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INTERNATIONAL STANDARD

Industrial networks – Coexistence of wireless systems – Part 2: Coexistence management

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INTERNATIONAL STANDARD

Industrial networks – Coexistence of wireless systems – Part 2: Coexistence management

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INDUSTRIAL NETWORKS – COEXISTENCE OF WIRELESS SYSTEMS –

Part 2: Coexistence management

FOREWORD

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IEC 62657-2 has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation. It is an International Standard.

This fourth edition cancels and replaces the third edition published in 2022. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) alignment of some definitions and specifications of coexistence parameters in order to facilitate their future inclusion in the IEC Common Data Dictionary (IEC CDD) maintained by the IEC;

b) alignment of some definitions and specifications to be consistent with the new IEC 62657-3 and IEC 62657-4;

c) edition 3 of this document was published in June 2022. Some comments were made in the last development stages of this document asking for explanations on how the parts of the IEC 62657 series were structured and how they were related to each other. Resolution of these comments was deferred until a next edition, which means this edition.

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

Draft	Report on voting
65C/1329/FDIS	65C/1337/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 the parts of the IEC 62657 series, under the general title *Industrial networks – Coexistence of wireless systems,* 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.

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INTRODUCTION

The overall market for wireless communication solutions spans a range of diverse applications, with differing performance and functional requirements. Within this overall market, the industrial automation domain could include:

- process automation, covering for example the following industry branches:
  - oil and gas, refining,
  - chemical,
  - pharmaceutical,
  - mining,
  - pulp and paper,
  - water and wastewater,
  - steel,
- electric power such as:
  - power generation (for example wind turbine),
  - power transmission and distribution (grid),
- factory automation, covering for example the following industry branches:
  - food and beverage,
  - automotive,
  - machinery,
  - semiconductor.

Industrial automation requirements for wireless communication systems are different from those of, for example, the telecommunications, commercial and consumer markets. These industrial automation requirements are identified and provided in IEC 62657-1.

Industrial premises can contain a variety of wireless communication technologies and other sources of radio emissions.

This document is intended for designers and persons responsible for production and process plants, system integrators and mechanical engineers having to integrate and start up wireless systems in machines and plants, and producers of industrial wireless solutions. In particular, it is intended to motivate the exchange of information between automation and radio engineers.

Many wireless industrial automation applications are also located in physical environments over which the operator/owner can exert control, that is, within a physical facility where the presence and operation of all radio emitting devices are under the control of a single entity. This allows wireless management strategies to be employed which are not feasible for equipment installed in public or other unmanaged areas.

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In industrial automation, many different wireless communication systems can operate in the same premises. Examples of these communication systems are IEC 62591 [1][1] (WirelessHART®[2]), IEC 62601 [2] (WIA-PA) and IEC 62734 [3] (ISA100.11a). All these communication systems use IEEE 802.15.4 [4] for the process automation applications. Other examples of wireless communication systems are specified in the IEC 61784-1 series [5] and IEC 61784-2 series [6] CP that use IEEE 802.11 [7] and IEEE 802.15.1 [8] for factory automation applications. Different to wired fieldbuses, the wireless communication devices can interfere with others on the same premises or environment, disturbing each other. Other sources of radio energy in these bands, often at high energy levels, include radiated process heating, plastic welding, plasma lamps, and microwave irradiation devices.

Clearly, without a means to manage the coexistence of these varied emitters, it would be problematic to ensure that wireless systems meet the time-criticality and other performance requirements of industrial automation.

This document describes the management of independent radio sources that use the same transmission medium. The management within a wireless communication system is not the subject of this document. It is assumed that the standard of a wireless system regulates it, for example by a medium access control mechanism.

The IEC 62657 series has four parts:

- Part 1: Wireless communication requirements and spectrum considerations,
- Part 2: Coexistence management,
- Part 3: Formal description of the automated coexistence management and application guidance,
- Part 4: Coexistence management with central coordination of wireless applications.

IEC 62657-1 provides general requirements for industrial automation and spectrum considerations that are the basis for industrial communication solutions. This document specifies the coexistence management of wireless devices to ensure predicable performance. It is intended to facilitate harmonization of future adjustments to international, national, and local regulations.

This document provides the coexistence management concept and process. Based on the coexistence management process, a predictable assuredness of coexistence can be achieved for a given spectrum with certain application requirements. This document describes principles to manage the potential mutual interference that ~~might~~ could occur due to the operation of multiple wireless devices in a plant.

This document provides guidance to the users of wireless systems on selection and proper use of wireless systems. To provide suitable wireless devices to the market, it also serves vendors in describing the behaviours of wireless devices to build wireless systems matching the application requirements.

This document is based on analyses of a number of International Standards, which focus on specific technologies. The intention of this document is not to invent new parameters but to use already defined ones and to be technology independent.

---

[1] Numbers in square brackets refer to the Bibliography.

[2] WirelessHART® is the registered trade name of the FieldComm Group, see www.fieldcommgroup.org. 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.

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INDUSTRIAL NETWORKS – COEXISTENCE OF WIRELESS SYSTEMS –

Part 2: Coexistence management

1 Scope

This part of IEC 62657

- specifies the fundamental assumptions, concepts, parameters, and procedures for wireless communication coexistence;
- specifies coexistence parameters and how they are used in an application requiring wireless coexistence;
- provides guidelines, requirements, and best practices for wireless communication's availability and performance in an industrial automation plant; it covers the life-cycle of wireless communication coexistence;
- helps the work of all persons involved with the relevant responsibilities to cope with the critical aspects at each phase of life-cycle of the wireless communication coexistence management in an industrial automation plant. Life-cycle aspects include: planning, design, installation, implementation, operation, maintenance, administration and training;
- provides a common point of reference for wireless communication coexistence for industrial automation sites as a homogeneous guideline to help the users assess and gauge their plant efforts;
- deals with the operational aspects of wireless communication coexistence regarding both the static human/tool-organization and the dynamic network self-organization.

~~This document provides a major contribution to national and regional regulations. It does not exempt devices from conforming to all requirements of national and regional regulations.~~

This document provides a major contribution to national and regional regulations by supporting to fulfil the requirements using coexistence management.

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 62443 (all parts), ~~*Industrial communication networks – Network and system security*~~ *Security for industrial automation and control systems*

IEC 62657-1:2017, *Industrial communication networks – Wireless communication networks – Wireless communication requirements and spectrum considerations*

IEC 62657-3:2022, *Industrial networks – Coexistence of wireless systems – Part 3: Formal description of the automated coexistence management and application guidance*

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IEC 62657-4:—, *Industrial networks – Coexistence of wireless systems – Part 4: Coexistence management with central coordination of wireless applications*[3]

3 Terms, definitions, abbreviated terms and conventions

3.1 Terms and definitions

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

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

- IEC Electropedia: available at http://www.electropedia.org/ [9]
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
active environmental influence
influence on the signal propagation through interfering of the wireless communication application or wireless application

3.1.2
adjacent channel interference
interference that occurs from wireless devices using adjacent frequency channels

3.1.3
adjacent channel selectivity
ability of a radio receiver to respond to the desired signal and to reject signals in adjacent frequency channels

3.1.4
antenna gain
measure of the effectiveness of an antenna that expresses the ratio between the power required at the input of a reference antenna ~~to~~ and the power ~~supplied to~~ delivered at the input of the given antenna ~~to produce, in a given direction,~~ to achieve the same field strength at the same distance of a given direction

~~[SOURCE: Federal Standard 1037C:1996, modified – Deletion of "loss-free" before "reference antenna", deletion of the two notes and synonyms] [29]~~

3.1.5
antenna radiation pattern
variation of the field intensity of an antenna as an angular function with respect to the axis

3.1.6
antenna type
kind of part of a radio transmitting or receiving system which is designed to provide the required coupling between a transmitter or a receiver and the medium in which the radio wave propagates

Note 1 to entry: In practice, the terminals of the antenna or the points to be considered as the interface between the antenna and the transmitter or receiver should be specified.

Note 2 to entry: If a transmitter or receiver is connected to its antenna by a feed line, the antenna may be considered to be a transducer between the guided waves of the feed line and the radiated waves in space.

[3] Under preparation. Stage at the time of publication: IEC/FDIS 62657-4:2024.

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[SOURCE: IEC 60050-712:1992, 712-01-01, modified – "Addition of "type" after the term, addition of "kind of" at front.] [10]

3.1.7
application communication requirements
quantitative requirements specifying the required conditions and the required characteristics of wireless communication solutions at the communication interface that is met in order to achieve the purpose of the automation application

3.1.8
area of operation
distinguishing properties of the area where the wireless communication system is operated

3.1.9
automated collaborative coexistence management
tool supported collaborative coexistence management with defined interfaces between the tool and the wireless communication system

Note 1 to entry: The tool can be according to IEC 62657-4[4].

3.1.10
automation application
industrial automation application
application of measurement and automatic control in the industrial automation domain

3.1.11
automation application data length
user data length
number of octets that are exchanged at the reference interface

3.1.12
bit rate of the physical link
measure of the number of binary digits transferred per second

~~**3.1.13**~~
~~**blocking frequency**~~
~~ability of a device to avoid part of the available spectrum~~

~~[SOURCE: ETSI TR 102 889-2: 2011, modified – Changed "blacklisting frequencies" to "blocking frequency"] [22]~~

3.1.13
blocked frequency list
list of the blocked frequencies to avoid part of the available spectrum

~~[SOURCE: ETSI TR 102 889-2: 2011, modified – Exchanged "blacklisting frequencies" by "blocked frequency list" and added "to avoid part of the available spectrum"] [22]~~

3.1.14
cellular topology
cellular network topology
network topology where the geographical area is divided in cells

Note 1 to entry: A device can move from one cell to another cell. Devices that are in a cell communicate through a central hub. Hubs in different cells are interconnected.

~~[4] Under preparation. Stage at the time of publication: IEC FDIS 62657-4:2022.~~

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3.1.15
centre frequency
geometric mean of lower cut-off frequency and upper cut-off frequency of a frequency channel

3.1.16
channel number
unsigned integer number identifying a wireless communication channel in accordance with an authoritative document or rule

3.1.17
channel occupation
time interval in which the medium is busy

Note 1 to entry: Beyond the pure transfer of user data, this time includes all time slices necessary to process the transmission protocol, for example to transfer an acknowledgement.

3.1.18
coexistence
wireless communication coexistence
state in which all wireless communication solutions of a plant using shared medium fulfil all their application communication requirements

Note 1 to entry: In IEEE 802.15.2-2003 [11], coexistence is defined as a characteristic of a device.

3.1.19
coexistence management
process to establish and to maintain coexistence that includes technical and organizational measures

3.1.20
coexistence management information
parameters for the wireless coexistence management process

3.1.21
coexistence manager
role of a nominated person to manage coexistence

3.1.22
coexistence planning
process that describes the allocation of wireless communication resources (time, frequencies, coding, space) to each wireless communication system in order to achieve coexistence

3.1.23
collaborative coexistence management
coexistence management process in which data is exchanged between the wireless communication applications involved with the aim of influencing the wireless communication so that all applications meet the requirements

3.1.24
communication availability
<wireless communication> ratio of the time interval of error free transmission (uptime) to an observation time

3.1.25
communication availability
<performance> ability of an item to be in a state to perform as required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

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Note 1 to entry: This ability depends on the combined aspects of the reliability performance, the maintainability performance, and the maintenance support performance.

Note 2 to entry: Required external resources, other than maintenance resources, do not affect the availability performance of the item.

3.1.26
communication load
amount of user data to be transmitted from the automation application within a certain period of time

3.1.27
communication reliability
ability of a physical link and the related nodes to perform communication services under given conditions for a given time interval

3.1.28
cut-off frequency
frequency limit, nearest to the frequency where the spectral power density drops below a certain level, defining the frequency bandwidth

3.1.29
data throughput
ratio between the number of user data transferred to the application at the target reference interface and the observation time

3.1.30
device
piece of hardware that provides connectivity and functionality

Note 1 to entry: Does not exclude software using the hardware to perform functions or support connectivity.

3.1.31
device type
shared characteristics of a device as specified so that the used devices build instances of the shared characteristics

EXAMPLE The specification can be part of a catalogue from a manufacturer.

Note 1 to entry: These shared characteristics include: technology, design, area of application, parts or modules with respect to safety, EMC, performance, functionality, etc.

Note 2 to entry: The shared characteristics of a device type may be engineered, configured and parameterized in a device instance.

3.1.32
distance between wireless devices
geographical distance between devices within a three-dimensional space

3.1.33
distributed automation system
functions of the automation devices that are the spatial extent of a wireless industrial automation

3.1.34
duty cycle
ratio of the transmitter sequence referenced to a given observation time for the used frequency channel

3.1.35
dwell time
period spent at a particular frequency during any single hop of a frequency hopping system

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3.1.36
equivalent isotropic radiated power
product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna (absolute or isotropic gain)

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.161, modified – Term modified from isotropically to isotropic and definition reformatted according to the ISO/IEC Directives Part 2] [12]

3.1.37
effective radiated power
product of the power supplied to the antenna and its gain relative to a half-wave dipole in a given direction

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.162, modified – Deleted "(in a given direction)" and definition reformatted according to the ISO/IEC Directives Part 2] [12]

3.1.38
electromagnetic interference
EMI
degradation of the performance of equipment or transmission channel or system caused by an electromagnetic disturbance

Note 1 to entry: In French, the terms "perturbation électromagnétique" and "brouillage électromagnétique" designate respectively the cause and the effect, and should not be used indiscriminately.

Note 2 to entry: In English, the terms "electromagnetic disturbance" and "electromagnetic interference" designate respectively the cause and the effect, and should not be used indiscriminately.

[SOURCE: IEC 60050-161:2018, 161-01-06] [13]

3.1.39
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.

3.1.40
frequency bandwidth
bandwidth
difference between upper cut-off frequency and lower cut-off frequency

3.1.41
frequency channel
span of the frequency spectrum which is characterized by lower cut-off frequency and upper cut-off frequency or by centre frequency and frequency bandwidth

3.1.42
frequency hopping sequence
sequence of frequency channels used for transmission (hopping sequence) and dwell time

3.1.43
future expansion plan
possible installation of new wireless communication solutions and buildings that can affect coexistence

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3.1.44
general plant characteristics
parameters that characterize the plant in general with respect to all wireless communication applications

3.1.45
geographical dimension of the plant
length, width and height of the intended space of the wireless system

3.1.46
geolocation capability
capability of equipment to determine its geographical location

3.1.47
industrial, scientific and medical application
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

Note 1 to entry: Reproduced with the permission of ITU.

[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.15] [12]

3.1.48
industrial communication network
data communications sub-systems for industrial-process measurement and control as well as on instrumentation systems used for research, development or testing purposes

3.1.49
infrastructure device
device that is essential for building up a wireless communication system according to a technology or standard, but not having an interface to an automation application

EXAMPLE Router or base stations without interfaces to the wired industrial network or without automation application functions.

3.1.50
initiation of data transmission
method that specifies how the application initiates the data transfer

3.1.51
interference
radio frequency interference
effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a wireless communication system, manifested by any performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.166, modified – Deleted leading "The" according to ISO/IEC Directives Part 2] [12]

3.1.52
interference type
kind of unwanted energy caused by a certain source or application

Note 1 to entry: Examples of interference types are: an EMI source, an ISM application, or a non-industrial wireless application.

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3.1.53
intermodulation sensitivity
levels of out-of-band interfering signals that, when mixed in the receiver front-end, produce an in-band third order non-linearity product

3.1.54
intervisibility
property of a logical link that describes a possible influence on radio signal propagation by obstruction, refraction or reflection

EXAMPLE Line of Sight (LOS), Non Line of Sight (NLOS) and Obstructed Line of Sight (OLOS) between those devices are possible parameters.

3.1.55
immunity
ability of an item to continue operating properly in the event of an interference, up to a certain level of interference, and to be resilient above this level

Note 1 to entry: Immunity of an item is achieved by adding to the robustness of the item the ability to be resilient to interference.

3.1.56
jitter
time variation of an expected occurrence

Note 1 to entry: Examples are variation of transmission time and update time.

3.1.57
length of user data per transfer interval
number of the octets sent out during a transfer interval, where the octets that are added because of the requirements of the wireless communication protocol are subtracted

Note 1 to entry: The application data length affects the communication load and might account for the temporal separation of the wireless communication systems.

3.1.58
life-cycle
length of time from the start of the development phase of a product type to the product abandonment

[SOURCE: IEC 62890:2020, 3.1.22] [14]

3.1.59
limitation from neighbours of the plant
description of the neighbours of the plant that are likely to cause limitations for wireless communication

EXAMPLE High power radio source(s).

3.1.60
linear topology
linear network topology
topology where the nodes are connected in series, with two nodes connected to only one other node and all others each connected to two other nodes (that is, connected in the shape of a line)

Note 1 to entry: This topology corresponds to that of an open ring.

[SOURCE: IEC 61918:2018, 3.1.51, modified – Added an admitted term.] [15]

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3.1.61
line of sight
LOS
path of propagation of a radio frequency (RF) signal that is not obscured (partially or completely) by obstacles

3.1.62
logical link
application oriented communication relationship which enables the transmission of user data between one logical end point of the reference interface in a source device and one logical end point of the reference interface in a target device

3.1.63
lower cut-off frequency
frequency furthest below the frequency of maximum power where the power spectral density drops below a certain level

3.1.64
maximum number of retransmissions
upper limit of how many times the communication stack is allowed to retransmit user data automatically because of transmission errors

3.1.65
mechanism for adaptivity
measures to modify one or more of the systems operational parameters in order to improve the systems robustness against interferences and to minimize the medium utilization

3.1.66
medium access control mechanism
transmission technique for how to access the medium

Note 1 to entry: Examples are CSMA, TDMA, or combination of both.

3.1.67
medium utilization factor
measure to quantify the amount of resources (power and time) used by non-adaptive equipment

3.1.68
message
ordered series of octets intended to convey information

Note 1 to entry: During the transport of the conveyed information, the octets can be split in various packets.

[SOURCE: ISO/IEC 2382-16:1996, 16.02.01, modified – Replaced "sequence of characters" by "series of octets", Note to entry added.] [16]

3.1.69
message loss ratio
ratio of number of messages, transferred from the application at the reference interface within the producer, and the number of messages, transferred at the reference interface to the application within the consumer

3.1.70
mesh topology
mesh network topology
network topology in which redundant physically-diverse routing paths are available between each pair of network nodes

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Note 1 to entry: Wireless mesh topology is usable to extend coverage via multi-hop capability and/or to facilitate communication reliability by providing redundant paths between devices.

[SOURCE: IEC 62734:2014, 3.1.2.95, modified – Added an admitted term.] [3]

3.1.71
modulation
process of varying one or more properties of a periodic waveform with a modulating signal that contains information to be transmitted

3.1.72
natural environmental condition
condition that surrounds the wireless device and wireless system

Note 1 to entry: Examples are temperature, humidity, air pressure.

3.1.73
network
all of the media, connectors, repeaters, routers, gateways and associated node communication elements by which a given set of communicating devices are interconnected

[SOURCE: IEC 61158-2:~~2014~~2023, 3.1.30] [17]

3.1.74
network topology
topology of a network
pattern of the relative positions and interconnections of the individual elements of the network

[SOURCE: IEC 61918:2018, 3.1.81, modified – Deleted the "Note 1 to entry" and added an admitted term.] [15]

3.1.75
node
addressable logical or physical device attached to the network

[SOURCE: IEC 62591:2016, 3.2.75] [1]

3.1.76
non line of sight
NLOS
path of propagation of a radio frequency (RF) signal that is obscured (partially or completely) by obstacles, thus making it difficult for the radio signal to pass through

Note 1 to entry: Common obstacles between radio transmitters and radio receivers are tall buildings, trees, physical landscape and high-voltage power conductors. While some obstacles absorb and others reflect the radio signal, they all limit the transmission ability of signals.

3.1.77
number of consecutive lost messages
counted value of not correct received messages between two successfully received messages

3.1.78
obstructed line of sight
OLOS
~~obstacles that intrude into the first Fresnel zone but do not block the LOS path, it is the constructive or destructive interference from the reflected wavefront that is of concern~~

path of propagation of a radio frequency (RF) signal that is obscured (partially or completely) by obstacles, thus making it difficult for the radio signal to pass through

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Note 1 to entry: An intrusion into the inner most area of the first Fresnel zone will result in a decrease or fading of the received signal level. At the point where the obstruction becomes tangent to the LOS path, signal losses will be as much as 6 dB or more. Best practice is to maintain at least 60 % of the first Fresnel zone radius free of obstructions to avoid fading of the received signal.

3.1.79
operating time between failures
sum of the operating time periods between two successive failures on a logical link where the message is considered as a repairable item in the sense that a message can be repeated within the survival time

3.1.80
other frequency user
user which generates and uses radio energy without having the objective of telecommunication

Note 1 to entry: Examples are welding machine, electrical drive and frequency converter.

3.1.81
out-of-band emission
emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.144] [12]

3.1.82
object movement
specification of the trajectory of mobile assets that can significantly influence the radio propagation conditions

Note 1 to entry: Examples for mobile objects are vehicles, cranes or persons.

3.1.83
observation time
duration of the supervision of events

Note 1 to entry: Examples are the reception of user data or the use of a transmission medium by a wireless device. For them the observation time is the reference parameter to calculate the data rate and the duty cycle.

3.1.84
packet
formatted, aggregated bits that are transmitted together in time across the physical medium

[SOURCE: IEC 62591:2016, 3.2.77] [1]

3.1.85
passive environmental influence
influence on the signal propagation through the characteristic of the area of operation, the dimension of the space of operation, the intervisibility, mobile objects and natural environmental conditions

3.1.86
performance requirements
requirements describing the time and error behaviour necessary to achieve the purpose of the automation application

3.1.87
physical link
relation between radio transceivers (physical end points) of two wireless devices

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3.1.88
plant
managed facility, typically with a physically protected perimeter, hosting the physical process, operation, personnel, equipment

3.1.89
point-to-point topology
point-to-point network topology
topology where two nodes are directly connected to each other

3.1.90
position of wireless device
geographical position of the three-dimensional space in absolute or relative coordinates where the device is located

3.1.91
power spectral density
distribution as a function of frequency of the power per unit bandwidth of the spectral components of a signal or a noise having a continuous spectrum and a finite mean power

[SOURCE: IEC 60050-713:1998, 713-09-12 modified – Deleted the admitted term and the abbreviation.] [18]

3.1.92
purpose of the automation application
summary of the automation application supported by the wireless system to the extent needed to provide a useful overview of the requirements imposed on the wireless system

3.1.93
radio channel
~~model considers~~ radio propagation model that takes into account the characteristic of the frequency channel, the environmental conditions, the distance between the wireless devices, the antenna characteristic

3.1.94
radio environment
~~represents~~ surroundings for the ~~transmission medium~~ radio signal propagation with its passive environmental influences and active environmental influences

3.1.95
radio resource
means used by multiple wireless communication solutions for the purpose of radio signal transmission

3.1.96
radio robustness
attribute of wireless communication to fulfil the designated function despite the presence of other active wireless applications interfering in the sphere of influence

Note 1 to entry: This term has the same meaning as the definition of the term coexistence in IEEE 802.15.2:2003, 3.1.2 [11].

3.1.97
received signal strength indication
relative number for the field strength at the receiver of wireless devices, depending on the respective implementation of a radio technology

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3.1.98
receiver blocking
effect of a strong interfering signal on the receiver's ability to detect a low-level wanted signal

3.1.99
receiver maximum input level
maximum signal power that the system can tolerate without distortion of the signal

3.1.100
receiver sensitivity
minimal signal power to receive data with a defined bit error ratio

3.1.101
reference interface
exposed interface between an automation application and the wireless communication function

Note 1 to entry: There is no consistently defined interface for measurement and automation. The interface of the device might be a serial or a parallel hardware interface, a fieldbus interface, a software interface, or serial, parallel, discrete, and analog interface.

3.1.102
regional radio regulation
regulation of important coexistence parameters such as frequency band and output power related to the region where the wireless application is intended to be used

3.1.103
relative movement
position of a wireless device over time

3.1.104
requirements influencing the characteristic of wireless solutions
application communication requirements that influence the performance of wireless solutions and thus the coexistence state

3.1.105
response time
time interval between the instant delivery of the first user data bit, or octet, of a message to the reference interface of a transmitter, and the instant when the last bit, or octet, of the confirmation message is delivered at the reference interface of the same transmitter, which can be assigned to the request

3.1.106
ring topology
ring network topology
active network where each node is connected in series to two other nodes

[SOURCE: IEC 61918:2018, 3.1.71, modified – Changed "ring" to "ring topology" and added an admitted term.] [15]

3.1.107
robustness
ability of an item to continue operating properly in the event of an interference, up to a certain level of the interference

Note 1 to entry: The robustness of an item ~~may~~ can be increased with measures that modify one or more of its operational parameters.

3.1.108
security level
requirement category for cyber security

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3.1.109
spatial extent of the application
cuboid defined by the positions and/or the maximum movement radius of the automation devices of a distributed automation system

3.1.110
shared medium
resource of frequency band in particular area shared by several wireless applications

Note 1 to entry: In the industrial, scientific and medical (ISM)-bands, many wireless applications are used. Due to this joint use, the term shared medium is used in this document. The frequency bands are used by diverse ISM applications and wireless communication applications.

3.1.111
signal-to-interference and noise ratio
quotient of the strength of the wanted signal and the strength of the unwanted signals, consisting of noise and interference

3.1.112
spatial coverage of the wireless communication system
spatial coverage specified by length, width and height of a cuboid that encloses the wireless communication system

3.1.113
spurious emission
emission on a frequency or frequencies which are outside the necessary bandwidth and the level of which ~~may~~ can be reduced without affecting the corresponding transmission of information, including harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.145] [12]

3.1.114
spurious response
receiver output due to unwanted signals

Note 1 to entry: That means having frequencies other than those of the tuned frequency channel.

3.1.115
star topology
star network topology
network of three or more devices topology where all devices are connected to a central device

[SOURCE: IEC 61918:2018, 3.1.77, modified – "topology" has been added, "point (which may be active or passive)" has been replaced by "device", and an admitted term has been added] [15]

3.1.116
survival time
time that an application, consuming a communication service, continues without receiving an anticipated message

3.1.117
telecommunication
any transmission, emission or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems

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[SOURCE: ITU Radio Regulations, edition of 2020 – Art.1 §1.3] [12]

3.1.118
total radiated power
spatial power density integrated across the surface of the sphere

3.1.119
transfer interval
time difference between two consecutive transfers of user data from the automation application via the reference interface to the wireless communication function

3.1.120
transmission gap
gap between two successive channel usages by a transmitter

3.1.121
~~transmission~~ transmitter output power
total radiated power reduced by losses between the transmitter output and the antenna

3.1.122
transmission time
interval from starting the delivery of the first application data octet of a message to the reference communication interface of a producer until the delivery of the last application data octet of the same message from the reference communication interface of a consumer

3.1.123
transmitter sequence
time that a transmitter uses a frequency channel without the possibility to be interrupted by a wireless device of the same system

3.1.124
transmitter spectral mask
envelope of maximum values of power spectral density over a frequency range

3.1.125
tree topology
tree network topology
network topology where all nodes are connected in a combination of a linear and a star topology

3.1.126
update time
interval from the delivery of the last user data octet of the message of a producer, from the reference interface of a consumer to the automation application, until the delivery of the last user data byte of the following message of the same producer

3.1.127
upper cut-off frequency
frequency furthest above the frequency of maximum power where the power spectral density drops below a certain level

3.1.128
wireless application
any use of electromagnetic waves with devices or equipment for the generation and use of radio energy using radio environment with active and passive environmental influences

Note 1 to entry: The definition includes wireless communication systems with wireless communication functions representing a set of spatially distributed automation functions, distributed automation system with local functions and physical system with physical system functions.

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Note 2 to entry: The definition includes radio determination equipment.

3.1.129
wireless communication
communication in which electromagnetic radiations are used to transfer information without the use of wires or optical fibers

3.1.130
wireless communication application
part of an industrial automation application that uses wireless communication

3.1.131
wireless communication solution
parameters of wireless communication solutions which are implementations of wireless communication systems and devices

3.1.132
wireless communication solution density
ratio of the number of wireless communication solutions and the spatial coverage of the plant

3.1.133
wireless communication system
set of wireless communication devices, infrastructure devices and physical links communicating using radio frequencies using various topologies

3.1.134
wireless device
wireless automation device
equipment of wireless communication applications that uses radio waves for wireless communication with other equipment of wireless communication applications

3.1.135
wireless device density
number of wireless devices within the spatial coverage of the wireless communication system

3.1.136
wireless device receiver parameters
wireless receiver parameters
specification of wireless receiver characteristics

3.1.137
wireless device solution
parameters related to individual nodes within a system implementing a wireless communication solution

3.1.138
wireless device transmitter parameters
wireless transmitter parameters
specification of wireless transmitter characteristics

3.1.139
wireless device type
specification of a device according to the catalogue data

3.1.140
wireless network
wireless communication network
network consisting of at least two wireless devices that established wireless communication

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3.1.141
wireless network solution
parameters related to a network as a whole used implementing a wireless communication solution

3.1.142
wireless solution
wireless communication solution
specific implementation or instance of a wireless communication system

Note 1 to entry: A wireless solution ~~may~~ can be composed of products of one or more producers.

3.1.143
wireless system
wireless communication system
set of interrelated elements providing wireless communication

Note 1 to entry: A wireless system is a high-level representation of a system, while a wireless solution is a practical instance of a system.

3.1.144
wireless system type
parameters describing the kind of wireless communication system

3.1.145
wireless system type and wireless device type
parameters that characterize the model of a wireless system or a wireless device by providing the parameters to specify a wireless system type and a wireless device type

3.1.146
wireless technology or standard
naming the wireless technology or standard

EXAMPLE Examples of standards specifying a wireless communication system are IEC 62591 [1], IEC 62601 [2] and IEC 62734 [3].

3.2 Abbreviated terms

AFH adaptive frequency hopping

BFWA broadband fixed wireless access

CEPT European conference of postal and telecommunications administrations

CP communication profile according to IEC 61784-2 series [6]

CSMA carrier sense multiple access

DAA detect and avoid

DAR detect and reduce

DAS detect and suppress

~~DECT Digital enhanced cordless telecommunications~~

ECO European communications office (the electronic communications committee of CEPT)

EIRP equivalent isotropic radiated power

EMC electromagnetic compatibility

EMI electromagnetic interference

ERP effective radiated power

~~GSM Global system for mobile communications~~

IF intermediate frequency

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IP	Internet protocol
ISM	industrial, scientific and medical
IT	information technology
ITU	International telecommunication union
LAN	local area network
LOS	line of sight
~~MAC~~	~~Medium access control~~
MLR	message loss ratio
NLOS	non line of sight
N/A	not applicable
OLOS	obstructed line of sight
PCB	printed circuit board
~~PHY~~	~~Physical layer~~
PSD	power spectral density
RF	radio frequency
RFID	radio frequency identification
RSRP	reference signal received power
RSRQ	reference signal received quality
RSSI	received signal strength indication
SIR	signal-to-interference ratio
TDMA	time division multiple access
TRP	total radiated power
~~UMTS~~	~~Universal mobile telecommunications system~~
WD	wireless device
WIA-PA	wireless network for industrial automation – process automation
WLAN	wireless local area network
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e.V.; the german electrical and electronic manufacturers' association

3.3 Conventions

NOTE The graphical representations of flow charts in figures are based on ISO 5807 [19].

The following conventions for the coexistence management parameter templates in Clause 8 apply:

- The column "Parameter" uses indentations to cluster certain parameters. The parameters that are more to the right belong to the parameter above that is more left.
- The column "Usage" specifies whether the parameter is mandatory, optional, or selection, if one out of several parameters is selected.
- The item "Value" can contain a range or a list of values if the parameters allow multiple options. If a parameter does not have a unit, then the item "Unit" shall be marked with not applicable (N/A).

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4 Coexistence concept in industrial automation

4.1 Overview

Wireless communication allows industrial processes to be implemented more cost-efficiently, flexibly and reliably, as well as allowing the use of new automation concepts. Industrial automation applications usually place stricter requirements on reliability and real-time capability of wireless communication than applications in the domestic and office domain. Industrial automation applications can also reside in industrial facilities with higher ambient electromagnetic interference (EMI) levels than those in non-industrial domains.

Additional sources of radio emissions will also need to be taken into account during coexistence management.

NOTE In some industrial environments, other sources of radio emissions can be present within the same bands as used by the wireless communications systems. These emitters can include devices with unintentional emissions, such as high-power welding devices which generate wideband electromagnetic energy.

Because of those requirements, different wireless systems are used. It is quite likely that several wireless systems ~~may~~ can operate simultaneously in one place. Since these wireless systems share a common medium, interferences can be assumed throughout their life-cycles. This impacts system performance including reliability and its ability to meet real-time response requirements. This document is intended to help identify potential risks and to recommend measures to control these risks, depending on the requirements of the industrial automation application. This document also illustrates that most often the coexistence of several wireless systems and simultaneously the efficient handling of the frequency spectrum as a limited resource is feasible if an appropriate approach is chosen, taking into account the respective requirements. In order to achieve this, a process is needed in which all aspects of the coexistence of wireless systems during design, commissioning, and operation, as well as maintenance, are considered. This process, called coexistence management of wireless solutions, is the subject of this document. Associated actions and decisions serve to comply with the claimed limit values for the application over the whole life-cycle of the plant.

This process can be more or less complex, depending on the relevance of the requirements related to the wireless communication for the plant. This complexity depends, among other aspects, on the characteristics of the wireless communication application served by each wireless solution (for example control with strict real time requirements), the number and location of the wireless solutions that can potentially interfere with each other, and the presence of any other radio emitters in the same bands.

If no, or just modest, requirements are made on the wireless system, a lower effort for the coexistence of wireless solutions will be necessary than in the case of a wireless system that is part of a control application with strict real-time requirements. However, it is strongly recommended to consider that additional wireless systems ~~might~~ could be implemented later or that the requirements on the present wireless system might change in the future (for example due to additional applications). The plant design shall ensure that the applied coexistence measures match the requirements of the wireless system.

The state of coexistence is characterized by meeting the limit values of relevant parameters for all wireless communication applications in the considered area. This state of coexistence is accomplished with appropriate actions in planning and in operation. This clarifies that coexistence is not a static attribute of a wireless solution, but rather a state within the life-cycle of a plant. It is possible to leave this state temporarily or permanently due to certain events. The parameter limit values are determined by the automation application in which the wireless communication takes place. This also implies that the coexistence management shall be evaluated and established contextually and in full accordance with the automation application.

From a general point of view, coexistence of two or more wireless solutions can be achieved by making orthogonal the transmissions that come from different sources.

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There are three possibilities to manage coexistence, where a) means a higher amount of labor hours to establish and maintain the coexistence management and b) and c) means an increasing level of automation:

a) manual coexistence management (lowest level);

a) automated non-collaborative coexistence management;

b) automated collaborative coexistence management (highest level).

Automated techniques, and the algorithms on which they are based, are usually classified into two broad categories: collaborative and non-collaborative.

4.2 Objective

This document is focused on measures to provide coexistence of wireless systems for measurement and automation applications. These industrial automation applications can be classified in various ways. For example, in Table 1 they are classified according to the degree of the application criticality. Efforts for coexistence management can vary according to the classification described in Table 1.

Table 1 – Example of a classification of application communication requirements

Class	Application	Application communication requirements
Functional safety	Implementation of a safety-related system whose failure could have an impact on the safety of persons and/or the environment and/or the plant	The communication protocol should support functional safety communication and the coexistence management shall be established in order to fulfil all requirements of this document.
Control	Closed or open loop control	The communication protocol should support a higher availability, reliability, and time-criticality protocol than the one used for other application domains like consumer industry or telecommunication. The coexistence management shall be established in order to fulfil most of the requirements of this document.
Monitoring	Process visualization and alerting	No specific add-ons required for the communication protocol. Typically, monitoring application can be satisfied by a relaxed set of requirements. The coexistence management shall be established in order to fulfil these minimum requirements.
NOTE The relative terms "most" and "minimum" are based on the graphical description in Figure 3.		

The classification of automation applications provided with Table 1 refers to the functional requirements of the process industry application to be satisfied. This classification can also be adapted in other application domains.

However, the determination of the criticality and the associated application communication requirements shall be determined on a case-by-case basis by the coexistence manager.

NOTE 1 Application communication requirements are described in IEC 62657-1.

Applications ranging from radio bar code readers to voice and video over IP applications can be classified likewise and can be dealt with according to this document.

The applicability of this document is not confined to a specific frequency band, for example the 2,4 GHz ISM band. Both concurrent communication systems and other approved wireless applications, such as microwave systems for drying or plastics welding, are considered as

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interferences. Moreover, further interferences might occur due to powerful low frequency electromagnetic fields (for example transformers, powerful motors or other electromagnetic interferences (EMI), see Figure 1). The interference sources to be considered are detailed in 4.4.

NOTE 2 The analysis of EMI is outside of scope of this document but has been considered.

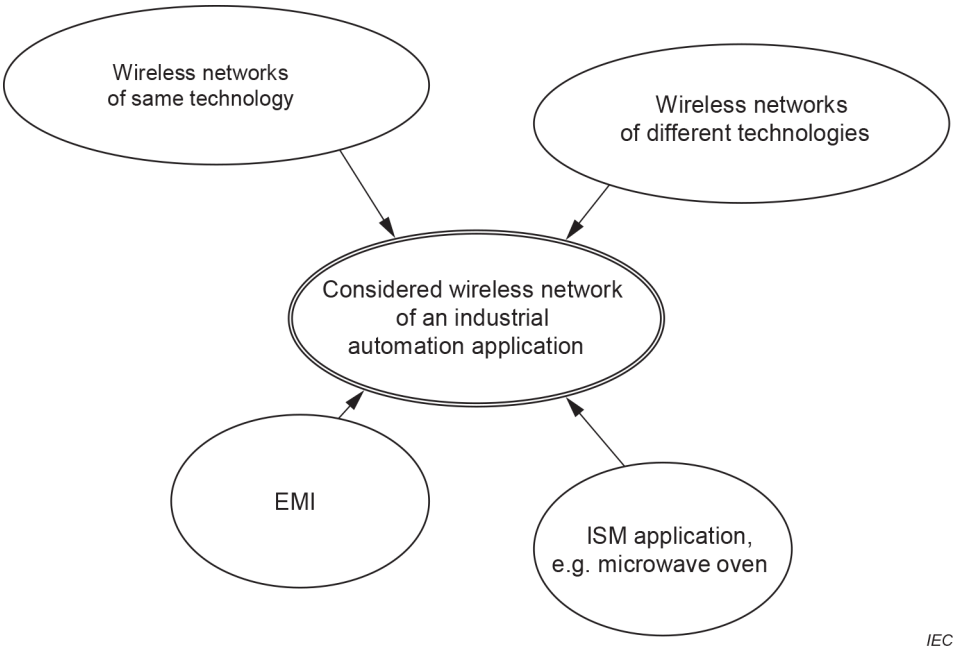

Figure 1 – Issues of consideration

In Figure 2, the relation between industrial automation application, wireless communication application, EMI, industrial, scientific and medical (ISM) application and non-industrial wireless application is depicted. Wireless application is used as generic term for wireless communication application, ISM application and non-industrial wireless communication (grey in Figure 2). Wireless communication applications are parts of an automation application. Other parts of automation applications may use ISM spectrum e.g. for welding processes. Furthermore, equipment of industrial automation applications can be source of electromagnetic interference (EMI). In addition, non-industrial wireless applications (e.g. smart phones or laptops) may use the spectrum in an industrial environment.

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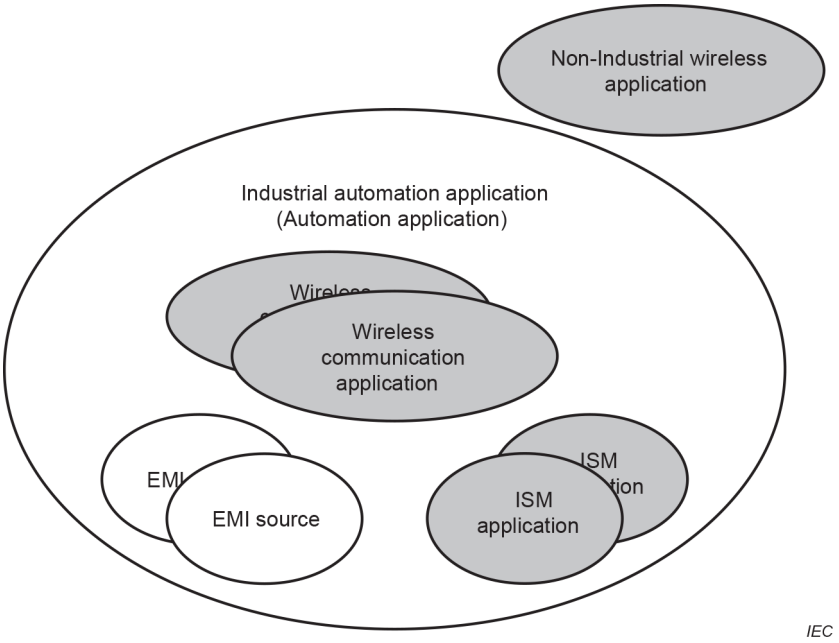

Figure 2 – Applications using frequency spectrum

This document is aimed at addressing coexistence management at the location of an enterprise; however, the manager shall take into consideration the fact that some interference could come from outside the location of the plant. The manager shall identify and characterize potential external radio energy sources and their distance from the enterprise. Controls should be in place to ensure that unauthorized or unaccounted mobile sources are not allowed in the enterprise area.

It is assumed that, in conditions without interference, a wireless communication system basically meets the requirements of the wireless automation application and that, in particular, the limit values for time and error behaviour are taken into account by planning the communication requirements.

The measures described here are to ensure the required performance even in the presence of other wireless applications.

4.3 Necessity to implement a coexistence management

The frequency spectrum is a valuable limited resource which will be rapidly exhausted in the case of unmanaged use.

The following list shows an example of wireless devices to be found in industrial environments:

- wireless sensors and actuators;
- WLAN access points and clients;
- mobile panels;
- RFID devices and RFID readers.

There are also devices which can emit radiated power in the same bands as the wireless devices:

- radio-frequency process heating;
- plastic welding;
- plasma lamps;

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- general welding; and
- other devices.

There is a high risk of interference whereby, under certain conditions, the assumed availability and performance requirements cannot be observed. In order to avoid this, or rather to reduce the risk of interference, a company-wide process for the administration of wireless applications for all parties involved is strongly recommended, and if adopted, shall be implemented according to this document. Coexistence management is an intra-company process which should be adjusted to the structure and the internal processes of the enterprise. In each individual company, the structure and the processes can be organized differently.

Moreover, the focus in defining the process or its sub-steps can vary according to the user groups concerned:

- wireless communication applications with a high data throughput, but relaxed real-time requirements: the coexistence management puts the focus on the provision of ~~adequate~~ frequency bandwidth meeting the application requirements;
- wireless communication applications without specific requirements for performance and real-time: the coexistence management aims at ensuring the spatial coverage;
- wireless communication applications with strict real-time requirements: the coexistence management safeguards against functional problems caused by the influence of other wireless applications (application classes Functional Safety or Control).

In addition, the following basic measures to implement coexistence management are recommended:

- nomination of a company-wide coexistence manager;
- nomination of a location-specific coexistence manager if the company has several facilities;
- establishment of a committee, consisting of contact persons of all company divisions using wireless applications (task of the committee should be the issues shown in Figure 1 and Figure 2);
- inventory of all installed and, if possible, all planned wireless applications including wireless communication;
- establishment of a policy to register new wireless applications or solutions and for the identification of existing ones;
- coordination and adoption of decisions regarding the approval and application of wireless systems within the committee;
- establishment of a policy and enforceable consequences for non-authorized introduction of new wireless applications or solutions.

Effective coexistence management is a concerted process with representation of all company divisions concerned (sub-divisions, departments, technologies). The divisions concerned are those involved in planning, procurement, installation, commissioning, operation and maintenance of wireless applications, for example process planning, IT, automation, plant operation (production), development, purchasing, facility management.

Coexistence management offers various benefits:

- reduction or elimination of interferences leading to unplanned downtimes;
- reduction or elimination of laborious, cost-intensive and time-consuming fault troubleshooting;
- reduction or elimination of disinvestments in wireless solutions that cannot be operated in the present radio environment of the enterprise.

NOTE The term 'wireless solution' is used here instead of the term 'wireless system' because it takes into account the distinct attributes of a product that are important for the coexistence management.

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4.4 Interference potential

For wireless communication applications, interference will occur at a point in space (corresponding to an antenna location, received energy, antenna characteristics and polarization) if the received signals:

- overlap in the frequency domain;
- overlap in the time domain; and
- overlap in coding.

NOTE 1 In the case of buildings and areas close to airports, harbors, transmitter masts and other places of powerful wireless systems, the interference potential is extremely high.

This leads to interferences between wireless solutions with the consequence of lost packets so that, for example, a transferred packet ~~has~~ needs to be repeated. The system reaction to the described interference depends on several factors, for example on the wireless standard, on the hardware and software implementation or on the application class (see Table 1) the wireless system uses for transfer.

The separation of non-overlapping frequency channels is a method to achieve coexistence. However, there might be interference between wireless systems using different channels in the same frequency band, for example because of adjacent channel interference. This is called cross-channel interference. In particular, analog wireless systems hold a high interference potential for digital wireless systems due to their high channel occupation.

Moreover, wireless systems using different frequency bands ~~may~~ can interfere with each other. Beneath the main signal, a wireless system also emits outer band signals that might penetrate the frequency channel of the endangered wireless system, thus affecting the wanted signal.

The received signal quality at a receiver as a function of interference by other wireless systems is typically measured by the signal-to-interference ratio (SIR), which is the ratio of the power of the wanted signal to the total residual power of the unwanted signals. The receiver can correctly interpret incoming data only if the SIR is above a given threshold.

The value of the threshold depends on the adopted modulation, while the actual SIR value depends on the superposition of interferers with respect to the intentional communication in the following two domains: time and frequency.

Different performances can be obtained if superposition (that means interference) in these domains is complete or only partial.

For the time domain, since the traffic of victim and interferer(s) wireless system(s) ~~may~~ can change each time, the SIR evaluation should be preceded by the definition of a time interval in which the interference is constant.

For the frequency domain, the SIR evaluation should consider at least the combined effect of interfering transmitter(s) and receiver victim spectral masks. In fact, the interfering transmitter(s) can have spurious emission even outside the adopted frequency channel. On the other hand, the receiver blocking mask can reject the interferer(s) signal(s), mitigating its effect.

In order to foresee/estimate the effect of interferers, it is possible to use analytical models, simulations and experimental test beds. These three approaches have different (increasing) complexity and hence different (increasing) accuracy.

In order to assess whether there is a risk of interference or not, an interference risk should always be assumed if wireless applications are operating in parallel in the same frequency band without proof of their radio robustness.

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NOTE 2 This term wireless application is more comprehensive than the term wireless system, because in wireless applications, the radiated power is not only used for information transfer.

NOTE 3 The use of the electromagnetic energy can be either intentional (as needed to serve the specific application) or unintentional/accidental.

However, an interference risk does not mean that parallel operation of competing wireless systems is unfeasible. They can co-exist if the requirements on the wireless solutions involved are met. This criterion should be taken as a basis for decisions regarding the application of wireless systems.

If possible, future changes in the requirements, implicating changes of the interference potential, should also be considered. In industrial automation, the life-cycle of a wireless solution typically lasts more than 5 years. During this time, new applications for the existing wireless system can be developed and deployed. Determination, coordination and control of these changes are part of coexistence management.

One more influence is radiated EMI. In particular, regional regulations can allow significant radiated power for specific wireless applications in unlicensed spectrum, potentially generating a high field strength in the proximity of a wireless system.

A wireless solution shows a certain interference resistance against those radiated interferences. This limit value can be exceeded by the signal of a powerful wireless application.

EXAMPLE RFID applications in Europe are allowed to use 4 W in the 2,4 GHz band whereas other short-range devices are limited to 100 mW.

Even though wireless solutions often hold a higher interference resistance than normatively claimed, and exceeding the limit value does not always result in harmful interference, the design of the wireless solutions shall be such that the noise level at the receiver does not exceed this limit value. Interferences from the same frequency band are much more likely than from other frequency bands. Nevertheless, the interference potentials from other frequency bands also shall be taken into account.

EMI caused by defective devices and exceeding the normal operating limits should not influence the coexistence management. The defective device should instead be repaired to return to normal operating conditions.

4.5 Ancillary conditions

For wireless communication, there are only limited communication resources available, thus thorough planning is required. The higher the requirements of the application class on the wireless system, as to time behaviour, availability, dimension and others, the higher is the technical and organizational effort required to guarantee coexistence. The costs rise disproportionately as shown in Figure 3. A certain span of expense results from the complexity of the wireless network solutions (for example, simple point-to-point link or linear-, ring-, star-, cellular-, tree-, mesh- topology ~~network~~) and from the number of influencing factors to be considered (for example medium load, transmitter power). The span between the two curves moves upwards the more efficiently the spectrum is used. This applies to both:

- the expenses for the coexistence management in the coexistence planning phase; and
- the costs of developing appropriate wireless solutions.

The bold arrow in Figure 3 shows that the curves will go higher as the coexistence management efforts increase to gain a higher efficient use of the spectrum.

The effort might be reduced by strategic regulations for coexistence management. A possible regulation is to confine the number of considered influencing factors, for example by exclusive assignment of frequencies to specific wireless applications. It is essential to take into account that strategic decisions in the coexistence planning phase have effects on the future expenditures and therewith on the life-cycle costs of the plant. The technical and organizational

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expenses for coexistence management in the operating phase can multiply the coexistence planning costs throughout the life-cycle of a plant.

It is therefore important to analyze whether the requirements of the planned application fit the intended application requirements. In relaxing the requirements, a more efficient use of the resource can be achieved. If the resource is exhausted, other solutions will need to be found.

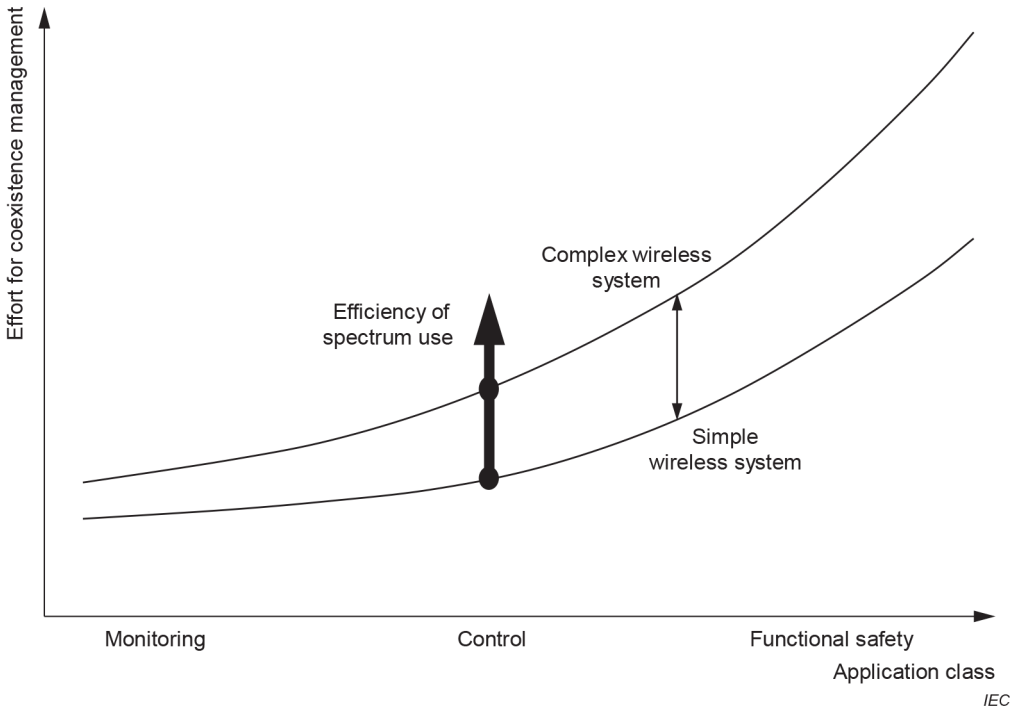

Figure 3 – Progression of expense to achieve coexistence corresponding to the application classes

4.6 Requirements to wireless devices for support of coexistence management

Wireless devices shall be capable to vary parameters that are specified in Clause 5 to achieve the coexistence management by reducing the interference potential as specified in 4.4.

EXAMPLE The device is so constructed that certain frequencies can be blocked; power can be adjusted to be below the threshold of the incumbent services/applications.

4.7 Concepts

4.7.1 Manual coexistence management

In the case of manual coexistence management, the coexistence manager (see 7.2.1) shall define a fixed planning of the wireless solutions intended to prevent transmission overlaps. The manager shall implement manual measures to react to modifications that change the wireless coexistence state. This is the simplest management method, especially if multiple wireless solutions of different technologies and from several vendors are involved, or if several frequency bands ~~have~~ need to be managed.

This method can be used if there are non-manageable radio emitters in the same bands as used by wireless solutions.

However, the manual coexistence management capabilities are limited if some coexistence management parameters cannot be configured.

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4.7.2 Automated non-collaborative coexistence management

In automated non-collaborative coexistence management, the different wireless solutions are not capable of exchanging information. They are fully independent and rely only on interference detection and estimation. In other words, each offended wireless solution classifies the behaviour of the offending ones and tries consequently to adapt its own behaviour to the new estimated situation. For this reason, non-collaborative techniques are more general but less efficient than the collaborative ones. As an example, non-collaborative algorithms dynamically modify the communication strategies (for example the frequency band, the timeslot/packet scheduling, and so on) as a result of an assessment of the wireless application requirements versus the wireless application solution capable of establishing the required communication performance.

Such methods are being proposed to address coexistence in uncontrolled public areas, however such methods would not be effective for the management of industrial automation wireless devices which ~~have~~ need to meet performance requirements.

NOTE Some metrics are described in IEEE Std.802.15.2 [11].

4.7.3 Automated collaborative coexistence management

4.7.3.1 General

In automated collaborative coexistence management, the different wireless solutions shall be able to exchange characteristic parameters.

The precondition for collaborative coexistence management for wireless systems using multiple technologies provided by multiple vendors is that a common standardized communication link is available amongst these solutions. This link can either be:

- a pilot channel between the collaborative coexistence manager and the coordinated devices using a common standardized communication protocol and service set, as for example specified in IEC 62657-4, to make the task of the collaborative coexistence manager easy;
- a wireless solution of the coordinated devices that is also understood by the collaborative coexistence manager, which means that the collaborative coexistence manager shall talk the language of all the coordinated devices that participate in the automated collaborative coexistence management;
- a wired link between the coordinated devices and the collaborative coexistence manager using a common standardized communication protocol and service set.

An automated collaborative coexistence management could result in some restrictions on the adopted hardware since, for instance, collaborative methods are usually implemented by means of a centralized arbiter/scheduler. The exchanged information allows each offended wireless solution to effectively adapt its own behaviour to the real new situation, taking into account the requirements of its own application and the applications of the other wireless systems. These dynamic modifications could influence the determinism or reliability of the communication and can therefore be inappropriate for various wireless communication applications.

An example of such an automated collaborative coexistence management is a central coordination point (CCP), see IEC 62657-1:2017, 4.3.4.3. National, regional and regulatory aspects are also described there.

IEC 62657-3 provides the formal description of the automated coexistence management and application guidance.

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Three different application use cases for automated collaborative coexistence manager exist:

a) for sharing the same frequencies with other incumbent services/applications (see 4.7.3.2, 4.7.3.3 and 4.7.3.4);

b) for intra-system coexistence in a controlled environment;

c) for intra-system coexistence in a public area.

A possible approach of an automated collaborative coexistence management for industrial automation is specified in IEC 62657-4.

4.7.3.2 Simple CCP

A collaborative coexistence manager is responsible for detecting the primary users and identifying the devices which are coordinated. The CCP shall then inform the underlying coordinated devices that they shall react to fulfil the requested mitigation techniques of the primary user. No reconfiguration of the assigned frequencies is requested. Examples of how the coordinated devices could react are to lower the transmit power or stop transmission.

4.7.3.3 Intra-system CCP

All or at least most radio equipment in space is known with their dynamic requirements. It is assumed that the installed devices are static. Nomadic devices are known and as such seen as static in configuration, for example if they have geolocation capability. The collaborative coexistence manager is responsible for detecting primary users and for informing the underlying coordinated devices (incumbent services/applications) if they could interfere with primary users. The collaborative coexistence manager can decide whether the coordinated devices shall react to fulfil the requested mitigation techniques of the primary user, or the coexistence manager can assign different spectrum to the coordinated devices. Some additional alternatives could be that the collaborative coexistence manager organizes time synchronization or influences other parameters specified in 4.4.

4.7.3.4 Public CCP

All behaviours described in 4.7.1 and 4.7.2 as well as 4.7.3.2 and 4.7.3.3 could be supported. In addition, unknown devices can ask the collaborative coexistence manager to also be managed.

The coordinated coexistence management increases the spectrum efficiency and the quality of service.

4.8 Best practices to achieve coexistence

The establishment of coexistence is a combination of technical and/or organizational measures to ensure the correct operation of wireless communication applications in their environments. The main criteria in the selection of appropriate actions to achieve coexistence are effectiveness, feasibility, economic efficiency and the loss of performance acceptable for the application if the wireless solution ~~has~~ needs to share the medium with other wireless systems. Future developments of the wireless communication application in the enterprise should be considered here as well.

Technically, signals of wireless communication at a point in space (corresponding to an antenna location, received energy, antenna characteristics and polarization) can be separated by:

- frequency;
- time;
- coding.

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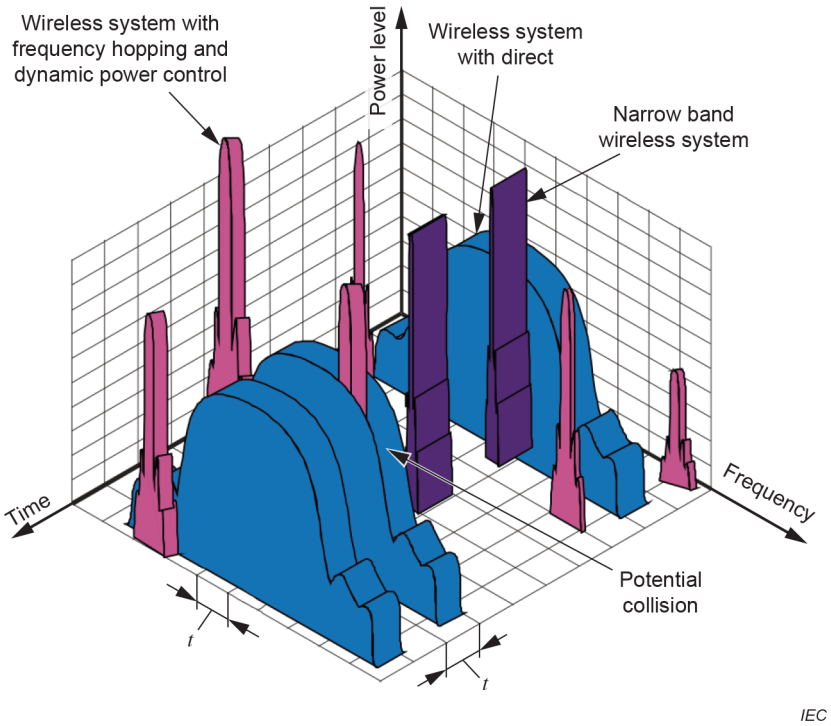

Figure 4 – Separation of wireless systems according to frequency and time

The separation in the frequency domain (see Figure 4) usually causes the least performance loss and initially the lowest expense. However, these measures occupy the medium to a great extent and should therefore be reserved for specific application classes used in the plant such as functional safety and control. A separation in time can be accomplished by configuring the communication request with respect to the application communication requirements.

For applications with a certain dynamic, the communication cycle should be set as long as possible and/or event driven communication should be used. Wireless technologies with automatic adaptive medium sharing mechanisms should also be used.

A spatial separation is rarely possible in the case of a wireless communication application. Radio propagation can only be restricted spatially with great efforts. Structural conditions (for example large steel reinforced concrete walls) and the reduction of the radiated power (by adjusting the output power of the radio transmitter and the choice of the antenna radiation pattern) can be used for spatial separation. For larger facilities, the control of power levels can be a viable approach. If the power is reduced, the power of all related wireless devices (for example base stations, repeaters, and end devices) should be adjusted accordingly.

If the transceivers have multiple antennas, then it would be possible to utilize spatial processing, such as interference rejection techniques, to separate simultaneous transmissions in space.

Separation via polarization involves the specific attribute of an antenna to subdue radio waves with an orthogonal polarization (cross polarization). For example, a horizontally polarized antenna of a signal receiver can attenuate a vertically polarized interference signal. However, inside buildings or in other highly reflective surroundings, the effects of a polarization separation are relatively small.

In addition, directional pillbox antennas or other emerging antenna concepts can be used to restrict the radio propagation within a certain area.

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The organizational measures apply to the operation of the wireless system and they have indirect implications for the uncoupling mechanism described in Figure 4. Hence the application of a wireless system can, for example, be restricted in space or time, or just services of a wireless solution meeting the coexistence requirements can be approved. The organizational measures (in particular those for wireless systems related to business process or safety) should evaluate in advance to what extent compliance with the specifications can be ensured and controlled.

Impact of the typically non-ideal radio propagation characteristics found in many industrial environments can impact the time and error behaviour of a wireless solution. Therefore, suitable allowances shall be made in the planning of wireless systems.

In the operation phase, investigation of mechanisms to enhance the agility of wireless communication applications against the appearance of unexpected interferences shall be considered, for example diversity techniques and cognitive radio medium access methods.

In order to define adequate measures and to evaluate their efficiency, the assistance of wireless experts is recommended.

4.9 Coexistence conceptual model

Figure 5 shows the coexistence conceptual model. ~~A wireless communication application (Automation application A) has application requirements to fulfil its intended tasks. Part of the wireless communication application A is the selected wireless system A. It has certain immunity against interference from other wireless communication systems and the utilization of its resources can interfere with other wireless communication systems.~~ In this example, three wireless communication applications (A, B and C) are assumed. According to the definition of wireless coexistence, all three wireless communication applications shall fulfill their application communication requirements. Each wireless communication system in a wireless communication application has certain immunity against interference from other wireless communication systems and the utilization of its resources can interfere with other wireless communication systems.

The conceptual model of coexistence can be seen as a closed loop control process. This process of coexistence management is not just one activity during the system planning; it is an iterative process throughout the entire life cycle of the system.

NOTE IEC 62890 provides more details about a life-cycle management.

An investigation of the requirements, the characteristics of the wireless communication systems and the medium utilization factor shall be reported in an inventory. According to the life cycle phase (see 7.4), the resulting coexistence planning or maintenance shall be carried out. This results in a current resource allocation plan, which shall be the basis for configuring or implementing the wireless communication applications.

The coexistence state is achieved if the robustness to interference in a wireless communication system is better than the interference produced by the resource, and if the wireless communication applications fulfill their application communication requirements.

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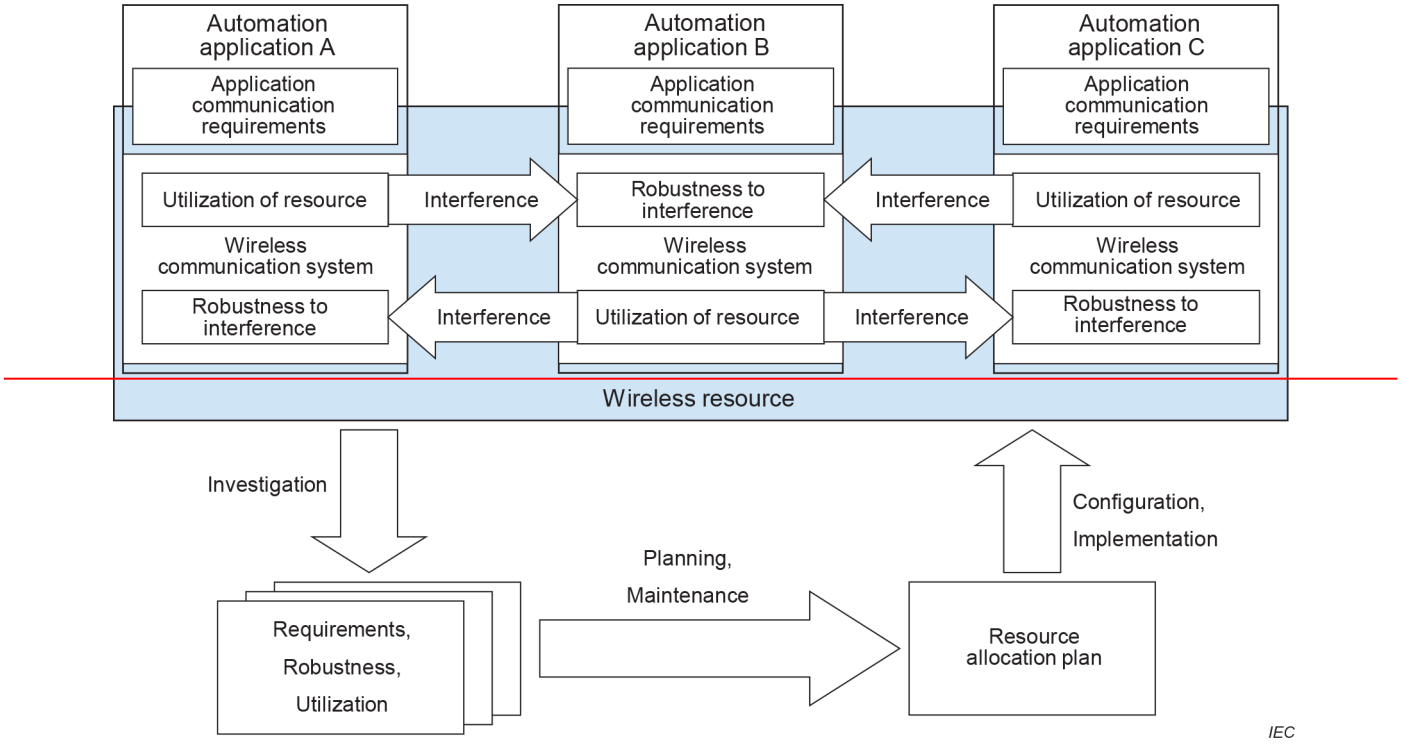

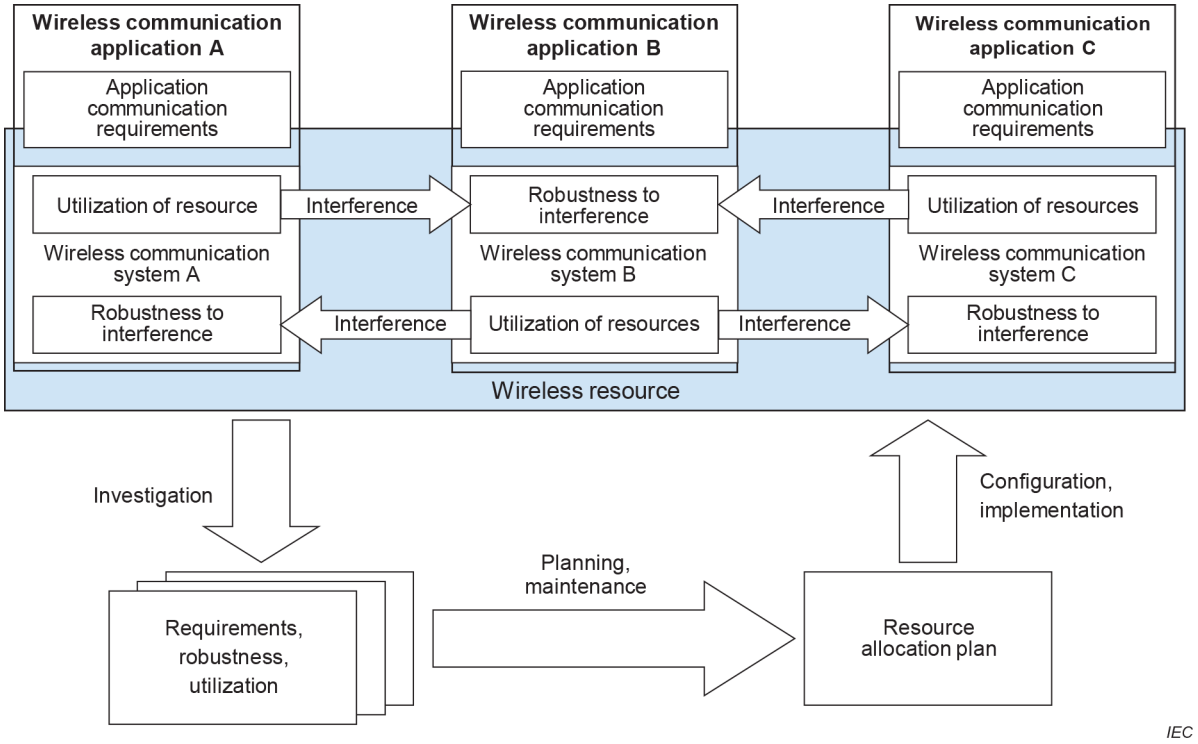

Figure 5 – Coexistence conceptual model

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Figure 6 shows some of the contents of Figure 5 as a flow chart to provide the relations to Figure 7, Figure 29 and Figure 30. The coexistence management system specification is shown in Figure 6 only at the start to keep the figure simple. The documentation shall be extended and updated at each phase. If the requirements of a certain phase are not fulfilled, then the process should restart from the beginning, see lines in Figure 6 going from the output of a phase to the return path. The documentation is specified in 7.1.2.

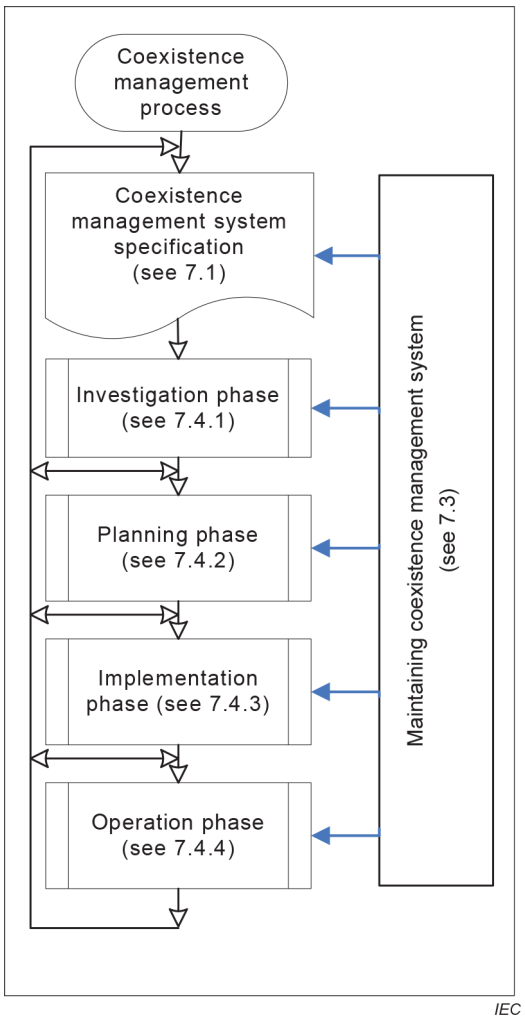

Figure 6 – Flow chart of the coexistence conceptual model

4.10 Coexistence management and selection of a wireless solution

The starting point and precondition for the implementation phase is that the wireless solution is suitable for the requirements made on it. The investigation phase begins by reviewing the wireless system requirements and making a determination as to whether or not the system is able to fulfil application communication requirements. As part of this process, new wireless systems can be evaluated against application communication requirements. Figure 7 maps decisions and actions into the flowchart shown in Figure 6.

While investigating whether a wireless solution meets the requirements of an automation application, radio transmission shall be analyzed to see whether it is a reasonable approach when considering the efforts that are required to be taken to achieve coexistence. In this respect, the selection process of a wireless solution is already part of the coexistence management process.

The decision to install a wireless system shall be followed by the decision to implement a coexistence management process (see 6.8). The coexistence management process includes

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coexistence planning, installation, operation and maintenance of wireless systems. The coexistence planning phase (see 7.4.2.2) begins with the inventory of all wireless applications, because they can be regarded as potential interferers (see 7.3).

In the coexistence planning phase, it might become apparent that a chosen wireless solution cannot be integrated into the existing plant. Another wireless solution might be chosen or the idea of a wireless system might be abandoned. If, in the coexisting planning phase, it is ensured that all wireless communication applications meet the respective requirements, the coexistence management process for the operating phase can be initiated (see 7.4.4).

NOTE 1 Processes in the planning phase and in the operating phase are specified in more detail later in this document.

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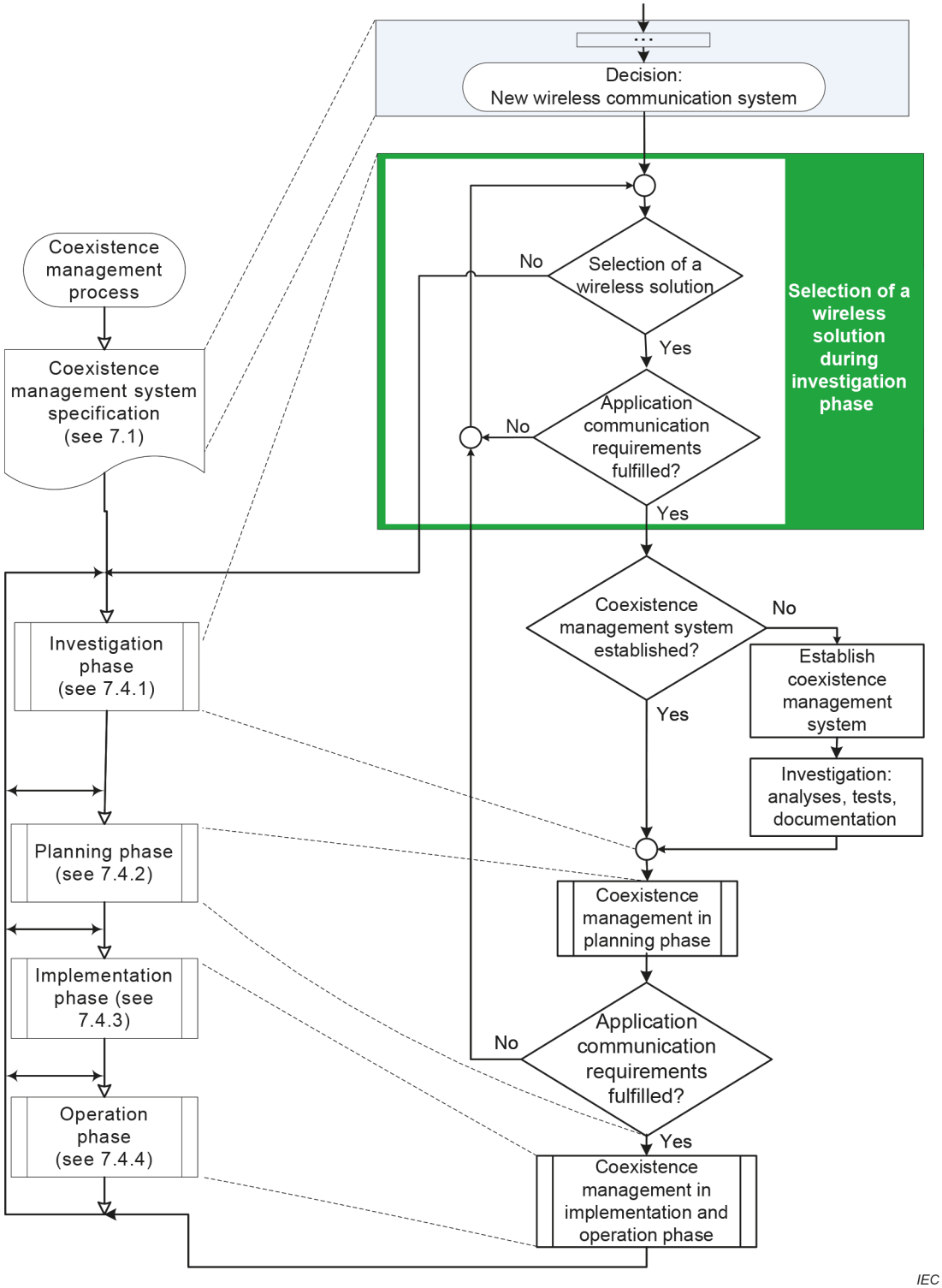

Figure 7 – Selection of a wireless system in the coexistence management process

NOTE 2 Figure 7 does not show the box "Maintaining coexistence management system (see 7.3)" as it is shown in Figure 6, to avoid making Figure 7 too complicated.

4.11 Coexistence management system

The coexistence management system consists of an organizational structure and procedural documents. The execution of the coexistence management brings the system into a state of "coexistence management in operating phase". The coexistence management system specification shall include the following information:

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- scope of the coexistence management;
- commitment of the organization to coexistence management;
- procedure for maintaining the coexistence management system specification;
- organizational issues including structure of the organization, roles of personnel, communication with external organizations and personnel education;
- procedures for coexistence management.

The coexistence management system specification shall be documented, see 7.1.2 and maintained, see 7.3.

5 Coexistence management parameters

5.1 General

5.1.1 Definition and usage of parameters

Clause 5 specifies the parameters of a coexistence management process. These parameters are relevant to the automation communication requirements and conditions within the area of operation and characterize wireless devices and systems.

Their usage is specified in Clause 6. Clause 8 contains the templates related to some of these parameters.

The parameters are listed in alphabetical order. All parameters also have a definition in 3.1. As there are more definitions than parameters, the numbering is different.

The data types of the parameters can be defined in the Common Data Dictionary (CDD) or other tools where the parameters are part of the electronic repository.

Annex A shows the parameter usage in the IEC 62657 series.

5.1.2 Physical link

The concept of physical link is used in the definition of several coexistence parameters.

A physical link is the relation between radio transceivers (physical end points) of two wireless devices. The set of physical links of a wireless system forms its physical topology. A physical link may use different frequency channels for transmissions. Wireless transmission conditions can be described with a radio channel model. Such a model considers the characteristic of the frequency channel, the environmental conditions, the distance between the wireless devices, the antenna characteristic, etc. Because the antenna systems of the wireless devices ~~may~~ can be different and the propagation conditions depend on the position of the wireless devices, the radio channel is normally different for both directions of a physical link.

Where wireless devices have redundant wireless modules, for example for different frequency channels, the related physical links shall be counted separately. It is not required that a wireless device has a physical link to all other wireless devices. There can be physical, technological or application related reasons. The communication load of a physical link is determined by the logical links which use this physical link. A logical link may use more than one physical link, in sequence (via repeater) or in parallel (for redundancy). More than one logical link may use one physical link (different communication services).

5.2 Adjacent channel selectivity

Adjacent channel selectivity is the lower value (of the upper and lower adjacent channels) of the ratios, in decibels, of the levels of the unwanted signal level, expressed as field strength to a specified wanted signal level expressed as field strength producing a data signal with a bit

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error ratio of 10^{-2}. Adjacent channel selectivity is suitable to estimate the immunity of the equipment against systems in adjacent channels.

NOTE This is in line with the specification of adjacent channel selectivity in ETSI TR 100 027 [20].

The unit of this parameter shall be the decibel (dB) over the intended frequency range.

5.3 Antenna gain

The antenna gain is a value that describes the focusing of a transmitted or received signal. The values are given in relation to a half-wave dipole or a theoretical isotropic radiator. Since the isotropic gain of a half-wave dipole is 2,15 dBi, the antenna gain of a half wave-dipole is 2,15 dBi lower than the antenna gain of an isotropic radiator.

The antenna gain together with transmit power values, the receiver sensitivity and taking into account the propagation conditions can be used to optimize the location and orientation of the wireless device or antenna.

The unit of this parameter shall be the decibel relative to isotropic (dBi).

5.4 Antenna radiation pattern

A radiation pattern illustrates the directional (angular) dependence of the strength of the radio waves of an antenna. It is usually represented graphically for the far-field conditions in either the horizontal or vertical plane. This information can be used to optimize the location and the orientation of the wireless device or antenna.

This parameter shall be represented as a figure or a table.

5.5 Antenna type

Wireless devices can use different kinds of antennas to collect or radiate electromagnetic waves. Examples include omni-directional antennas, directional antennas, antenna arrays, smart antennas and PCB antennas. The antennas can be integrated into the wireless device (internal) or antenna connectors are available to mount antennas externally. If a device has an antenna connector, special antenna systems such as radio coaxial radiating cables or slotted waveguide antennas can also be connected. In addition, the antenna can be mounted independently of the device in a position that is favorable for error-free transmission. If a wireless device can only be used with one certain antenna, it is called dedicated antenna. The information concerning the antenna type can be used to estimate the quality of the physical link and the sensitivity to interferences.

The parameter shall be an indexed list with the items omni-directional antennas, directional antennas, antenna arrays, smart antennas and PCB antennas extensible with entries of new antenna types.

5.6 Communication availability

Communication availability is a measure to quantify the dependability of wireless communication. Requirements for availability of wireless communication shall be specified.

Other wireless solutions could cause degradation of availability of target wireless communication application. Tolerable availability levels to achieve the target of the application should be clarified. Depending on the granularity of coexistence management, the parameter can refer to a logical link or, more generally, to a local application or wireless communication application. The communication availability is the ratio between the up time to the observation time. This can also be expressed by the ratio of successful transmitted messages and all messages.

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The unit of this parameter shall be the percent (%).

5.7 Communication reliability

The communication reliability of a physical link and the related nodes is a measure to quantify the dependability of wireless communication. Requirements for reliability of wireless communication shall be specified for a given time interval that the communication services under given conditions shall perform without an error.

The unit of this parameter shall be the second (s).

5.8 Bit rate of physical link

The bit rate of the physical link is a measure of the number of binary digits transferred per second. Since data is often combined by modulation or coding, the time utilization of a telegram cannot always be calculated by simply dividing the number of bits of the telegram by the bit rate. It has also to be mentioned that the bit rate of the physical link is normally not identical to the bit rate of the reference interface. A high bit rate of the physical link does not automatically mean a high quality of service.

The unit shall be the bit per second (bit/s).

5.9 Blocked frequency list

Avoiding the use of the same radio frequency ranges for different wireless communication systems is the first measure to prevent interference. For wireless communication systems that use Frequency Hopping Spread Spectrum (FHSS) technology, this means that frequency ranges in the hopping sequence that are used by other wireless communication systems are blocked and with that, not used. A list of frequency channels that shall not be used, called blocked frequency list, shall be specified for the wireless system.

~~Blocking frequencies~~ A blocked frequency list can also be used in non-FHSS systems with dynamic frequency allocation.

The parameter shall be a list of frequency channels according to 5.22.

5.10 Centre frequency

Some wireless standards define frequency channels using centre frequency and frequency bandwidth. Thus, the centre frequency indicates the position of a frequency channel within the frequency spectrum. The centre frequency shall be calculated based on the relevant cut-off frequencies. The centre frequency is the geometric mean of lower cut-off frequency and upper cut-off frequency.

The unit of this parameter shall be the hertz (Hz).

5.11 Area of operation

The following areas of operation shall be considered:

- indoor;
- outdoor;
- indoor and outdoor.

For indoor areas of operation, it is reasonable to define whether the communication is concentrated in a machine or manufacturing cell or if it operates all over the entire factory hall or plant.

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The content of this parameter shall be text expressed with a multiple octet string.

5.12 Communication load

The communication load describes the requirement of the automation application to transfer a certain amount of user data within a certain period of time as shown in Figure 8. The communication load is the ratio of ~~user~~ automation application data length and transfer interval. The communication load (L_c) is determined as follows:

$$L_c = \sum_i \frac{DL_{Ui}}{T_{Ii}}$$

where

DL_U is the number of user data transferred per device i;

T_I is the transfer interval per device i.

Depending on the granularity of coexistence management, the communication load and its parameters can refer to a logical link or, more generally, to an application.

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