures

3.1.53

SDCI Device

Device

single passive peer to a Master such as a sensor or actuator

Note 1 to entry: Uppercase "Device" is used for SDCI equipment, while lowercase "device" is used in a generic manner.

[SOURCE: IEC 61131-9:2022, 3.1.14, modified – The preferred term SDCI Device has been added.]

3.1.54**segmented data**

data to be splitted over multiple packets

3.1.55**SerialNumber**

unique vendor specific code for each individual W-Device

3.1.56**Service Mode**

operational mode in which a W-Master track also utilizes the configuration channels

Note 1 to entry: This mode is required for discovery, pairing and roaming procedures. A W-Master shall only operate with one of its tracks in Service Mode at the same time.

3.1.57**Single Slot**

type of time slot required for the transmission of a Single Slot packet

3.1.58**synchronization**

process of matching timing and the frequency tables between a W-Master and corresponding W-Devices

3.1.59**UniqueID**

Unique identifier for each W-Device

Note 1 to entry: 9 octet identifier that consists of the 16 bit manufacturer distinguishing VendorID, 24 bit DeviceID and a 32 bit W-Device distinguishing identifier, which is related to the SerialNumber. See C.4.4.

3.1.60**unpairing**

user action via PDCT, to delete the permanently stored ConnectionParameter on the W-Device side and subsequently disconnects the W-Device and on the W-Master side the Unpairing command clears the current W-Port configuration which disables the communication with the unpaired W-Device

3.1.61**uplink**

single cast W-message from a W-Device to its W-Master consisting of header, payload, and cyclic redundancy check

3.1.62**W-Bridge**

W-Device that connects a SDCI Device via wireless digital communication interface to a W-Master

3.1.63**W-Coexistence**

state of a wireless communication solutions within an industrial area if it fulfills their communication requirements application

3.1.64**W-Cycle**

combined utilization of TDMA and FDMA with several W-Sub-cycles to achieve a reliable wireless transmission

3.1.65

W-Device

single peer to a W-Master such as a single-drop digital communication interface wireless sensor or actuator

3.1.66

W-Frame

virtual structure to arrange message transmissions comprising a W-Master message (in downlink direction) and all subsequent W-Device messages (in uplink direction)

Note 1 to entry: For details see Figure 17.

3.1.67

W-Master

peer connected through W-Ports via radio to one up to n W-Devices and which provides an interface to the gateway to the upper level communication systems or PLCs

3.1.68

W-Message

content of payload comprising control octet and (segmented) data exchanged between W-Master and W-Device

3.1.69

W-Parameter

generic term that describes all the parameters located in the wireless specific index range

3.1.70

W-Port

logical wireless port number to address a paired W-Device

3.1.71

W-Sub-cycle

time duration to transmit one W-Frame

3.1.72

W-Track

physically wireless transmission track comprising a (narrowband band) transceiver with its own antenna and dedicated frequency channels for transmitting the messages between W-Master and W-Device by W-Frames

3.1.73

W-Track and W-Device-Mapper

assignment of a W-Port to a specific W-Track number and Slot number

3.1.74

WLAN channels

frequency blocks intended to be used by WLAN

3.2 Abbreviated terms

ABA	Alert Back Alive
ACK	Acknowledgement
AHT	Adaptive Hopping Table
AL	Application Layer
Avg.	Average
BC	Broadcast

C	Conditional
CO	Control octet
CRC	Cyclic redundancy check
DL	Data Link Layer
DL-A	Data scheduling
DL-B	Data handling
DLink	Downlink
DS	Data Storage
DSlot	Double Slot
ED	Event Dispatcher
FDMA	Frequency division multiple access
GFSK	Gaussian frequency shift keying
HMI	Human machine interface
I	Initiator
IL	InspectionLevel
IMA	I am alive
IO	Input Output
IODD	IO Device Description
IOL	IO-Link
IOLW	IO-Link Wireless
ISDU	Indexed Service Data Unit
ISM	Industrial, scientific and medical application
LE	Low energy
LFSR	Linear Feedback Shift Register
LQI	Link quality indication
LQI_D	Link quality indication of the W-Device
LQI_M	Link quality indication of the W-Master
LSO	Least Significant Octet
M	Mandatory
MSB	Most Significant Bit
MSO	Most Significant Octet
NACK	Negative Acknowledge
OD	On-request data
PD	Process Data
PDCT	Port and Device Configuration Tool
PDE	Process Data Exchange
PEP	Packet error probability
PER	Packet error ratio
PL	Physical Layer
PLC	Programmable logic controller
PM	Parameter Manager
ppm	part per million = 1/1 000 000
R	Receiver

RF	Radio frequency
RFP	Residual Failure Probability
RSSI	Received Signal Strength Indication
RSSI_D	Received signal strength indication, received by a W-Device
RSSI_M	Received signal strength indication, received by a W-Master
Rx	Receive
S	Selected
SDCI	Single-drop digital communication interface (see IEC 61131-9)
SDCI-W	Single-drop digital communication interface wireless (see this document)
Slot_N	Slot number
SM	System Management
SMI	Small Medium
SSlot	Single Slot
TDMA	Time Division Multiple Access
TDMapper	Track and W-Device-Mapper
Track_N	Track number
Tx	Transmit
ULink	Uplink
W-<term>	Wireless <term>
WLAN	Wireless local area network

3.3 Conventions

3.3.1 General

The service model, service primitives, and the diagrams shown in this document are entirely abstract descriptions. The implementation of the services can reflect individual issues and can be different.

3.3.2 Service primitives

Service primitives are used to represent service provider/consumer interactions (see ISO/IEC 10731 [26]). Each service consists of up to four service primitives:

- request primitive (.req),
- indication primitive (.ind),
- response primitive (.rsp), and
- confirmation primitive (.cnf).

An indication can occur with or without the corresponding response, a request can occur with or without the corresponding confirmation.

Figure 1 shows a generalized example of a confirmed service. In this case, "Initiator" and "Responder" correspond to either Master or Device and not to the layer within one of each.

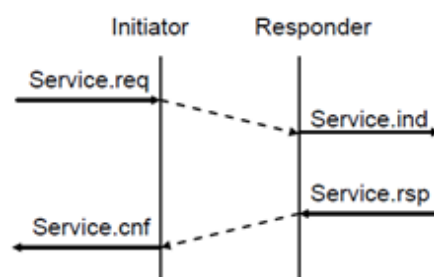


Figure 1 – Generalized example of a confirmed service

3.3.3 Service parameters

Service primitives convey parameters which indicate the information available in the provider/consumer interaction. In any particular interface, not each and every parameter needs to be explicitly stated.

The service specification in this document uses a tabular format to describe the component parameters of the service primitives. The parameters which apply to each group of service primitives are set out in tables. Each table consists of up to five columns:

- 1) parameter name;
- 2) request primitive (.req);
- 3) indication primitive (.ind);
- 4) response primitive (.rsp); and
- 5) confirmation primitive (.cnf).

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

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

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

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

3.3.4 Service procedures

The procedures are defined in terms of:

- the interactions between application entities through the exchange of protocol data units; and
- the interactions between a communication layer service provider and a communication layer service consumer in the same system through the invocation of service primitives.

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

3.3.5 Service attributes

The nature of the different (W-Master and W-Device) services is characterized by attributes. All services are defined from the view of the affected layer towards the layer above.

- I Initiator of a service (.ind) (towards the layer above)
- R Receiver (responder) of a service (.req) (from the layer above)

Figure 2 shows the example of initiator / receiver of services (W-Device)

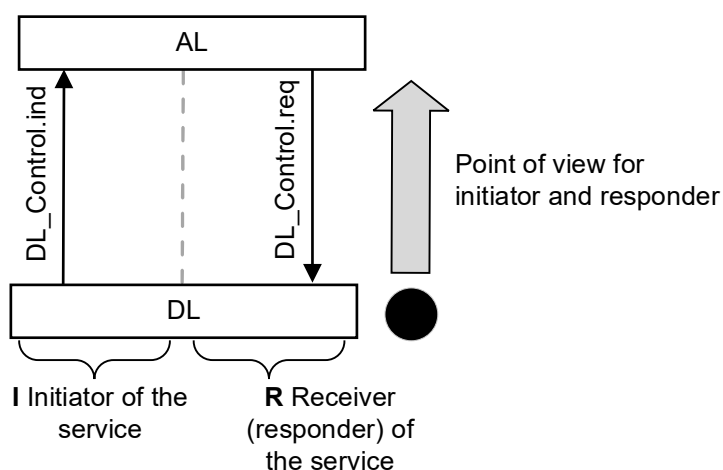


Figure 2 – Example of initiator / receiver of services (W-Device)

3.3.6 Figures

For figures that show the structure and services of protocol layers, the following conventions are used:

- an arrow with just a service name represents
 - a request and the corresponding confirmation (the request being in the direction of the arrow);
 - an indication and the corresponding response (the indication being in the direction of the arrow);
- a request without confirmation as well as an indication without response are labelled as such (i.e. service.req, service.ind).

Figure 3 shows the example of service between W-Master and W-Device in generalized and detailed view.

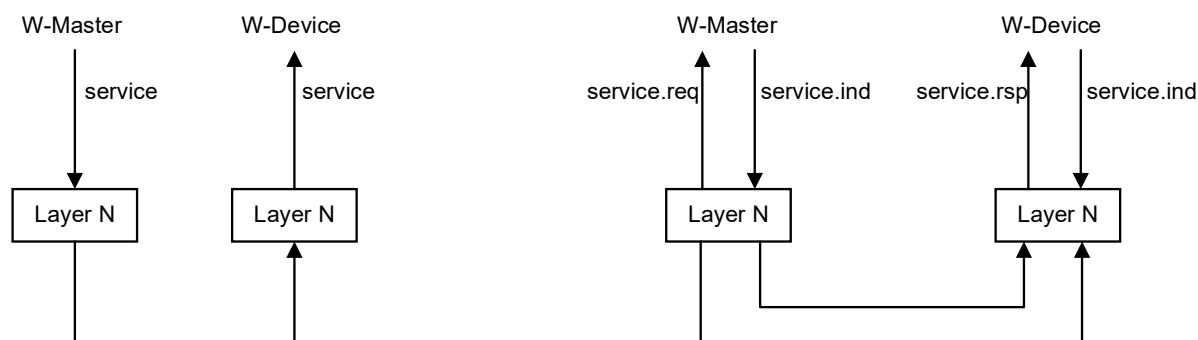


Figure 3 – Example of service between W-Master and W-Device in generalized and detailed view

Figure 4 shows the example of confirmed / non-confirmed services (W-Device).

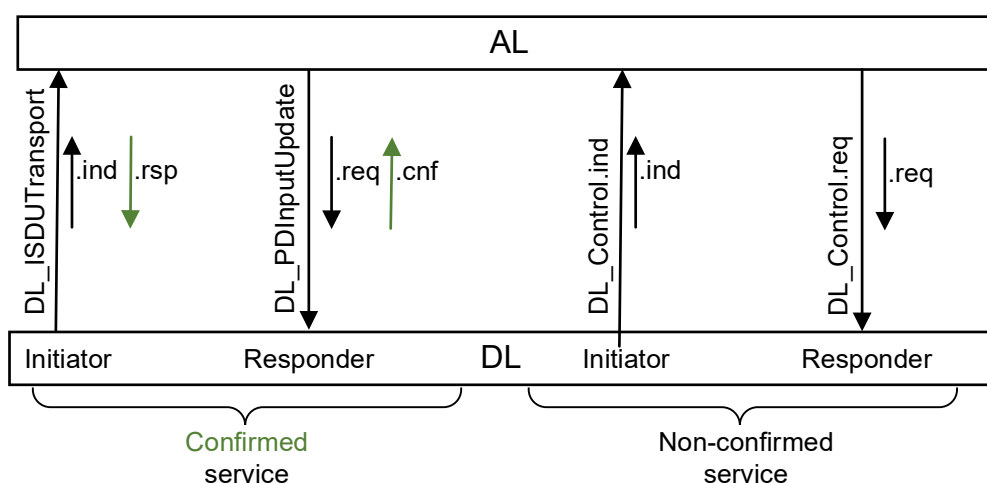


Figure 4 – Example of confirmed / non-confirmed services (W-Device)

3.3.7 Transmission octet order

See 5.3.1.

3.3.8 Behavioral descriptions

For the behavioral descriptions, the notations of ISO/IEC 19505 (UML 2) are used (e.g. state, sequence, activity, timing diagrams, guard conditions). The layout of the associated state-transition tables is following the IEC TR 62390.

Due to design tool restrictions the following exceptions apply. For state diagrams, a service parameter (in capital letters) is attached to the service name via an underscore character, such as for example in `DL_SetMode_INACTIVE`. For sequence diagrams, the service primitive is attached via an underscore character instead of a dot, and the service parameter is added in parenthesis, such as for example in `DL_Event_ind (OPERATE)`. Timing constraints are labelled "tm (time in ms)".

Asynchronously received service calls are not modelled in detail within state diagrams.

To find the balance between clearness and degree of detailing not all negative responses or confirmations are modelled explicitly in the state machines.

3.3.9 Triple table format

Some tables, like Table 35 and Table 36, are split in 3 parts and using a single table caption. This triple table format is used according to IEC 61131-9, which is the base standard for this document.

4 Overview of wireless digital communication interface

4.1 Purpose and topology

The SDCI wireless extension is a wireless digital communication interface technology intended to replace the cable(s) for remote sensor/actuator control in production automation of the SDCI technology. Figure 5 shows the general topology of SDCI wired and wireless. The key features are real-time capabilities, very low latency and robustness. Applications within factory automation comprise moving parts such as rotating bottle filling, robot arms and linear moving machinery. These applications are difficult to realize with wired sensor/actuator equipment or suffer from frequently broken wires. These kinds of applications are targets of this document.

Equipment according to this document operates in the unlicensed 2,4 GHz industrial, scientific and medical application (ISM) band and using frequency hopping to reduce the impact of interference. This document specifies the communication between the wireless Master (W-Master) and one or more wireless Devices (W-Devices).

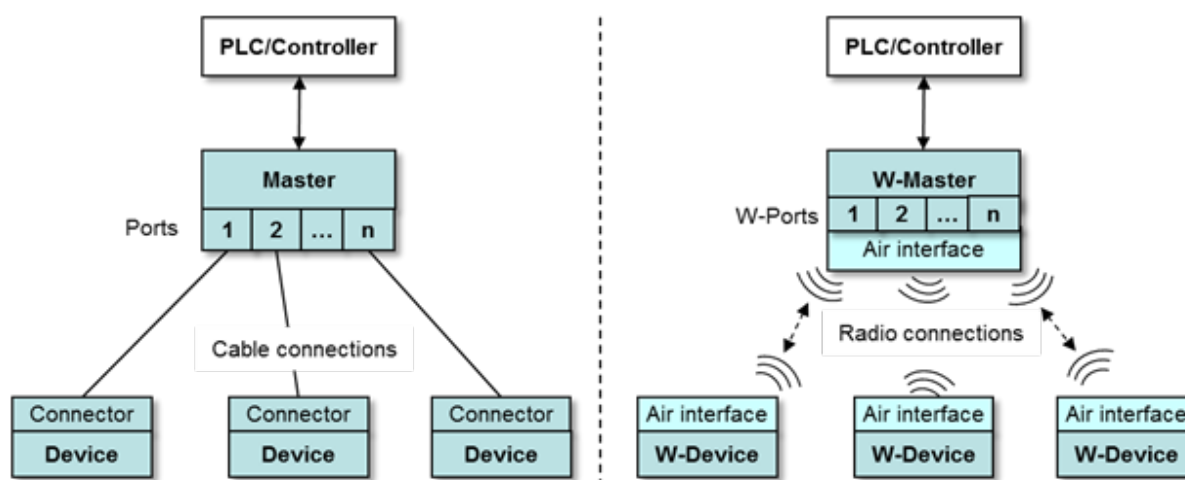


Figure 5 – SDCI wired and wireless topology

From a PLC or Controller users' point of view, Master and W-Master provide the same functionality in respect to Process Data (PD) and On-request Data (OD). The main differences between the two topologies is during commissioning, the discovery of available W-Devices ("scan"), the connection configuration ("pairing") and the parameterization of the air interface ("W-Parameter").

4.2 Positioning in the automation hierarchy

4.2.1 General

Figure 6 shows the architecture of an automation topology with an SDCI wireless system comparable to the SDCI wired system.

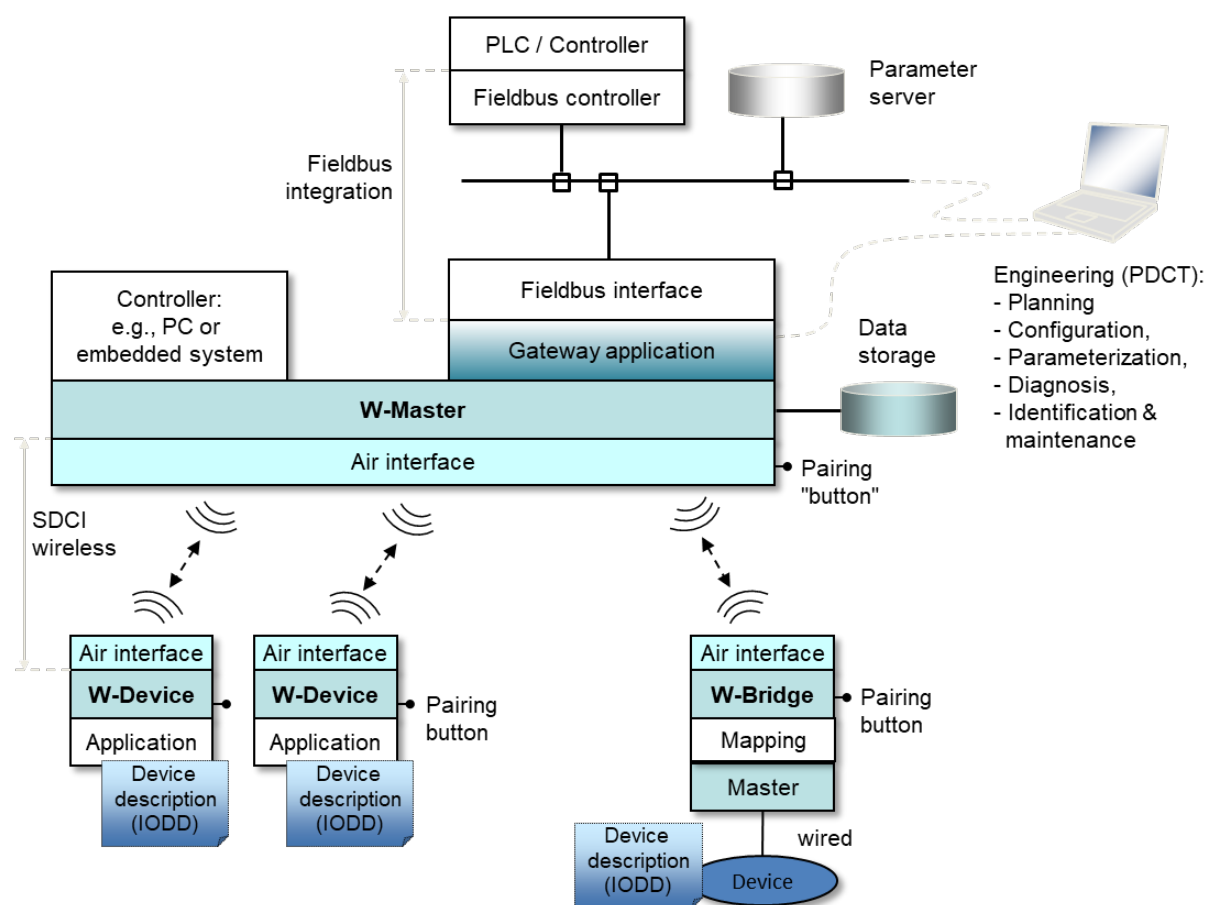


Figure 6 – SDCI wireless system

In all cases a PLC, a PC-based controller, or an embedded system can exchange Process Data (PD) and/or On-request Data (OD) with wire or radio connected devices via Master or W-Master, respectively.

Additional to the SDCI port and device configuration tool (PDCT) according to IEC 61131-9:2022, 11.7.7, the PDCT can be extended by features like:

- Device discovery and pairing support for unpaired Devices.
- Optimizing connection quality of W-Masters and W-Devices.
- Wireless coexistence management for a conflict-free layout of the radio transmissions such as overlapping frequencies of non-SDCI wireless systems.
- Configuration of the W-Parameters as described in the provided IODDs.

This document uses the data storage mechanism of IEC 61131-9 to support faulty Device replacement. To re-establish a wireless connection after a W-Device replacement, pairing buttons or software tools can be used. With pairing buttons activated on both W-Device and W-Master a W-Device can be exchanged without the need of any software tools.

After replacement, the parameters are downloaded automatically from the data storage, if enabled.

4.2.2 Relationship to IEC 61131-9

In relationship to IEC 61131-9, the transfer of the SDCI objects via the downlink and uplink mechanism is outlined in Figure 7.

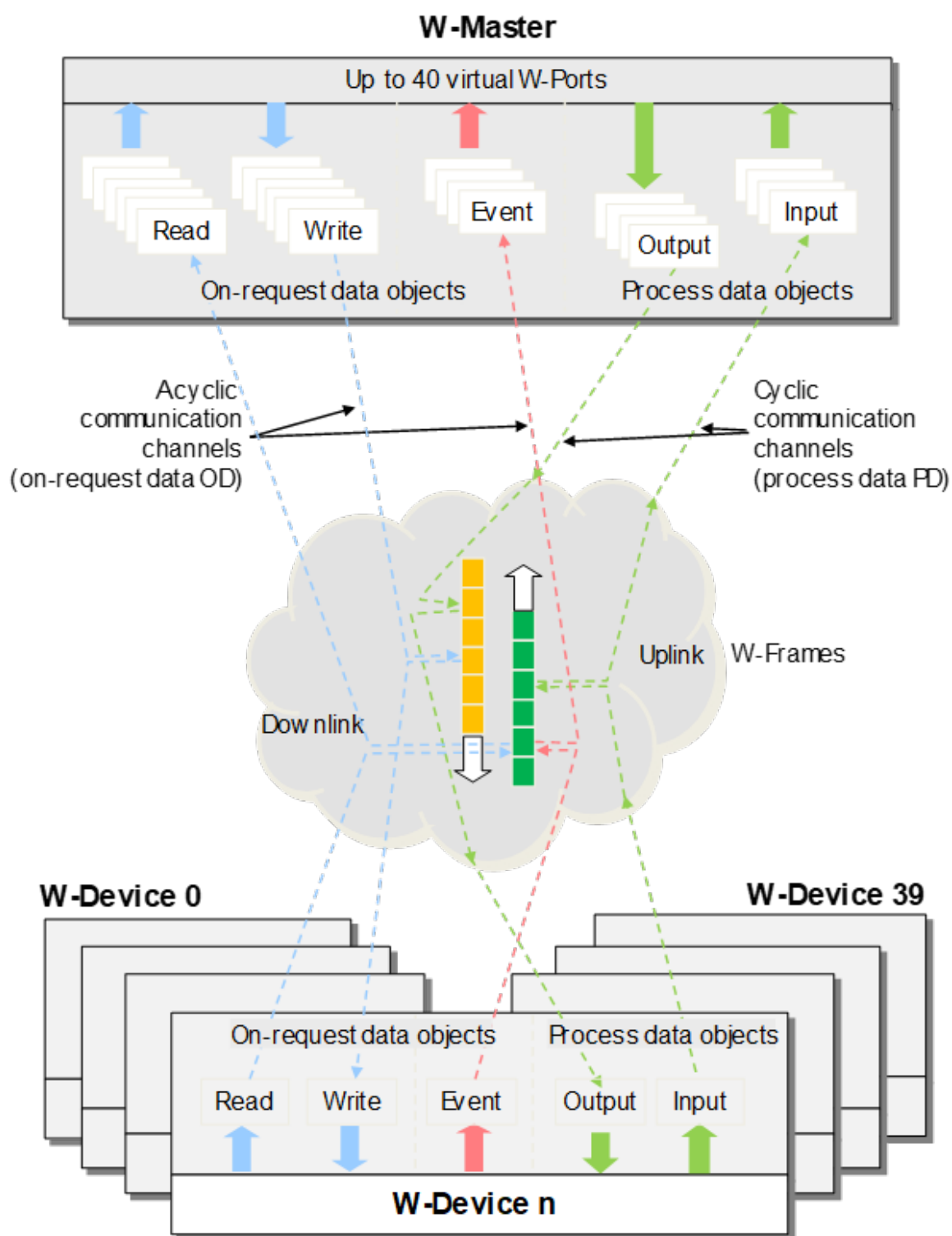


Figure 7 – Object transfer at the Application Layer (AL) level

4.2.3 Role of a W-Master

A W-Master manages up to 40 W-Port instances. The possible maximum number of W-Ports depends on the available tracks and slots and how they are utilized.

A W-Master can comprise up to five (small band) transceivers with their own antenna and dedicated frequency channels, called tracks. Each W-Track can serve up to 8 W-Devices and send and receive alternately. All tracks of a W-Master send at the same time on different frequencies according to the computed frequency hopping tables, providing an optimal medium utilization.

The user may manually operate the W-Master for discovery and pairing of Devices.

During commissioning or roaming Service Mode is used by the W-Master to establish communication with W-Devices (pairing), including checking of the "identity" of the W-Device, i.e. its VendorID, DeviceID, and communication properties. If there is a mismatch between W-Device parameters and the stored parameter set within the W-Master, the parameters in the W-Device are overwritten (see 11.4) or the stored parameters within the W-Master are updated depending on the configuration.

After power on with paired W-Devices, the W-Master establishes communication, including all checks described above.

The W-Master is responsible for the assembly and disassembly of all data from or to the W-Devices (see Clause 11).

4.2.4 Role of a W-Device

A W-Device consists of a single transceiver, the SDCI wireless Device stack and the technology specific application, i.e. the transducer with its technology parameters. The common W-Device applications are the same as in IEC 61131-9 and comprise of configuration parameters, diagnosis information and process data.

4.2.5 Role of a W-Bridge

A W-Bridge is a W-Device to connect a single SDCI Device. The application part of the W-Bridge basically contains a SDCI Master.

For compatibility reasons towards the SDCI Device according to IEC 61131-9 in the system configuration tooling, a straightforward parameter mapping of the wired SDCI Device via the W-Bridge is desired.

4.2.6 System configuration tool

Engineering support for a W-Master is usually provided by a PDCT. The PDCT configures both W-Port and W-Device properties. It combines both an interpreter of the IO Device Description (IODD) and a configurator (see 11.8.2). The parameters provide all the necessary properties to establish communication and the desired function of a sensor or actuator.

4.2.7 Mapping to fieldbuses

See 11.9.1 and IEC 61131-9:2022, 4.7.

4.3 Cell concept

Due to the limited transmission power (see 4.5), the possible range of a W-Master is limited to maximum 20 m in case of only one W-Track as shown in Figure 8. This value is derating to ≤ 10 m if more than one W-Track is active.



Figure 8 – Radius of a cell with a 1 W-Track W-Master

A single W-Master can consist of one up to five tracks. Up to 3 W-Masters are allowed within one cell to a certain extent. If there are more than one W-Master installed in a cell, the MasterID's shall be consecutive. To prevent frequency access conflicts between the tracks, the SDCI wireless extension provides mechanisms to create disjoint frequency tables by W-Masters. Every W-Master has its MasterID, a frequency hopping table and a blocklist.

One W-Master and a group of associated W-Devices form a W-Master cell as shown in Figure 9. The W-Master A is connected to W-Devices A1 to Ai. The W-Master B is connected to W-Devices B1 to Bj, whereas both systems are in an overlapping RF coverage area.

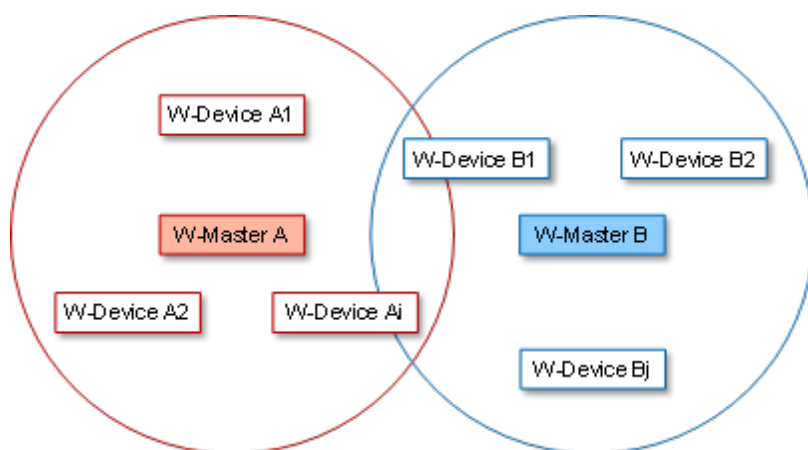


Figure 9 – Cell consisting of 2 W-Master cells

Figure 10 shows the SDCI wireless concept with partly overlapping W-Master RF coverage areas. In one area, there should not exist more than three W-Master in order to avoid interference. W-Master cells with a distance of more than 40 m can use the same MasterID again. W-Master cells with a distance less than 40 m require distinct MasterIDs. The MasterID is used to calculate individual frequency hopping tables.

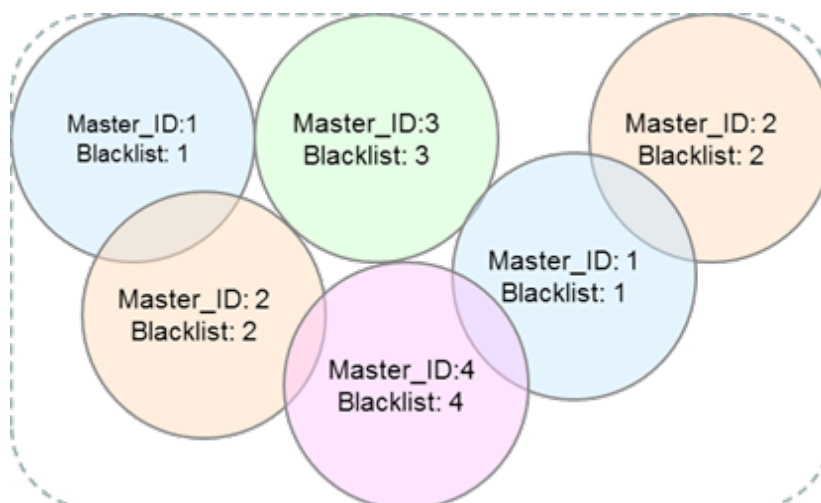


Figure 10 – Cell concept

4.4 Wireless Mechanisms

4.4.1 General

The following mechanisms are used to setup and operate the wireless connections.

4.4.2 Scan (W-Device Discovery)

After power-on, every unpaired W-Device is waiting for connection establishment from a W-Master on the configuration frequency channels. Upon user request for W-Device discovery, the W-Master sends scan request messages on the configuration frequency channels. Any unpaired W-Device receiving such a scan request message is responding with a scan response message, where the W-Device returns its unique identifier (UniqueID) for authentication purposes before pairing. With the help of this mechanism all unpaired W-Devices in the proximity of the W-Master can be discovered. Subsequently, the application can decide to pair the W-Devices.

Several W-Devices can simultaneously respond within an uplink slot. In order to minimize collisions, they are using randomly determined time slot positions within that uplink frequency. In this manner, the W-Master collects all non-paired W-Devices over time within several W-Sub-cycles.

4.4.3 Pairing

4.4.3.1 General

Pairing is the equivalent procedure to plug in the cable connection in a wired system.

4.4.3.2 Pairing by UniqueID

This mechanism is provided for pairing of a W-Device with a pre-configured W-Master and reflects the normal commissioning mechanism. The UniqueID of the W-Device is used for automatic identification of the W-Device within the pairing process. An engineering tool or HMI such as an PDCT is required for the pre-configuration of the W-Master, see 10.7.3.

4.4.3.3 Pairing by Button

This mechanism is for manual pairing without detailed knowledge about the W-Device. No Engineering Tool is required for this kind of pairing. The pairing shall be acknowledged on both entities by manual intervention (i.e. pressing a button or equivalent mechanism). In case of a faulty W-Device, which shall be replaced with a new, but identical W-Device, this document provides a simplified procedure for the pairing of both partners without using an engineering tool or PDCT.

4.4.3.4 Re-Pairing by Button

A W-Device previously paired to former W-Master can be re-paired to a new W-Master. If such a W-Device still has the ConnectionParameters of its "old" W-Master, it stays in state Configured. With a button press, the W-Device can be switched by the operator temporarily to state Re_Pairing and listens on the configuration channels for a pairing request message from the new W-Master. The pairing shall be started previously on the W-Master by manual intervention by UniqueID or pressing a button.

4.4.4 Unpairing

A W-Device can be removed from a communication relationship with a W-Master. When the operator wants to unpair one of the W-Devices, the W-Master is triggered by the operator via HMI and starts an unpairing procedure on the dedicated W-Device. This sends an unpairing request to the W-Device, which sends an acknowledgement back to the W-Master. The ConnectionParameters on the W-Device and the related W-Port configuration within the W-Master are deleted.

4.4.5 Roaming

Roaming is a feature that allows mobility to a predefined W-Device between multiple predefined W-Master cells. A W-Master W-Track configured to Roaming Mode is sending scan request messages on the configuration channels to detect roaming W-Devices in their range. Disconnected roaming W-Devices listening for a W-Master shall respond with a scan response message to indicate their presence to this W-Master. The application on the W-Masters can then decide to connect the roaming W-Device by initiating a pairing and configuration sequence.

The support of this function is mandatory for a W-Device and optional for a W-Master.

Handover disconnect is initiated by the W-Master when the application (e.g. the PLC) wants to release the W-Device, for example when the application has finished processing with the roaming W-Device in its current state (e.g. in a tool changer or conveyor belt application). Another reason for a disconnect procedure could be that the Wireless Quality of the W-Port has degraded to an absolute minimum, indicating that the W-Device leaves the range of the W-Master. Reconnection in the case of link quality degradation to the same W-Master should only be done if the link quality has improved substantially.

For any handover procedure with another W-Master, the scan message followed by a pairing and a W-Device startup sequence is utilized.

NOTE The handover procedure requests a certain amount of time where no process data can be exchanged.

An unexpected IMA-Failure detected by a W-Master from a roaming W-Device shall lead to an autonomous handover disconnect of this W-Device for the associated W-Port within the W-Master.

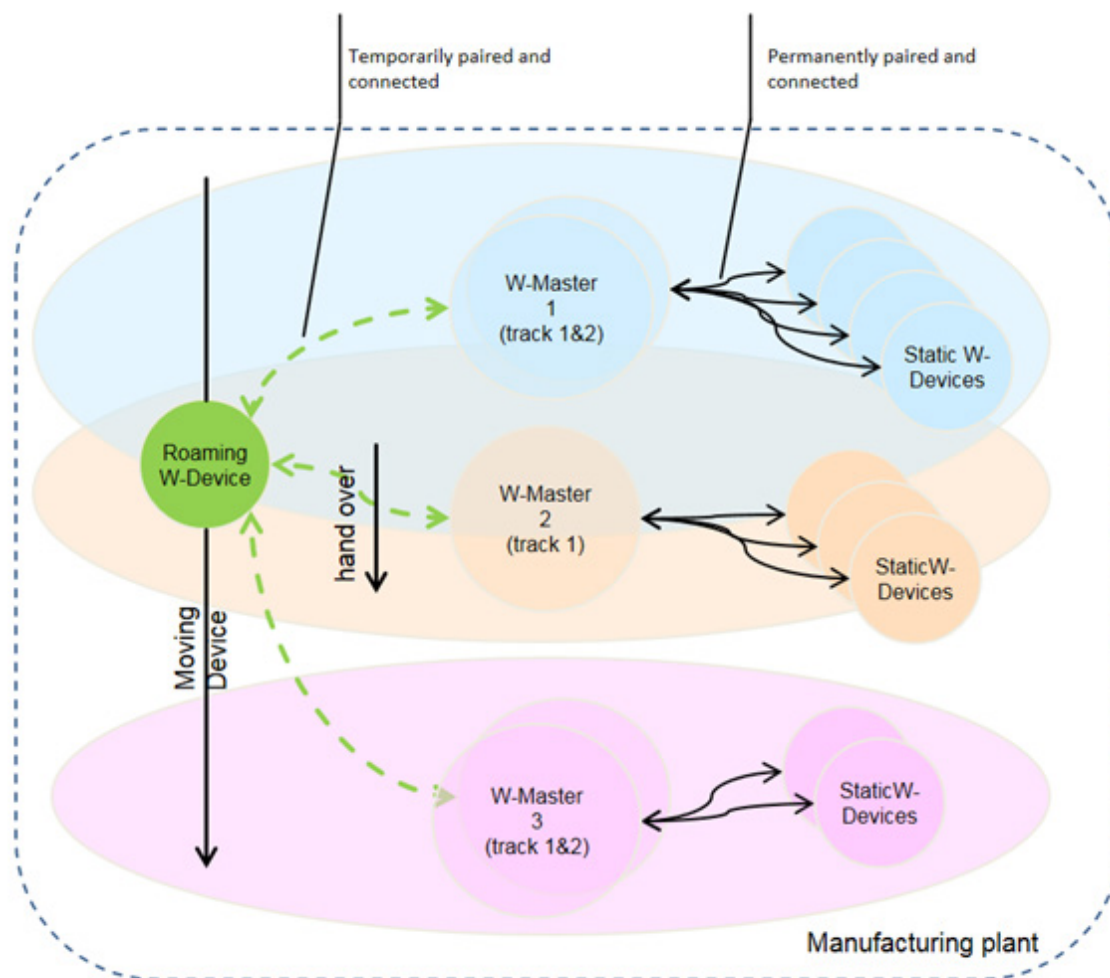


Figure 11 – Roaming between W-Master cells

Roaming is configurable on the W-Master. On each W-Master, not more than one W-Track shall be configured for Roaming Mode, as indicated in Figure 11 for W-Master 1 and W-Master 3. The tracks in Roaming Mode utilize a dedicated frequency hopping table which includes the configuration channels. For the "handover disconnect" procedure, the entire fault indications (e.g. IMA timeout) to the system/user are suppressed, since it is related to an intended action. Accordingly, all pending diagnosis messages of the related W-Port and W-Device are deleted once the "handover disconnect" procedure is completed. A roaming W-Device does not permanently store its pairing information and discards it when disconnected.

The computation of the frequency hopping tables for roaming is described in Clause H.2.

4.4.6 Automatic Pairing

Automatic pairing (AutoPairing) is a feature that allows the pairing of W-Devices to W-Ports directly after the configuration is set without the need for additional user interaction. The automatic pairing is configured in the "PortMode" element in parameter "WPortConfigList" (see E.1.2). If the "PortMode" element is set to "Cyclic AutoPairing" or "Roaming AutoPairing", the AutoPairing is activated for this port. The behavior of the AutoPairing mechanism depends on the active mode of the service track of the W-Master:

- If the service track is in Cyclic Mode, the pairing is triggered once after the W-Port configuration is set. If the configured W-Device is not available at that time, the pairing procedure will fail. The user will have to start the pairing manually again when the W-Device is available.

- If the service track is in Roaming Mode, the pairing is triggered once after the W-Port configuration is set. If the W-Device is not available at that time, the pairing procedure will fail. As the W-Master is permanently scanning for W-Devices in this mode, the pairing can be automatically triggered again, when the configured W-Device is found in the scan results.

The used pairing method for AutoPairing is always "Pairing by UniqueID" as described in 4.4.3.2.

4.4.7 Transmission Error Handling

Transmitted packets in both uplink and downlink direction are subject to error detection via CRC and shall be acknowledged by the receiving side. W-Devices acknowledge correct reception of their downlink packets within the respective subsequent uplink packets. Within the next downlink, the W-Master acknowledges correct reception of the uplink packet to each W-Device. In case of missing acknowledgments, the W-Master uses this information to initiate a retransmission within the same W-Cycle. When all retransmissions fail within a W-Cycle, a communication error is indicated towards system management.

4.4.8 "I am alive" supervision (IMA)

The activity of a W-Device is monitored via an "I am alive" (IMA) timer in the W-Master. When a W-Device has no data to transmit for a time period longer than its configured IMATime, an IMA message shall be sent by the W-Device before the IMA-timer expires. When the supervision IMA-timer of the W-Master expires, i.e. because the W-Device is down, a communication error shall be indicated via system management.

4.4.9 Wireless Quality supervision

Wireless Quality is used for evaluation of the functionality and reliability of the SDCI wireless system in its application environment of the wireless connection. The parameter WirelessQuality of a communication link between W-Master and a W-Device is continuously monitored and can be accessed on W-Master by the gateway application via service GetPortQuality.

4.5 Concept of air interface

4.5.1 General

SDCI wireless shall use the license-free 2,4 GHz ISM band from 2,4 to 2,483 5 GHz compliant to Bluetooth SIG – Regulatory Committee, "Bluetooth low energy Regulatory Aspects", V10r00, 26 April 2011 (see [7]²), which also forms the basis for the well-known Bluetooth^{®3}-technology. It is therefore possible to cost-effectively use existing integrated radio circuits available on the market to build SDCI wireless systems.

NOTE There is no system compatibility between Bluetooth and SDCI wireless technology. For more details see 5.4.

² Numbers in square brackets refer to the Bibliography.

³ Bluetooth[®] is the trade name of a product supplied by the Bluetooth Special Interest Group. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the product named. Equivalent products may be used if they can be shown to lead to the same results.

4.5.2 Frequency division multiple access (FDMA)

4.5.2.1 General

Using different carrier frequencies in this document follows in principle the frequency division multiple access (FDMA) technology. SDCI wireless shall periodically change the transmission frequencies ("frequency hopping") to improve robustness against burst interferences. W-Coexistence with other wireless systems and other SDCI wireless cells is possible through omitting those frequencies within the table of unusable transmission frequencies ("blocklisting").

4.5.2.2 Frequency Hopping Tables

To compute the frequency hopping tables for a W-Master and its W-Devices, SDCI wireless defines dedicated channel hopping sequence algorithms that depend on the individual MasterID to achieve W-Coexistence within neighboring SDCI wireless systems. For W-Coexistence with other wireless systems, a blocklist can be utilized to avoid certain frequency channels in the computed hopping table. The hopping sequence is transferred to the W-Device during pairing. For more details, see Clause H.2.

4.5.2.3 Blocklist

To suspend frequency ranges, they can be defined in the blocklist. The blocklist is configurable via SetMasterConfig. For more details, see Clause H.1.

4.5.2.4 Configuration channels

Configuration of W-Master and W-Devices is required prior to cyclic data exchange. For this purpose, the frequency channels "1" (2 401 MHz) and "80" (2 480 MHz) are exclusively used in an alternating manner for ConnectionParameter exchange and initial scan and pairing of W-Master with its W-Devices. For a detailed description of usage of the configuration channels see Clause H.3.

4.5.2.5 Data channels

The frequency channels 3 (2 403 MHz) to 78 (2 478 MHz) can be used for cyclic data exchange. This number of frequency channels allows the configuration of W-Master sets disjoint from their cell neighbors for W-Coexistence. The set of frequency channels a W-Master uses is configured in the frequency hopping table (see Clause H.2).

4.5.3 Time Division Multiple Access (TDMA)

4.5.3.1 General

SDCI wireless uses Time Division Multiple Access (TDMA) principles. A communication exchange between a W-Master and its W-Devices is splitted into a "downlink" phase that is immediately followed by an "uplink" phase for a dedicated W-Track and frequency channel. The transmitters on the W-Master and W-Devices are operating in half-duplex mode, switching between Tx and Rx mode according to their time slots.

TDMA requires precise timings on both, sender and receiver. At the beginning of a TDMA cycle, the frequency channel is selected from the hopping table. The W-Devices respond at their subsequent respective time slots using the same frequency channel.

4.5.3.2 Downlink

The downlink communication from W-Master to its W-Devices can contain W-Messages for several W-Devices as shown in Figure 12. It is therefore a multicast communication. Immediately after sending the downlink, the W-Master switches its radios from Tx to Rx mode, awaiting the subsequent uplink transmissions from the W-Devices of that W-Track.