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TECHNICAL SPECIFICATION

Industrial communication networks – Wireless communication network – Part 2: Coexistence management

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Industrial communication networks – Wireless communication network – Part 2: Coexistence management

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INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORK –

Part 2: Coexistence management

FOREWORD

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62657-2, which is a technical specification, has been prepared by subcommittee 65C: Industrial networks, of IEC technical committee 65: Industrial-process measurement, control and automation.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
65C/645/DTS	65C/661A/RVC

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

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

A list of all parts of the IEC 62657 series, under the general title *Industrial networks – Wireless communication network,* can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

The market is in need of several network solutions, each with different performance characteristics and functional capabilities, matching diverse application requirements. Industrial automation applications covering different industrial applications such as process automation, factory automation, water/waste water treatments and other industrial applications up to power generation and power distributions applications, require different behaviours of wireless networks as, for example, in telecommunications, or for commercial items such as remote controls or toys. These requirements will be specified in the future IEC 62657-1.

In industrial premises, a lot of different wireless communication networks have to operate together such as IEC 62591 [9] (WirelessHART® [1])[2] and future IEC 62601 [10][3] (WIA-PA), both using IEEE 802.15.4 for the process applications and such as IEC 61784-1 [5] and IEC 61784-2 [6] CPs using IEEE 802.11 [12] and IEEE 802.15.1 [13] for factory automation applications with different wireless communication systems. Different to wired fieldbuses, wireless communication interfaces can interfere with others on the same premises or in the same environment, disturbing each other. Therefore, it is not tolerable to have multiple wireless communication networks in the same facility or environment without a predictable assuredness of coexistence.

The IEC 62657 series has two parts:

– Part 1: Wireless communication requirements and spectrum considerations

– Part 2: Coexistence management

Future IEC 62657-1 [11] provides requirements for regulators in order to obtain additional dedicated and worldwide unique spectrum and its standardized usage. It is intended to facilitate harmonization of future adjustments to the international, national and local regulations.

This part of IEC 62657, which is a technical specification, provides guidance to the users of wireless communication networks on selection and proper use of wireless communication networks. To provide suitable wireless devices to the market, it also serves vendors in describing the behaviours of wireless devices to build wireless networks matching the application requirements.

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

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1 WirelessHART is the registered trade name of the HART Communication Foundation. 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.

2 Figures in square brackets refer to the bibliography.

3 To be published.

INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORK –

Part 2: Coexistence management

1 Scope

This part of IEC 62657, which is a technical specification, specifies the fundamental assumptions, concepts, parameters, and procedure for wireless communication coexistence.

This specification provides guidelines, requirements, and best practices for wireless communications' availability and performance, covering the life cycle of wireless communication coexistence to help the work of all persons involved with the relevant responsibilities to cope with the critical aspects in each phase of wireless communication coexistence management in an automation plant.

Additionally this specification 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. Life cycle aspects include: planning, designing, installation, implementation, operation, maintenance, administration and training.

This specification deals with the operational aspects of wireless communication coexistence regarding both the static human/tool-organization and the dynamic network self-organization.

This technical specification specifies coexistence parameters and how they are used in an application requiring wireless coexistence.

NOTE Measurement methods of parameters could be the subject of a later edition.

2 Normative references

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

IEC 61804-3, *Function blocks (FB) for process control – Part 3: Electronic Device Description Language (EDDL)*

IEEE 802.15.4, *IEEE Standard for Local and metropolitan area networks – Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)*

3 Terms, definitions, abbreviated terms and conventions

3.1 Terms and definitions

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

3.1.1
adjacent channel interference
interference that occurs when two or more wireless applications use adjacent frequency channels

3.1.2
adjacent channel selectivity
ability of a radio receiver to respond to the desired signal and to reject signals in adjacent frequency channels

3.1.3
antenna
structure or device used to collect or radiate electromagnetic waves

3.1.4
antenna gain
ratio of the power required at the input of a reference antenna to the power supplied to the input of the given antenna to produce, in a given direction, the same field strength at the same distance

[SOURCE: Federal Standard 1037C, modified] [16]

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
automation application data length
number of octets that are exchanged at the communication interface

3.1.7
automation application
application of measurement and automatic control in the industrial automation branches

3.1.8
bandwidth
difference between upper cut-off frequency and lower cut-off frequency

3.1.9
centre frequency
geometric mean of lower cut-off frequency and upper cut-off frequency of a radio channel

3.1.10
channel occupation
time 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, e.g. to transfer an acknowledgement.

3.1.11
co-channel
refers to emissions or transmissions in the same frequency channel

[SOURCE: IEC 60050-713:1998, 713-06-23, modified] [2]

3.1.12
coexistence
wireless communication coexistence
state in which all wireless communication solutions of a plant using shared medium fulfill all their application communication requirements

NOTE 1 to entry: The status of coexistence is characterized by meeting the limit values of relevant parameters for all wireless applications in the considered area. This status has to be ensured with appropriate measures in planning and in operation. This clarifies that coexistence is not a static attribute of a wireless communication solution, but rather a status within the life cycle of a plant. It is possible to leave this status 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 it is not reasonable to try to evaluate or ensure the coexistence separate from an automation application.

3.1.13
coexistence assessment
undertaking of an investigation in order to arrive at a judgment, based on evidence of the suitability of a set of products and their installation to achieve coexistence

[SOURCE: derived from IEC 62278] [8]

3.1.14
coexistence planning
process that describes the allocation of radio resources (such as time, frequencies, transmit power, space, etc.) to each wireless system in order to achieve coexistence

3.1.15
coexistence management
process to establish and to maintain coexistence that includes technical and organizational measures

3.1.16
communication interface
exposed interface between an automation application and the wireless component

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.

3.1.17
communication load
requirement of the automation application to transfer a certain amount of user data within a certain period of time

3.1.18
duty cycle
ratio of the transmitter sequence referenced to a given observation time for the used radio channel

3.1.19
dwell time
period spent at a particular frequency during any single hop of a frequency hopping system

3.1.20
effective radiated power
power supplied to the antenna multiplied by antenna gain

3.1.21
external wireless systems
wireless applications beyond the scope of the coexistence management process, but potentially affecting the wireless communication systems administrated by the coexistence management

NOTE 1 to entry: External systems can be operated on adjacent sites and irradiate into the considered location.

3.1.22
frequency band
range in the frequency spectrum that is assigned for use to specific applications by regulatory organizations

3.1.23
frequency channel
part of a frequency band that is used under a specification (standard or device specification) by a wireless communication system

NOTE 1 to entry: The coordinated use of different frequency channels is one of the measures to achieve coexistence.

3.1.24
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 changes if the environmental conditions change.

NOTE 2 to entry: Immunity of an item is achieved by adding to the robustness of the item the ability to be resilient to interference.

3.1.25
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

3.1.26
jitter
time variation of an expected occurrence

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

3.1.27
lower cut-off frequency
frequency furthest below the frequency of maximum power where the power spectral density drops below a certain level

3.1.28
mechanisms 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

3.1.29
metrics
set of quantitative indicators corresponding to selected properties of a communication device, equipment, or wireless communication system

3.1.30
plant
complete set of technical equipment and facilities for solving a defined technical task

NOTE 1 to entry: A plant includes apparatus, machines, instruments, devices, means of transportation, control equipment and other operating equipment.

[SOURCE: IEC 60050-351:2006, 351-21-45] [1]

3.1.31
power spectral density
signal power per defined bandwidth

3.1.32
radio channel
span of the frequency spectrum which is characterized by lower cut-off frequency and upper cut-off frequency or by centre frequency and bandwidth

3.1.33
(radio) resource
means used by multiple wireless communication solutions for the purpose of radio signal transmission

3.1.34
receiver blocking
effect of a strong out-of-band interfering signal on the receiver's ability to detect a low-level wanted signal

3.1.35
receiver maximum input level
maximum signal power that the system can tolerate without distortion of the signal

3.1.36
receiver sensitivity
minimal signal power to receive data with a defined bit error rate

3.1.37
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 be increased with measures that modify one or more of its operational parameters

3.1.38
spurious response
receiver output due to unwanted signals (i.e. having frequencies other than those of the tuned frequency channel)

3.1.39
radio robustness
attribute of wireless communication to fulfill the designated function despite the presence of other active wireless communication applications interfering in the sphere of influence

NOTE 1 to entry: This is consistent with the definition of coexistence in IEEE 802.15.2 [14].

3.1.40
shared medium
frequency band shared by several wireless applications as assigned by regulatory organizations

NOTE 1 to entry: Especially in the industrial, scientific and medical (ISM)-bands, many wireless applications can be used. Due to this joint use, the term 'shared medium' is used in this technical specification. The frequency ranges are used by diverse ISM and wireless applications.

3.1.41
transfer interval
time difference between two consecutive transfers of user data from the automation application via the communication interface to the communication module

3.1.42
wireless application
any use of electromagnetic waves with devices or equipment for the generation and use of radio frequency energy

NOTE 1 to entry: This term is more comprehensive than the term wireless communication system, because in wireless applications the frequency energy is not only used for information transfer.

NOTE 2 to entry: The use of the electromagnetic energy may be either intentional (as needed to serve the specific application) or unintentional/incidental.

3.1.43
wireless communication
communication in which electromagnetic radiations are used to transfer information without the use of wires or optical fibers

[SOURCE: IEC 60050-732: 2010, 732-01-05, modified] [3]

3.1.44
wireless communication solution
specific implementation or instance of a wireless communication system

NOTE 1 to entry: A wireless communication solution may be composed of products of one or more producers.

3.1.45
wireless network
wireless communication solution consisting of at least two wireless devices

3.1.46
wireless communication system
set of interrelated elements providing a wireless communication

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

3.1.47
total radiated power
spatial power density integrated across the surface of the sphere

3.1.48
transmission gap
gap between two successive channel usages by a transmitter

3.1.49
transmission sequence duration
time that a transmitter uses the spectrum for the specific sequence in order to transfer data

3.1.50
transmitter spectral mask
maximum limit of power spectral density over a frequency range

3.1.51
upper cut-off frequency
frequency furthest above the frequency of maximum power where the power spectral density drops below a certain level

3.2 Abbreviated terms

AFH	Adaptive Frequency Hopping spread spectrum
BOS	Wireless communication systems for public authorities and organizations with safety functions
CEPT	European Conference of Postal and Telecommunications Administrations
CP	Communication Profile according to IEC 61784-2 [6]
CSMA	Carrier Sense Multiple Access
DAA	Detect and Avoid
DAR	Detect and Reduce
DAS	Detect and Suppress
DECT	Digital Enhanced Cordless Telecommunications
EDDL	Electronic Device Description Language
EIRP	Equivalent Isotropic Radiated Power
EMC	Electro-Magnetic Compatibility
ERO	Electronic Communications Committee of the CEPT
ERP	Effective Radiated Power
FB	Function blocks
GSM	Global System for Mobile Communications
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
NLOS	None Line of Sight
OLOS	Obstructed Line of Sight
PCB	Printed Circuit Board
PHY	Physical Layer
PLR	Packet Loss Rate
PSD	Power Spectral Density
RegTP	Regulatory Authority for Telecommunications and Posts
RFID	Radio Frequency Identification
SIR	Signal-to-interference ratio
TDMA	Time Division Multiple Access
TRP	Total Radiated Power
TS	Technical Specification
UMTS	Universal Mobile Telecommunications System
WLAN	Wireless Local Area Network
ZVEI	The German electrical and electronics industry

3.3 Conventions

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 shall be selected.

4 Coexistence concept in industrial automation

4.1 Overview

Wireless communication in industrial automation contributes to organize production processes more cost-efficiently, flexibly and reliably as well as allowing the realization of new automation concepts. Automation applications usually place stricter requirements on reliability and real-time capability of wireless communication than applications in the domestic and office domain.

Because of those requirements, different wireless communication systems are used. It is quite likely that several wireless communication systems may operate simultaneously in one place. Since these wireless communication systems share a common medium, interferences can be assumed throughout their life cycles. This results in influences on the reliability and real-time capability. This specification is intended to help identify potential risks and to recommend measures to control these risks, depending on the requirements of the automation application.

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

The technical specification also illustrates that most often the coexistence of several wireless communication 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 communication systems during design, commissioning, and operation, as well as maintenance, are considered. This process called coexistence management of wireless communication solutions, is the subject of this specification. 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 elaborated, depending on the relevance of wireless communication for the plant. The requirements on the implemented wireless communication systems are decisive here. If no, or just modest, requirements are made on the wireless communication system, a lower effort for the coexistence of wireless communication solutions will be necessary than in the case of a wireless communication system that is part of a control application with strict real-time requirements. However, it is strongly recommended to consider that further wireless communication systems might be implemented later or that the requirement on the present wireless communication system might change in future (e.g. due to additional applications). Finally it is the responsibility of the reader to decide to what extent the required efforts to accomplish the coexistence measures meet the requirements on the wireless communication system, or the relevance of the wireless communication system within the plant.

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

There are three levels of possible organizations to manage coexistence, where the lowest level is the less efficient:

- manual coexistence management (lowest level);
- automated non-collaborative metrics-based coexistence management;
- automated collaborative metrics-based coexistence management (highest level).

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

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

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

In the metrics non-collaborative organization, the different wireless communication 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 communication 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 (e.g. the frequency band, the timeslot/packet scheduling, and so on) as a function of some metrics capable of establishing whether the communication performance is good enough or not.

NOTE Some of these metrics are described in IEEE 802.15.2. [14]

In a collaborative organization the different wireless communication solutions are able to exchange information.

The precondition for a collaborative organization for wireless systems using multiple technologies provided by multiple vendors is that a common standardized communication link is available amongst these solutions.

This approach may 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 communication 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 may influence the determinism or reliability of the communication and can therefore be inappropriate for various automation applications.

4.2 Objective

This technical specification is focused on measures to provide coexistence of wireless communication systems for measurement and automation applications. These applications can be classified in various ways, see for example Table 1 where 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 – Application communication requirements and profiles

Class	Application	Application communication requirements
Functional safety	Protection of human life	A functional safety application intent is to achieve or maintain a safe state in case of hazardous events
Control	Closed or open loop control	The control application class meets strict requirements with regard to availability, reliability, and time-criticality. Interactions with other applications and process interventions are included
Monitoring	Process visualization and alerting	The monitoring application class is not time-critical and exclusively provides additional information. Interactions with other applications and systems are excluded

The classification of automation applications primarily refers to the functional requirements of the application to be considered. However, it is possible that an automation application is allocated to a less critical application class with respect to their criticality corresponding to its functionality, but it is vitally important for business processes. In this case, it is recommended to allocate it to a more critical application class, to represent its meaning for the company properly and to indicate a higher effort to ensure coexistence.

The importance of coexistence in applications may vary, depending on the usage of the wireless communication system. Industrial applications can be mapped to different application classes as shown in Table 1 for the purpose of this technical specification.

Further 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 technical specification.

The considerations are not confined to a specific frequency band like the typically used 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 interferences. Moreover, further interferences might occur due to powerful low frequency electromagnetic fields (for example transformers, powerful motors or other EMC influences, see Figure 1). The interference sources to be considered are detailed in 4.4.

NOTE The analysis of EMC is outside of scope of this technical specification but has been considered.

This technical specificaiton assumes that actions apply to the location of an enterprise; however, electromagnetic wave propagation is not localized and influences from the vicinity cannot be excluded.

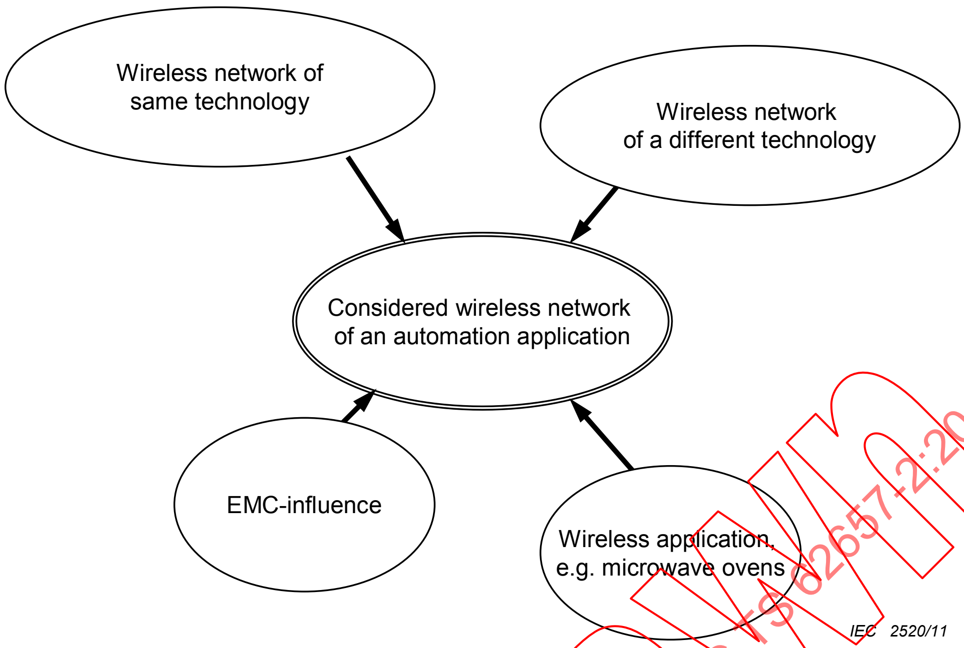


Figure 1 – Area of consideration

It is assumed that, in conditions without interference from other wireless systems, a wireless communication system basically meets the requirements of the automation application and that, in particular, the limit values for time and error behaviour are observed 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 bands reserved by regulation organizations are a valuable limited resource which will be rapidly exhausted in the case of unregulated use.

Figure 2 shows an example of wireless applications to be found in industrial environments. 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, it is recommended that a binding, company-wide process for the administration of wireless applications for all parties involved should be initiated.

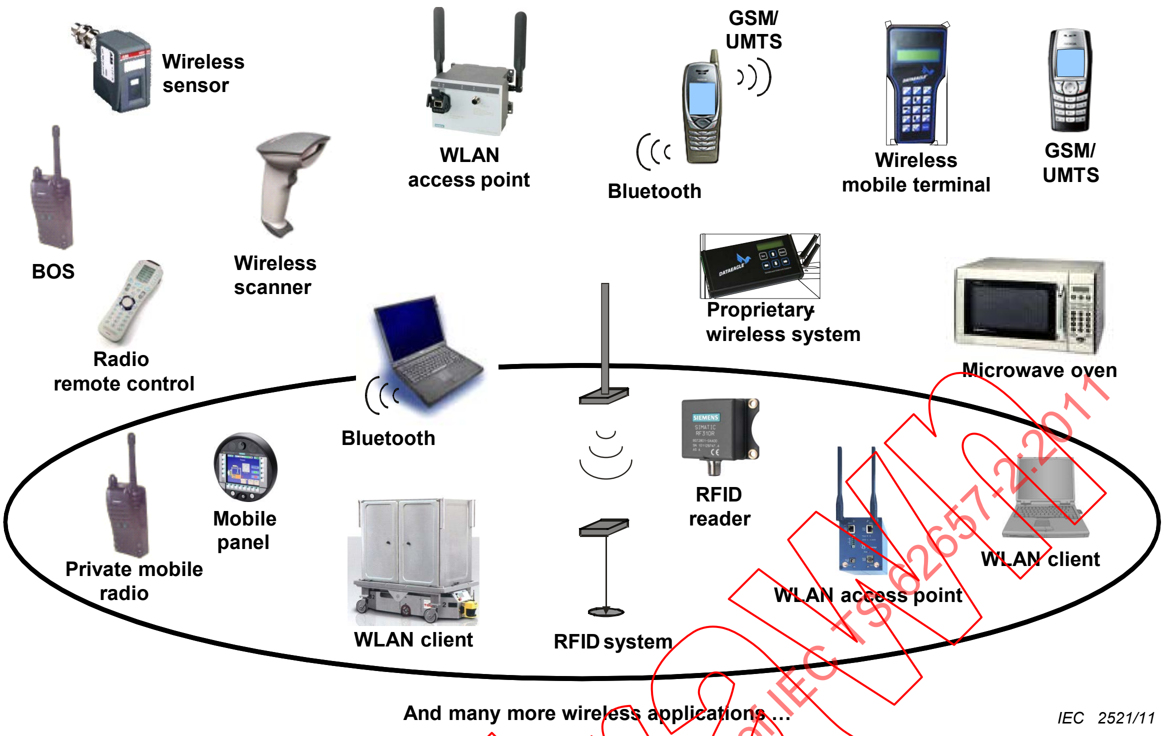


Figure 2 – Examples of wireless equipment in industrial environments

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 applications with a high data throughput, but relaxed real-time requirements (for example application class Monitoring). The coexistence management puts the focus on the provision of adequate bandwidth;
- wireless applications without specific requirements for performance and real-time- The coexistence management aims at ensuring the spatial coverage (for example application classes control to monitoring);
- wireless applications with strict real-time requirements. The coexistence management safeguards againstz functional problems, caused by the influence of other wireless applications, do not arise (application classes Functional Safety or Control).

Nevertheless, 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;
- inventory of all installed and, if possible, all planned wireless applications;
- 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 communication systems within the committee.

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, etc.

Coexistence management offers various benefits:

- reduction or elimination of interferences leading to plant downtimes with financial losses and resulting in potential image damage;
- reduction or elimination of laborious, cost-intensive and time-consuming fault finding;
- reduction or elimination of disinvestments in wireless communication solutions that cannot be operated in the present radio environment of the enterprise.

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

4.4 Interference potential

Wireless applications use the frequency spectrum as a "shared medium", meaning that different wireless applications contend for the same resource (for example time, frequencies, transmit power, space, etc.). Therefore, by definition, they mutually interfere. There are overlaps of wanted and disturbing signals.

If the following three conditions are met simultaneously, these overlaps lead to interferences:

- signals overlap in the frequency domain;
- signals overlap in the time domain;
- the ratio of wanted and disturbing signals is less than the required signal to interference ratio.

If these three conditions are fulfilled concurrently, then a co-channel interference results; this is the most likely kind of interference. This leads to collisions of wireless applications so that, for example a transferred packet has to be repeated. The system reaction to the described co-channel interference depends on several factors, for example on the radio standard, on the hardware and software implementation or on the application class the wireless communication system uses for transfer.

The separation of non-overlapping frequency channels is a method to achieve coexistence. However, there might be interferences between wireless communication systems using different channels in the same frequency band, for example because of adjacent channel interferences. In particular, analog wireless communication systems hold a high interference potential for digital wireless communication systems due to their high channel occupation. Moreover, interferences caused by wireless communication systems using different frequency bands can also be a collision risk. Beneath the main signal a wireless communication system also emits outer band signals that might penetrate the frequency channel of the endangered wireless communication 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 (i.e. collision) in these domains is complete or only partial.

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

For the second item, 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) may 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. Usually, the term co-channel is used to define the interference if both interferer(s') transmitter(s) and victim receiver use the same kind of radio (i.e., physical layer) and are tuned on the same frequency channel. Otherwise, the term cross-channel is used if both interferer(s') transmitter(s) and victim receiver use the same kind of radio (i.e. physical layer) but are tuned on different frequency channels.

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

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

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

If possible, future changes in the requirements, implicating changes of the interference potential, should also be considered. The life cycle of a wireless communication solution typically ranges between five and ten years. During this time new applications for the existing wireless communication system can be developed. Determination, coordination and control of these changes are part of coexistence management.

One more influence is radiated EMC-interference. Many wireless applications subject to the frequency regulation have significant radiated power, potentially generating a high field strength in the proximity of another wireless communication system. A wireless communication solution shows a certain interference resistance against those radiated interferences defined in the corresponding standards. This limit value can be exceeded by the signal of a powerful wireless application.

Even though real wireless communication solutions often hold a higher interference resistance than normatively claimed, and exceeding the limit value does not inevitably result in interferences, it should be taken 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.

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

EMC-influences not launched by a radio channel (for example powerful technical energy systems, frequency converters) can cause interferences. These EMC-influences are a topic of the EMC-guidelines and are not considered in the scope of this technical specification.

4.5 Ancillary conditions

For wireless communication there is only a limited resource at disposal. Thus, it shall be thoroughly planned as to how to use this resource. The higher the requirements of the application class on the wireless communication system, as to time behaviour, availability, dimension etc., the higher is the technical and organizational effort to guarantee coexistence. The costs rise disproportionately as shown in Figure 3. A certain span of expense results from the complexity of the wireless communication solutions (for example, simple point-to-point link or linear, star, cellular, tree, meshed 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 to develop appropriate wireless communication solutions.

The effort might be reduced by strategic regulations for coexistence management. A possible regulation is to confine the number of considered influencing factors, e.g. 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 lifecycle costs of the plant. The technical and organizational 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 analyse whether the requirements of the planned application fit the intended application requirements. In relaxing the requirements a more efficient use of the resource “radio” can be achieved. If the resource is exhausted, other solutions shall be found.

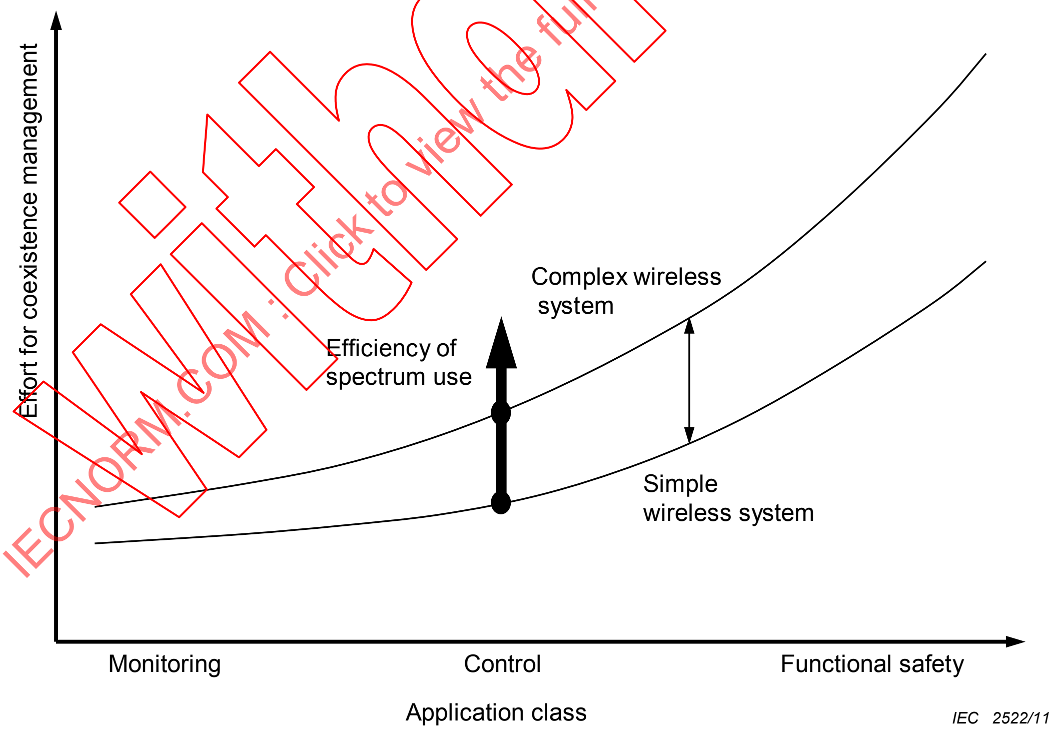


Figure 3 – Progression of expense to achieve coexistence corresponding to the application classes

4.6 Best practices to achieve coexistence

The establishment of coexistence is a combination of technical and/ or organizational measures to ensure the interference-free operation of wireless 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 communication solution has to share the medium with other wireless communication systems. Future developments of the wireless application in the enterprise should be considered here as well.

Technically, wireless communication systems can be uncoupled in four dimensions:

- frequency;
- time;
- space;
- polarization.

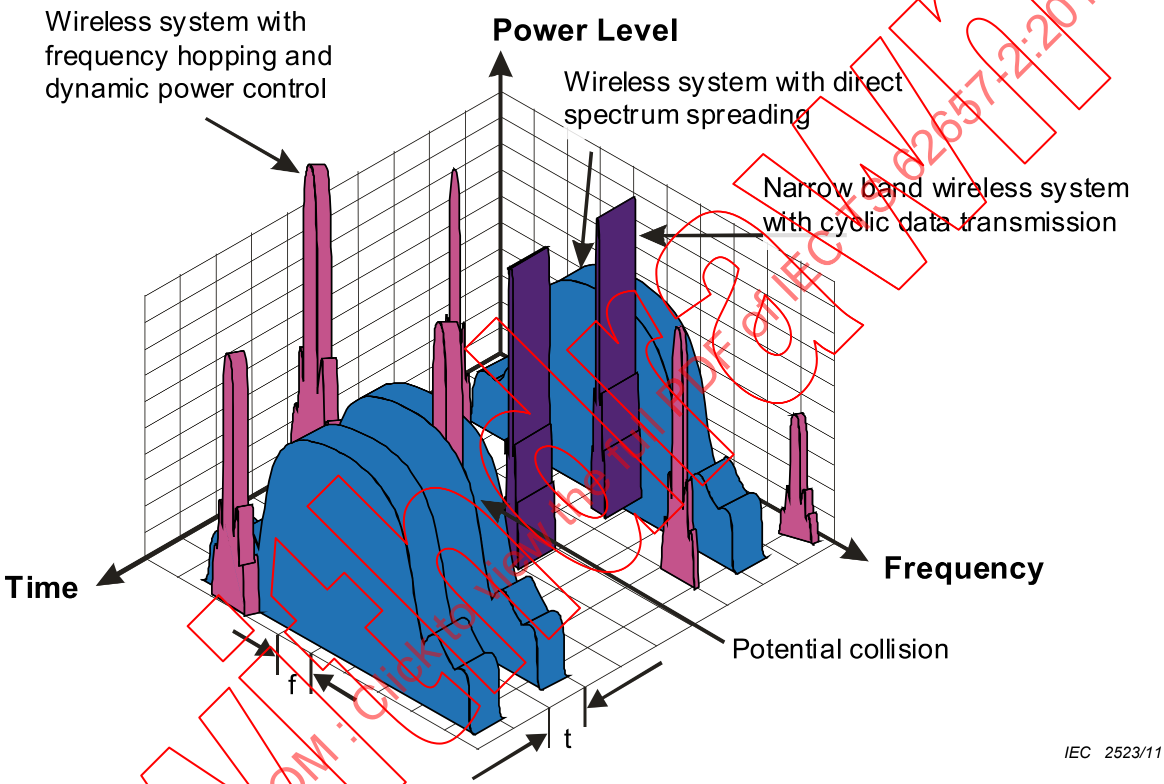


Figure 4 – Separation of wireless communication systems according to frequency and time

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 dynamics, the communication cycle should be set as long as possible and/or event driven communication may be used. Wireless technologies with automatic adaptive medium sharing mechanisms may also be used.

A spatial separation is rarely possible in the case of wireless application. Radio propagation can only be restricted spatially with great efforts. Structural conditions (for example massive armed hall 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. If the power is reduced, the power of all related radio components (base stations, repeaters, end devices, etc.) should be adjusted accordingly.

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.

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

In planning a wireless communication system it shall be considered that the propagation conditions in an industrial environment are not perfect, and thus impacts on the time and error behaviour of a wireless communication solution are possible.

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

4.7 Coexistence conceptual model

Automation applications have application communication requirements in order to fulfill their intended tasks. One of these applications is a selected wireless system which has a certain immunity against interference from other wireless systems. The utilization of the resources (frequency, time, space and polarization) can interfere with other wireless systems and might therefore influence the related automation applications. Propagation conditions shall be considered as they influence the communication quality of a wireless system but also interference from other wireless systems.

The application communication requirements and the characteristics of the wireless system (immunity and utilization) shall be reported in an inventory. The resulting coexisting planning shall be reported in a resource allocation plan. This shall be the basis for configuring and implementing the involved wireless systems. This process of coexistence management is not just one activity during the system planning but an iterative process throughout the entire life cycle of the system.

Figure 5 shows the coexistence conceptual model. A wireless application A has application requirements to fulfill its intended tasks. Part of the wireless application A is the selected wireless communication 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. An investigation of the requirements shall be reported in an inventory. The resulting coexistence planning shall be reported in a resource allocation plan. This shall be the basis for implementing the radio resources and their utilization.

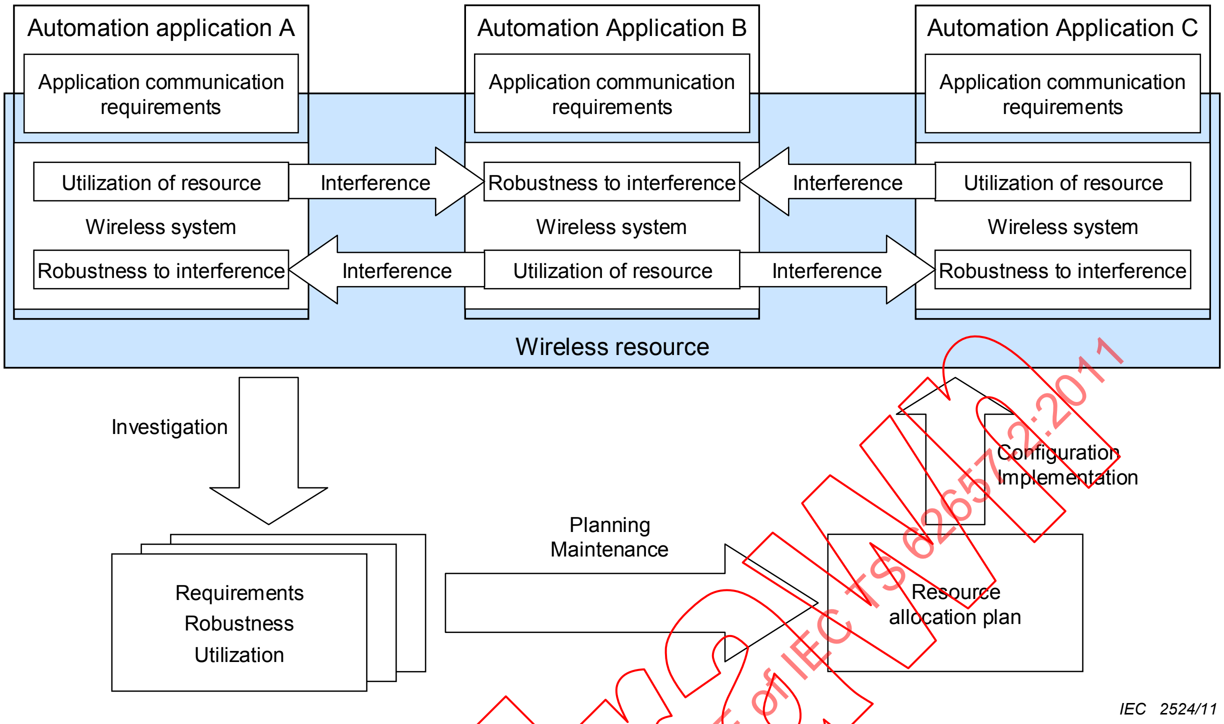


Figure 5 – Coexistence conceptual model

4.8 Coexistence management and selection of a wireless communication solution

Figure 6 outlines the process of coexistence management and represents the relationships between the selection of a wireless communication solution, the implementation of a coexistence management and the actual coexistence management process.

The starting point and precondition is that the wireless communication solution is suitable for the requirements made on it.

While investigating whether a wireless communication solution meets the requirements of an automation application, radio transmission shall be analysed 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 communication solution is already part of the coexistence management process.

The decision to install a wireless communication system shall be followed by the decision to implement a coexistence management process (see 4.4). The coexistence management process includes coexistence planning, installation and operation of wireless communication systems.

The next measure to be taken is the inventory of all wireless applications, because they can be regarded as potential interferers (see 7.3). The coexistence management process of the coexistence planning phase shall then be considered (see 7.4.3.2). In the coexistence planning phase it might become apparent that a chosen wireless application cannot be integrated into the existing plant. Another wireless communication solution might be chosen or the idea of a wireless communication system might be abandoned. If, in the coexisting planning phase, it is ensured that all wireless applications meet the respective requirements, the coexistence management process for the operating phase can be initiated (see 7.4.3.3).

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

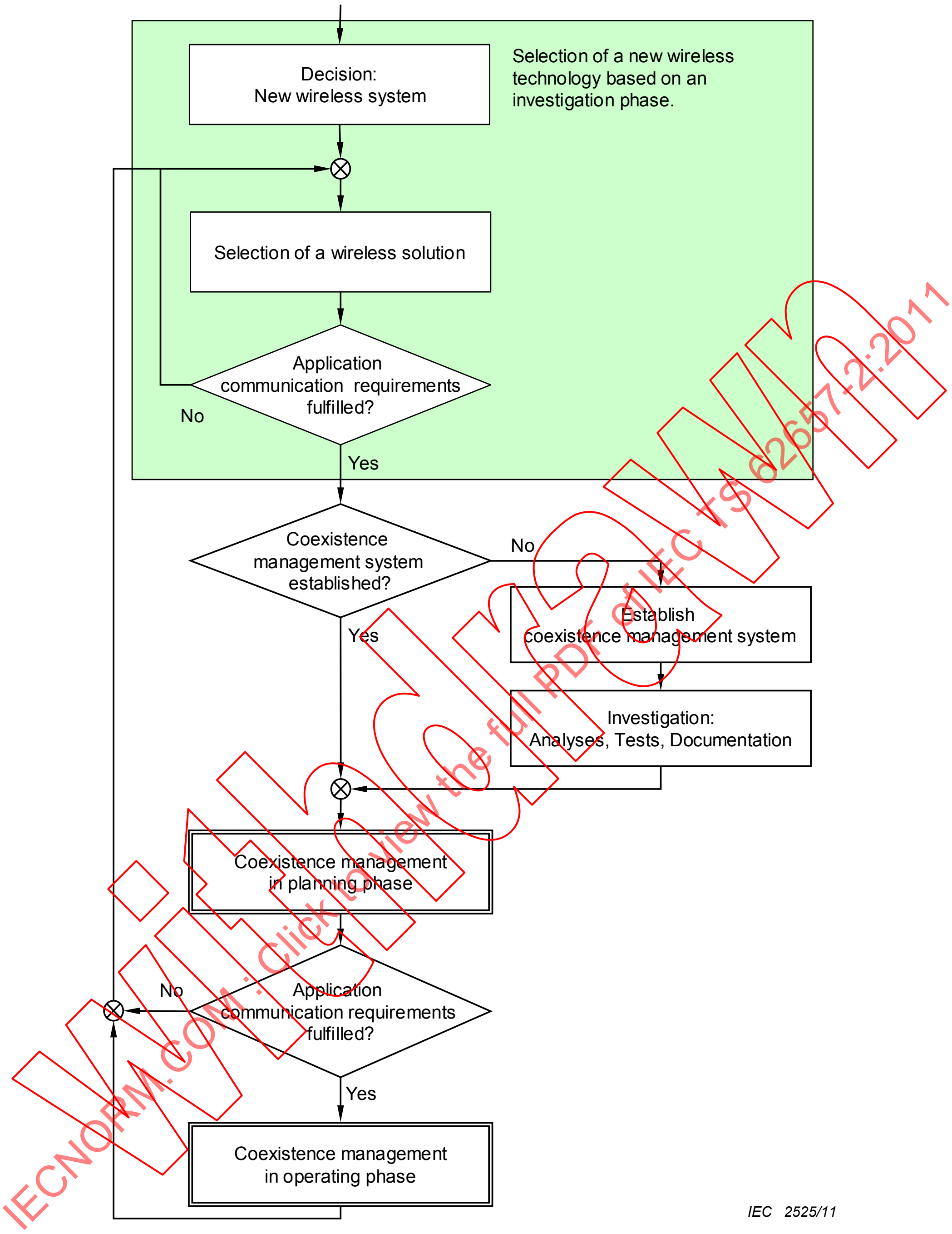


Figure 6 – Selection of a wireless communication system and coexistence management process

4.9 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". It shall include the following information:

- scope of the coexistence management;
- commitment of the organization to coexistence management;
- procedure for maintaining the coexistence management specification;

- organization issues including structure of the organization, roles of personnel, communication with external organizations and personnel education.
- procedures for coexistence management.

The coexistence management specification shall be documented and maintained appropriately.

5 Coexistence management parameters

5.1 General

This clause specifies the parameters which are relevant within a coexistence management process. These parameters describe automation communication requirements, conditions within the area of operation and characterize wireless devices and networks. Their usage is specified in Clause 6. Clause 7 contains the templates related to some of these parameters.

The parameters are listed in alphabetical order.

5.2 Explanation of coexistence parameters

5.2.1 Adjacent channel selectivity

In bibliographic reference [17] the following is defined:

> "The adjacent channel selectivity is a measure of the capability of the receiver to receive a wanted modulated signal at the nominal frequency without exceeding a given degradation due to the presence of an unwanted modulated signal which differs in frequency from the wanted signal by an amount equal to the adjacent channel separation for which the equipment is intended."

Adjacent channel selectivity is specified in [17] as "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 error ratio of 10-2." Adjacent channel selectivity is suitable to estimate the immunity of the equipment against systems in adjacent channels.

5.2.2 Antenna gain

The antenna gain describes the focusing of a transmitted or received signal. Values are given with respect to a half wave dipole or a theoretical isotropic radiator. As the isotropic gain of a half wave dipole is 2,15 dBi, the antenna gain with respect to a half wave dipole is 2,15 dB lower than the antenna gain with respect to an isotropic radiator.

Together with transmit power values, and with due consideration for propagation conditions, receiver sensitivity can be used to optimize the location and the direction of the equipment or antennas.

5.2.3 Antenna radiation pattern

A radiation pattern 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 direction of the equipment or antennas.

5.2.4 Bandwidth

The bandwidth is the range of frequencies occupied by a modulated carrier signal. The bandwidth value depends on the spectral power level referred to (see 5.2.32). The bit rate of a communication channel is proportional to the bandwidth of the signal used for the communication. From the point of view of coexistence management the bandwidth indicates the utilization of the frequency spectrum by the wireless equipment. Systems can also unintentionally radiate outside the defined bandwidth. This could lead to so-called adjacent channel interference (for the next) or even alternate channel interference (for the next but one).

The unit of this parameter shall be Hz.

5.2.5 Bit rate of physical link

The bit rate of the physical link is a measure of the velocity of wireless data transmission. 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 with the bit rate of the communication interface. A high bit rate of the physical link does not automatically mean a high quality of service.

5.2.6 Centre frequency

Some wireless standards define radio channels using centre frequency and bandwidth. Thus the centre frequency indicates the position of a radio 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 Hz.

5.2.7 Characteristic of the 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.

5.2.8 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 7. The communication load is the ratio of user data length and transmission interval.

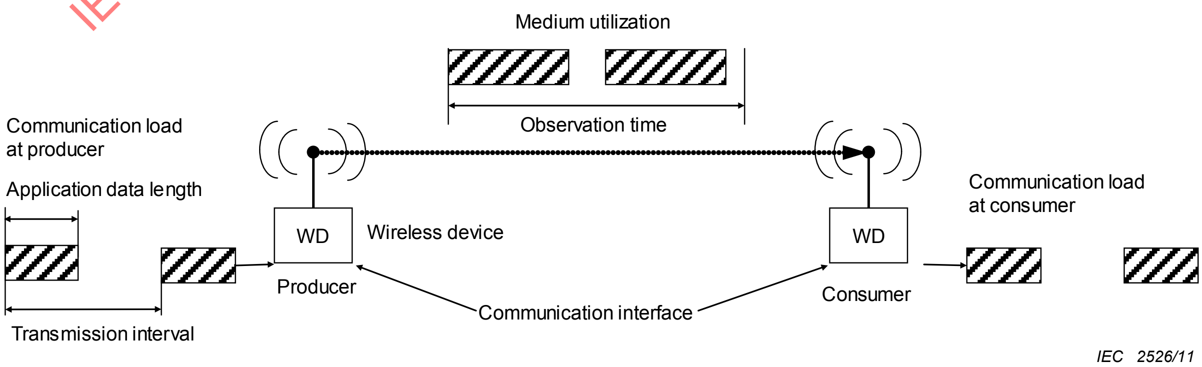


Figure 7 – Communication load in case of two wireless devices

However, the actual medium utilization depends on the applied wireless solution. In the example in Figure 8 the communication load is indicated for more than two radio components.

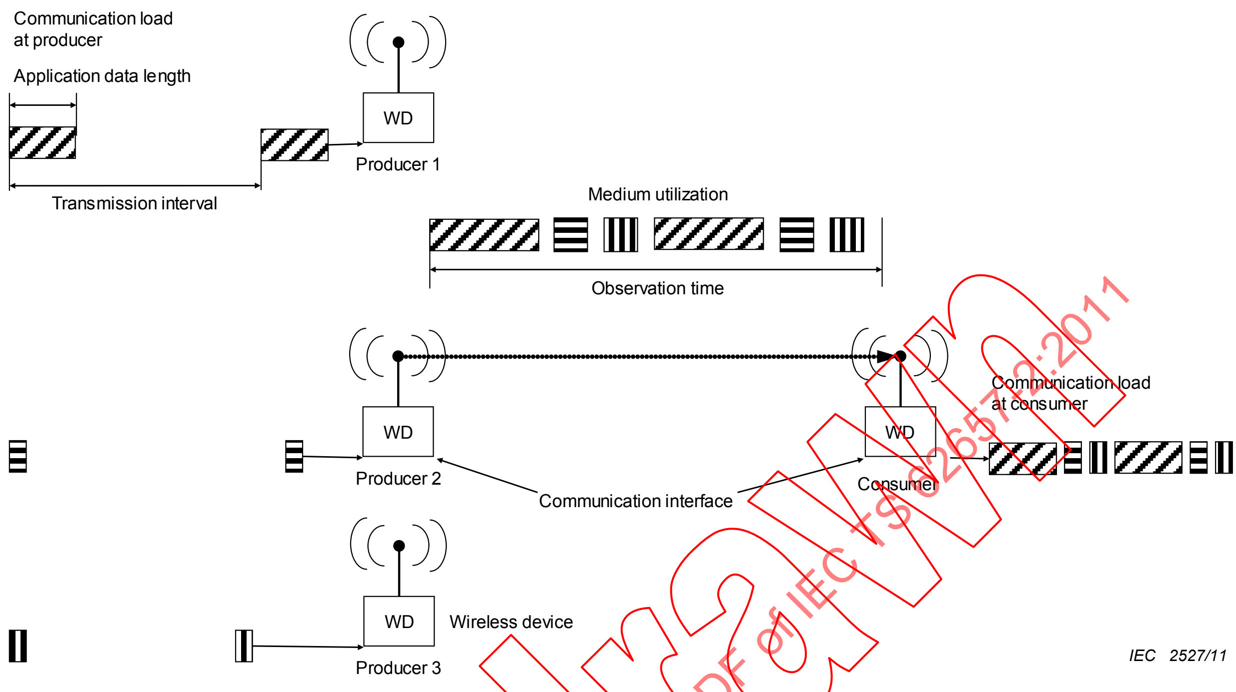


Figure 8 – Communication load in the case of several wireless devices

5.2.9 Cut-off frequency

In principle, there are two cut-off frequencies. The upper cut-off frequency is the highest relevant frequency of the spectrum envelope. The lower cut-off frequency is the lowest relevant frequency of the spectrum envelope. However, it depends on the wireless technology or standard as to what relevant means.

There are two principle approaches. The first approach is shown in Figure 9 with the help of a wireless LAN system. The initial level is the maximum transmitted power spectral density. From this maximum level a certain value is subtracted. An example of this value is 20 dB. The frequency furthest above the frequency where the power spectral density drops below the resulting level is called the lower cut-off frequency. Accordingly, the frequency furthest below the frequency, where the power spectral density drops below this level, is called the upper cut-off frequency. An alternative approach defines the cut-off frequencies with respect to a certain spurious emission level.

The cut-off frequencies determine the bandwidth of a system and thus the medium utilization in the frequency domain. Furthermore, the cut-off frequencies can be used to calculate the centre frequency.

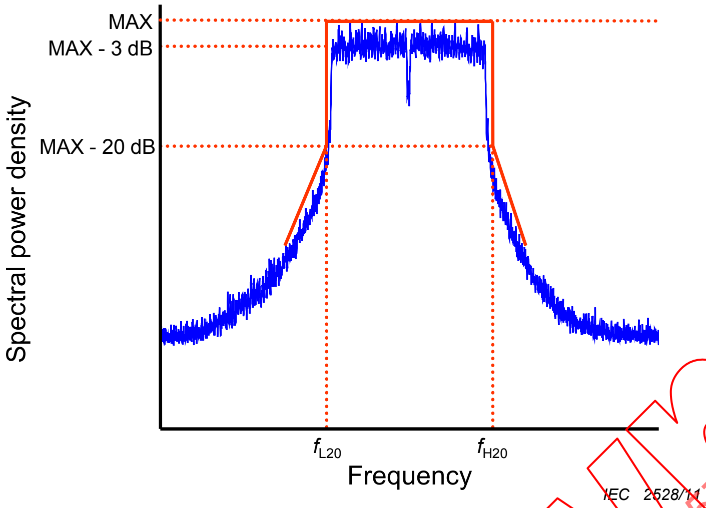


Figure 9 – Cut-off frequencies derived from maximum power level

The unit of this parameter shall be Hz.

5.2.10 Data throughput

The data throughput is relevant for the transfer of large amounts of data (for example the transmission of huge parameter data sets to drives, or the downloading of programs into complex field devices).

The data throughput is the number of usable data bytes, or usable data bits, transferred within a consumer from the communication interface to the application per time unit.

To evaluate the coexistence, the average value of a series of measurements can be used, compared with a value given by the automation application.

5.2.11 Duty cycle

The duty cycle is the ratio of the transmitter sequence referenced to a given observation time for the used radio channel. The way the observation time is chosen, influences the duty cycle value. This is illustrated in Figure 10. For system 1 with observation time 1, the duty cycle is greater than for system 2. However, it is lower for system 1 with observation time 2.

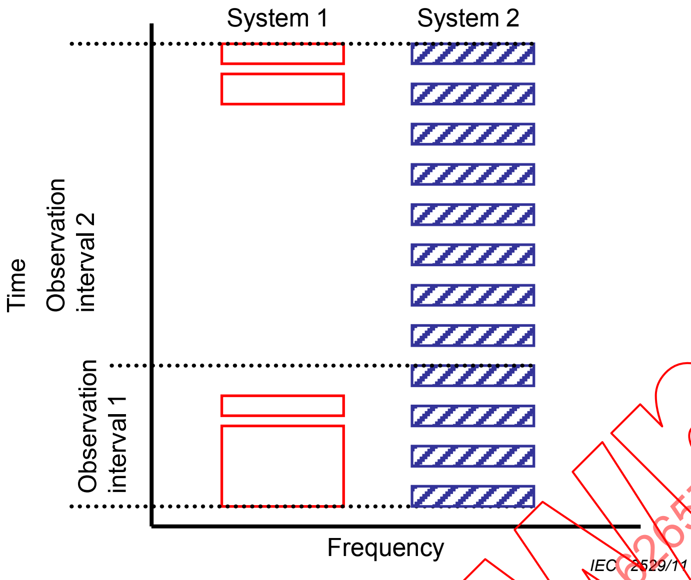


Figure 10 – Duty cycle

It is reasonable to specify the observation time with respect to the application profiles. The observation time shall be ten times the typical transmission interval of an application profile. The transmission interval is herewith the time difference between two transmissions of user data from the automation application. Thus, the observation time values as shown in Table 2 shall be used.

Table 2 – Application profile dependent observation time values

Application profile	Machine	Factory hall	Process plant
Transmission interval	100 ms	250 ms	4 s
Observation time	1 s	2,5 s	40 s

The duty cycle is the key parameter to assess the medium utilization in time. A small duty cycle results in small media utilization and therewith a smaller influence to other frequency users.

The parameter shall be expressed in %.

5.2.12 Effective radiated power (EIRP, ERP)

EIRP, ERP is the power supplied to an antenna multiplied by the antenna gain in a given direction. The power supplied to an antenna is given by integrating the power spectral density across the bandwidth. If the direction of an antenna is not specified, the direction of maximum gain is assumed. The effective radiated power takes into account the losses of the transmission line and connectors [19], thus, the total radiated power is lower than the power supplied to the antenna.

For frequencies below 1 GHz, a half wave dipole is taken as a reference for the antenna gain. The abbreviation of this effective radiated power is denoted by ERP. For frequencies above 1 GHz, a theoretical isotropic radiator is taken as a reference for the antenna gain. This effective radiated power is called effective isotropic radiated power (EIRP).

As the isotropic gain of a half wave dipole is 2,15 dBi, the EIRP values are 2,15 dB larger than the ERP values.

EIRP and ERP are the fundamental parameters in order to estimate the power level at a certain position. The relationship between EIRP and ERP is clarified by the following example.

EXAMPLE Assuming an antenna with an antenna gain of 3 dBi is used (see also 5.2.1), then to meet the requirement of ≤20 dBm EIRP the transmit power at the antenna input cannot exceed 17 dBm.

The unit of this parameter shall be W.

5.2.13 Frequency hopping procedure

The frequency hopping procedure shall include the sequence of frequency channels and time period of frequency hopping.

5.2.14 Future expansion plan

Future expansion plans should be taken into account. Installation of new wireless communication solutions and buildings can affect condition for wireless communications.

5.2.15 Geographical dimension of the plant

The geographical dimension of the area is specified as the scope of the coexistence management by the coexistence management system specification. The geographical dimension is the length, width and height of the area in which the wireless system is installed and which has impact on the propagation conditions. The superior area, e.g. the factory hall for a machine, should be considered.

5.2.16 Infrastructure components

Infrastructure components are devices such as router or base stations without direct relation to the automation application. Infrastructure components are necessary to build up the wireless system according to the technology or standard. They may improve the robustness of a network, however they also interfere with other wireless systems.

Router or base stations that have an interface to wired industrial networks or which implement automation application functions are not counted among infrastructure components but among wireless devices.

5.2.17 Initiation of data transmission

The initiation of data transmission influences the communication load and can contribute to a temporal separation of the radio systems. This parameter specifies how the application initiates the data transfer: periodically, aperiodically or stochastically. A periodic transfer might result in a higher communication load than an aperiodic transfer because the same values might be frequently transmitted. Independent of this parameter, the communication system may implement the data transmission differently.

5.2.18 Length of user data per transmission interval

The user data length affects the communication load and might account for the temporal separation of the wireless communication systems.

5.2.19 Limitation from neighbours of the plant

Neighbours of the plant might cause limitations for wireless communication. Examples are high power radio source(s) and sensitive equipment.

5.2.20 Maximum dwell time

The maximum dwell time is the period of time a system is assigned to a certain channel. If the system requires an immediate response, this and the idle time shall be considered. It is suitable for frequency hopping systems only. The maximum dwell time is shown in Figure 11 with max t_{Dw}.

The dwell time describes the agility of a frequency hopping system. Together with the number of radio channels it can be estimated how often the system appears in a certain channel.

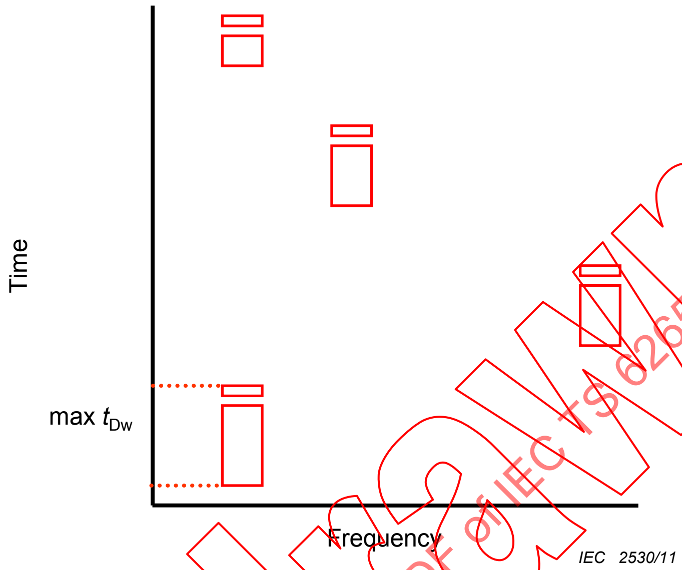


Figure 11 – Maximum dwell time

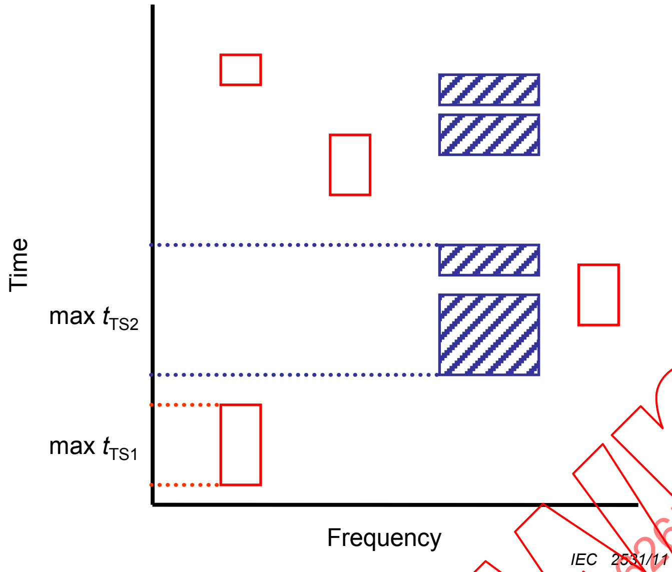
The unit of this parameter shall be s.

5.2.21 Maximum number of retransmissions

This parameter describes how often user data are retransmitted automatically by the communication stack because of transmission errors. It is possible that retransmissions are initiated by different protocol layers. Therefore, the maximum number of retransmissions shall be specified for each relevant layer. If possible, details of the mechanism, e.g. waiting times, should be explained. This parameter may This parameter may have a significant influence on medium utilization.

5.2.22 Maximum transmitter sequence

The maximum transmitter sequence is the maximal time that a transmitter uses a radio channel. If a request requires an immediate response, and during the idle time the medium cannot be used by a device of the same network, the entire time shall be considered. This is a reasonable simplification, even though devices of other systems could start a transmission. Thus, in Figure 12 the maximum transmitter sequence of system 1 is t_{TS1} and the maximum transmitter sequence of system 2 is t_{TS2}.



Key

red	system 1
blue hatching	system 2

Figure 12 – Maximum transmitter sequence

For frequency hopping systems this time shall be considered for each used frequency channel. The maximum transmitter sequence gives an impression of the maximum occupied time. Real applications may use a small portion only. Therefore, additionally the duty cycle should be considered.

The unit of this parameter shall be s.

5.2.23 Mechanisms for adaptivity

Mechanisms for adaptivity can be used to modify one or more of a system's operational parameters in order to improve a system's robustness against interferences and to minimize medium utilization. Adaptive communication mechanisms may use automatically feedback information obtained from a system itself or from the signals carried by a system to modify dynamically a system's operational parameters. It is also possible to plan the operational parameters in advance and configure the systems appropriately.

Examples of mechanisms for adaptivity are as follows:

- frequency manager: a central systems element controls the medium utilization
- Detect and Avoid (DAA): If the channel is occupied, change the channel (e.g. AFH);
- Detect and Suppress (DAS): If the channel is occupied, don't transmit (e.g. Listen Before Talk);
- Detect and Reduce (DAR): If the channel is occupied, reduce the output power.

Depending on how many systems are using mechanisms for adaptivity and which parameter they adapt, these measures may help improving coexistence or may lead to unstable and unreliable system behaviour.

5.2.24 Medium access control mechanism

The medium access control ensures, for example, that a communication request is served as long as the medium is free (see CSMA) or it allocates the request to well defined time slots (see TDMA). Combinations of these two as well as other access mechanisms are possible. The purpose of these mechanisms is primarily to control the medium access within one wireless system. However, it also influences the immunity and the medium utilization characteristic of a system and shall be considered, therefore, in the coexistence management process.

5.2.25 Modulation

A signal gets its information content by changing amplitude, frequency or phase of a wave. This is done by modulating the wave. Analog or digital modulations are known. Digital modulations can be combined with spreading schemes in order to improve the robustness of the physical signal.

5.2.26 Natural environmental conditions

Natural environmental conditions such as temperature, humidity or air pressure may influence the propagation conditions.

5.2.27 Organizational parameters

For each device, the typical organizational device parameters, such as model type, manufacturer, hardware version, etc. shall be provided. For details see IEC 61804-3.

5.2.28 Other frequency users

This parameter describes other frequency users emitting radio waves without transmitting data such as welding machines, electrical drives, frequency converters, etc. operating in the same area. The type of the other frequency user and its medium utilization shall be known.

5.2.29 Packet loss rate (PLR)

The packet loss rate reveals how many of the packets, transferred from the application to the communication interface within the producer, are transmitted from the communication interface to the application within the consumer.

The packet loss rate is determined as follows:

$$\mathrm{PLR} = \frac{N_t - N_r}{N_t}$$

where

N_t is the number of transmitted packets;

N_r is the number of regularly received packets.

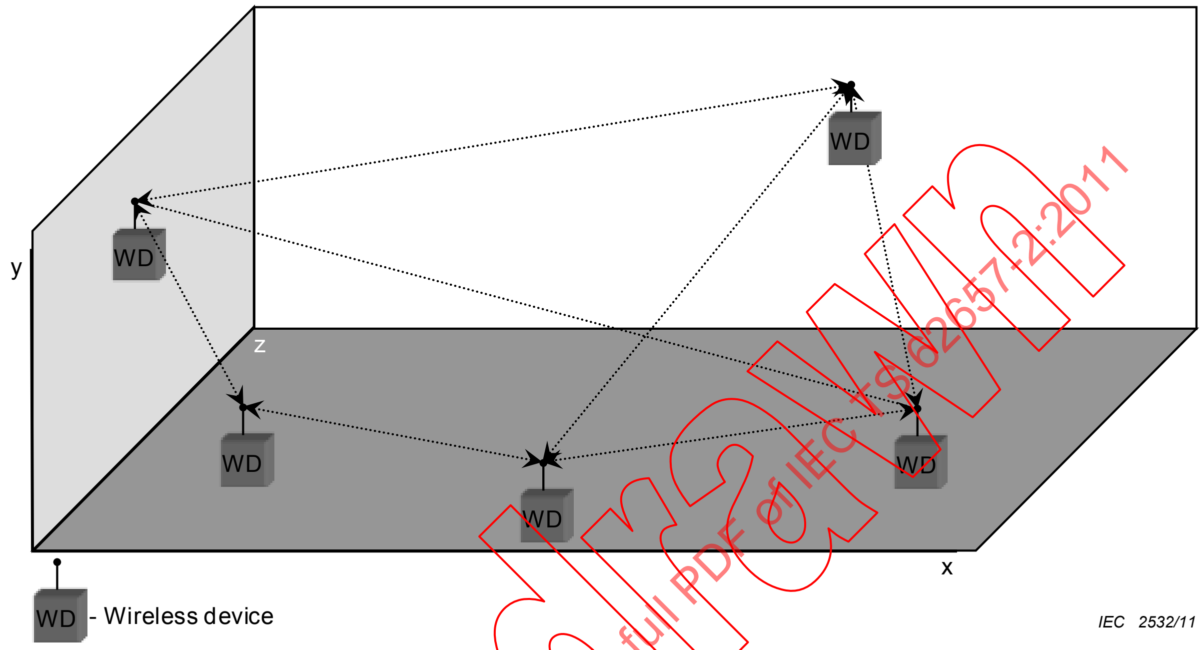
Assuming that an application expects a packet by a time t_{DL} at the latest, all packets with a transmission time greater than t_{DL} shall be counted as lost and assigned to the number of not received packets (N_t – N_r). For the evaluation of coexistence, it shall be proved how many batched packet losses are tolerated by the automation application before a plant down time results. The number of plant down times defines the plant availability which is the focal quality criterion of radio communication.

5.2.30 Physical links

The number of physical links includes all physical communication between two wireless devices of a wireless system. Only one physical link exists between two wireless devices. Where wireless devices have redundant wireless modules, e.g. for different communication channels, the related physical links shall be counted separately. It is not required that a physical link exists between each of two wireless devices. There may 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.

5.2.31 Positions of wireless devices and distances between them

The positions of all the wireless devices of a distributed automation application should be recorded in a sketch of the application area. Figure 13 shows the distances of wireless devices within a three-dimensional space. This distance can vary dynamically in the case of mobile radio components.



Key

d distance (m)

Figure 13 – Distance of the radio components

If feasible, the distance between the wireless devices of a wireless system should be chosen in a way leading to optimal signal power levels; this improves the robustness of the wireless system. The distance to wireless devices of other wireless systems should be chosen in a way that results in interference signal power levels being as low as possible. This reduces the interference of the other wireless system.

5.2.32 Power spectral density (PSD)

The power spectral density describes how the power of a signal is distributed with frequency. Colloquially, the area below the PSD curve is often called the spectrum of the signal. The measurement unit of the power spectral density is in Watts per Hertz. The PSD shall be provided as shown in Figure 14 for an IEEE 802.15.4 system.

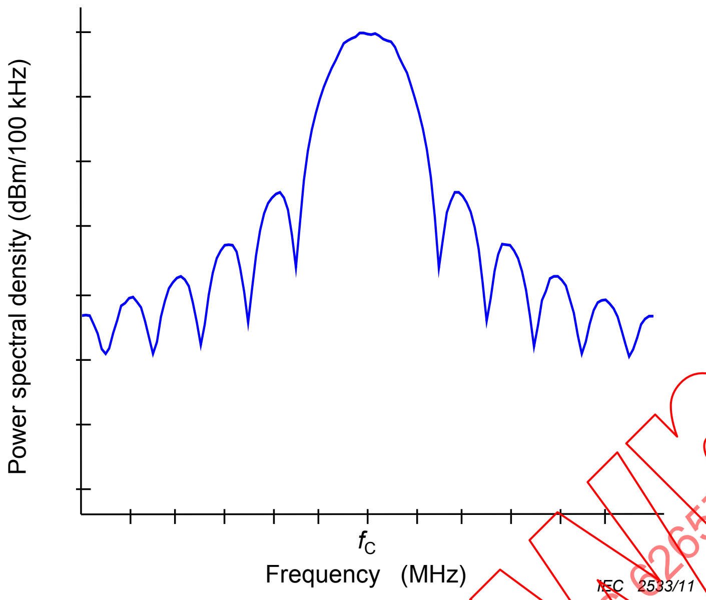


Figure 14 – Power spectral density of an IEEE 802.15.4 system

The PSD as shown in Figure 14 provides a comprehensive picture of the signal power in the frequency spectrum for the coexistence management.

The unit of this parameter shall be dBm/100 kHz over the intended frequency range.

5.2.33 Purpose of the automation application

The purpose of the automation application is to provide a useful overview of the application communication requirements.

5.2.34 Radio channel

A radio channel is characterized by a centre frequency and a bandwidth or by lower and upper cut-off frequency. Mostly the first combination is used. In the coexistence management process it is easier to cope with radio channels than with cut-off and centre frequencies or bandwidths. Equipment may be able to operate at more than one radio channel. A channel can be configured statically or selected automatically during start-up. Furthermore, a system may select a channel out of a specified number of channels according to a certain sequence during operation. This is called frequency hopping or frequency agility. The hopping sequence can be adapted in relation to the propagation conditions. Because of these options, a detailed description of the channel usage during operation is required for coexistence management.

This parameter shall be expressed as a number represented as an unsigned integer value.

5.2.35 Radio propagation conditions

Propagation conditions influence the robustness of a wireless system as well as the interference of other wireless systems. They depend on the used frequency, the dimension and characteristic of the operation area, natural environmental conditions and intervisibility. The latter considers LOS, NLOS and OLOS between two wireless devices.

5.2.36 Receiver blocking

The receiver blocking is an indicator of the correct receiver operation in the presence of out-of-channel signals.

Receiver blocking response (or performance level) is defined as the maximum interfering signal level expressed in dBm reducing the specified receiver sensitivity by a certain number of dB (usually 3 dB). Consequently, the receiver blocking response is normally evaluated at a wanted signal level which is 3 dB above the receiver sensitivity and at frequencies differing from that of the wanted signal [20].

Receiver blocking considers effects like spurious response, intermodulation sensitivity and adjacent channel selectivity.

5.2.37 Receiver maximum input level

Received signal levels above the receiver maximum input level disturb or disrupt the receiver. Together with transmit power values of the system and of interferers, and considering the propagation conditions, the minimum necessary distance to other equipment can be estimated and assessed.

5.2.38 Receiver sensitivity

Receiver sensitivity determines how well a receiver can accept wanted signals in the absence of interference (see also [17]). It defines the minimum received signal power that the receiver requires to achieve the given bit error rate. Together with transmit power values of the system and of interferers, and considering the propagation conditions, the power margin of the system can be estimated and assessed.

5.2.39 Regional radio regulations

Regional radio regulations specify important coexistence parameters such as frequency band and output power. These specifications shall be taken into account within the coexistence management process.

NOTE This list of coexistence parameters can be shortened by listing the regional radio regulation standards with which the system/device is compliant.

5.2.40 Relative movement

In planning the movement ranges of movable or mobile radio components, the same criteria shall be considered as in the case of static distances.

Both the relative speed between radio components and the trajectory can affect time and error behaviour of radio transmission and might therefore be adverse premises for coexistence.

5.2.41 Reliability required

Requirements for reliability of wireless communication shall be specified. Other wireless communication solutions could cause degradation of reliability of target wireless application. Tolerable reliability levels to achieve the application should be clarified.

5.2.42 Response time

The response time is primarily important in confirmed services, e.g. in application-oriented transmission of process data or parameter data.

The response time is the time interval between the instant delivery of the first user data bit, or byte, of a packet to the communication interface of a client, and the instant when the last bit, or byte, of the confirmation packet is delivered at the communication interface of the same client, which can be assigned to the request.

This means that the response time is composed of at least one transmission time between client and server and one transmission time between server and client. The processing time within the server shall be added.

The communication between client and server can be effected directly via infrastructure component (e.g. base station) or via further network nodes (e.g. sensor networks).

Interferences influence response time values. Coexistence exists as long as a limit value given by the automation application is met. Otherwise, the corresponding transmission shall be assessed as a packet loss.

The response time is a random variable. This is important because response times depend more highly on external transmission conditions compared to wire-bound communication.

5.2.43 Security level required

Requirements for cyber security could affect coexistence management. Some sensitive wireless communication solutions might need to be physically separated from some other kind of wireless systems, or might need to have clearance from the boundary of the site.

5.2.44 Spatial coverage of the wireless communication network

The spatial coverage of the wireless communication network depends on the application communication requirements. However, it is also decisive for the feasibility of spatial separation of wireless systems. In positioning the several wireless devices the antenna mounting height shall be regarded.

5.2.45 Spurious response

It is the receiver output due to unwanted signals (i.e. having frequencies other than the tuned frequency channel) that is specified in terms of the frequencies and signal levels that produce such unwanted receiver output.

5.2.46 Topology

Topology describes the structure and composition of a wireless system. Basic topologies are:

- point-to-point;
- network
  - line,
  - star,
  - cellular,
  - tree,
  - meshed.

Combinations of these basic topologies are possible. This information can be used to assess the intended coverage of a wireless solution.

5.2.47 Total radiated power (TRP)

The total radiated power is the power supplied to an antenna reduced by antenna losses. TRP is often specified in more recent standards. It can be measured with a three-dimensional turn table which allows integrating the spatial power density over 360°.

The unit of this parameter shall be W.

5.2.48 Transmission gap

The minimum transmitter gap is the time between two successive channel usages by a transmitter. If a request requires an immediate response, the idle time is not considered. In Figure 15 the minimum transmitter gap is depicted with t_{TG}.

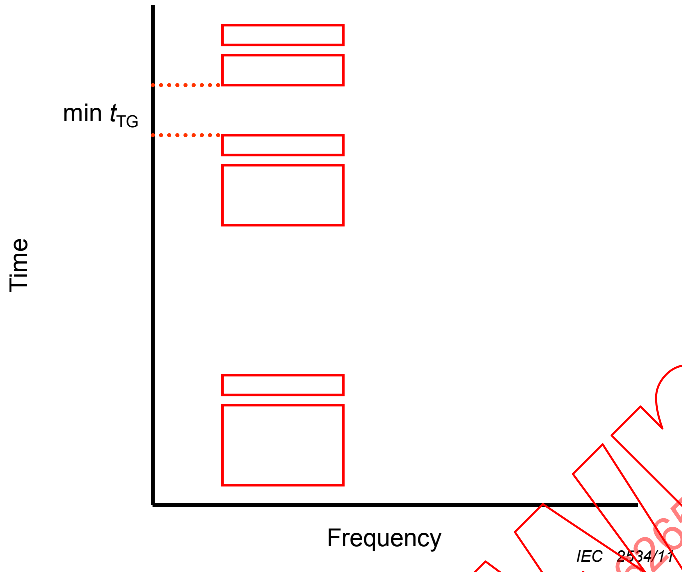


Figure 15 – Minimum transmitter gap

For frequency hopping systems, the minimum transmitter gap is related to one of the used channels and not between transmissions of different channels. The minimum transmitter gap gives an impression of the minimum available time. Real applications may leave larger gaps. Therefore, additionally the duty cycle should be considered.

The unit of this parameter shall be s.

5.2.49 Transmission interval

The transmission interval has an effect on the communication load and can contribute to temporal separation. For periodic transfers it is also called application cycle. For aperiodic transfer the minimum value is of interest. For stochastic transfers the parameters of the distribution function is relevant.

In Figure 16 the relation between machine/plant cycle, transmission interval and communication cycle is depicted. Usually, the industrial automation applications follow cycles of the production process. During such a machine or plant cycle, a number of events occur which shall be transmitted via a wireless communication medium. In the case of a periodic transmission, the communication cycle shall be faster than the transmission interval. If an aperiodic data transmission is involved, the transmission interval is the least possible time between two transfer requests.

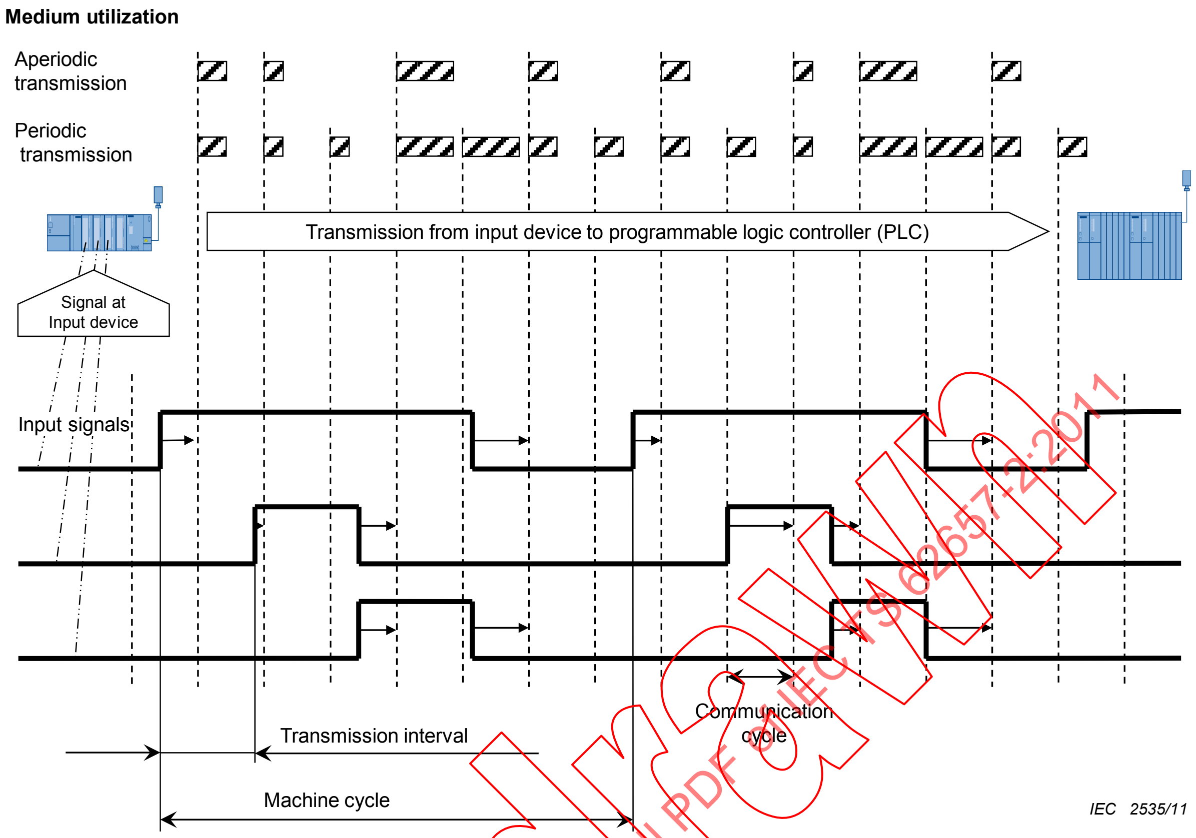


Figure 16 – Communication cycle, transmission interval and production cycle

5.2.50 Transmission time

The transmission delay is an adequate instrument to evaluate the coexistence in terms of automation application with event-driven transfer. A good example is the transmission of a state change in a proximity sensor.

The transmission delay is the interval from starting the delivery of the first user data byte of a packet to the communication interface of a producer until the delivery of the last user data byte of the same packet from the communication interface of a consumer.

The interferences described in 4.4 entail transmission time. Coexistence exists as long as the transmitted packets keep a limit value given by the automation application. Otherwise, the corresponding transmission shall be assessed as a packet loss (see also 5.2.29).

The transmission time is a random variable. This is important because transmission times more highly depend on external transmission conditions compared to wire-bound communication.

Figure 17 exemplifies density functions of the transmission times of radio solutions resulting from measurements with large samples. The density functions represent the number of packets needing a certain transmission time.

Usually, the number of packets with a greater transmission time e.g. t_{TT2} increases from N_2 to N'_2 if other wireless solutions interfere. On the other hand, the number of packets with a smaller transmission time e.g. t_{TT1} decreases from N_1 to N'_1 if other wireless solutions interfere. The causes might be, e.g. waiting times for a free medium or retransmissions due to packet losses.

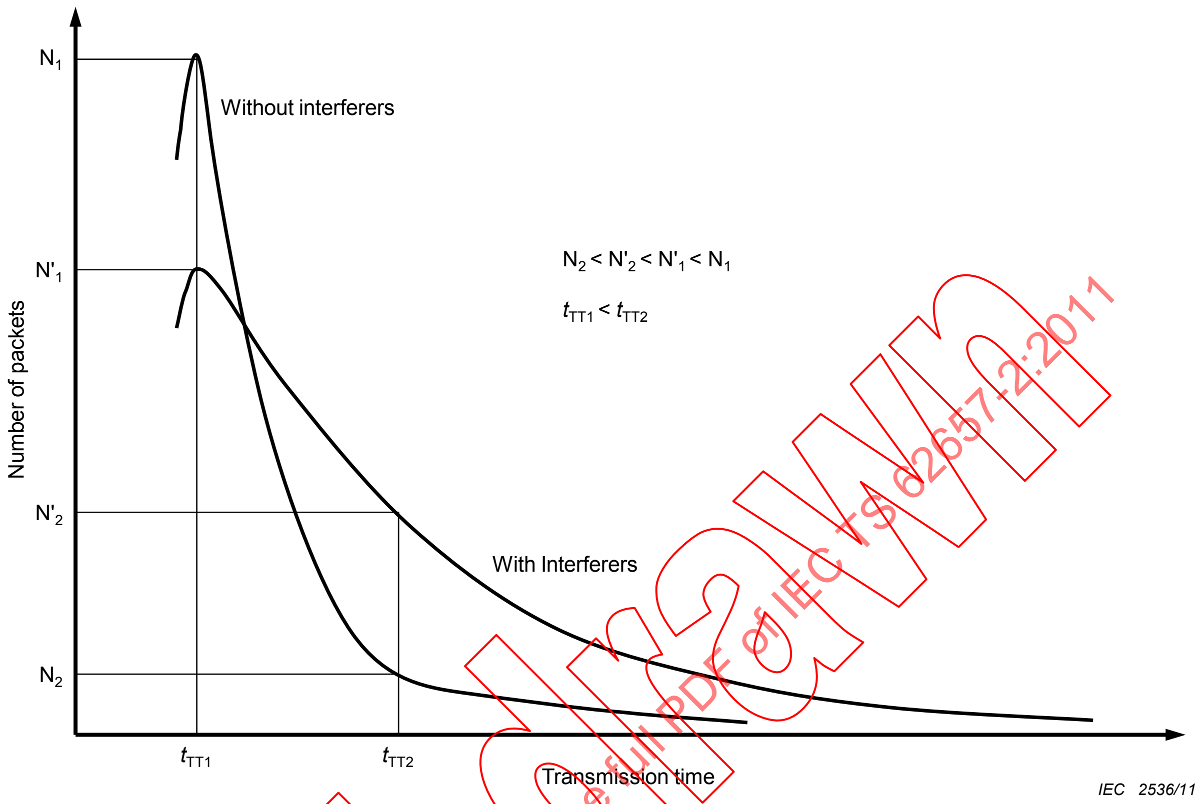


Figure 17 – Example of the density functions of transmission delay

Figure 18 shows an example of the distribution functions of the transmission time. The two curves show the number of received packets that arrives within a certain transfer time.

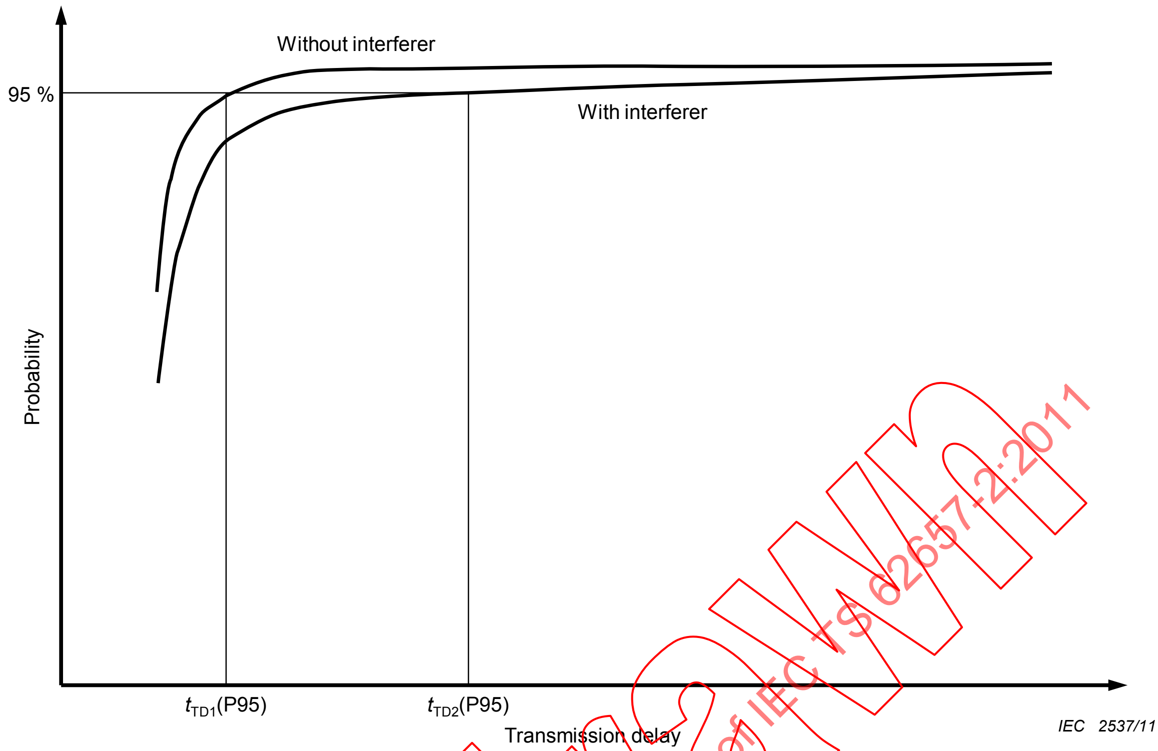


Figure 18 – Example of the distribution functions of transmission time

In a metrological ascertainment of transmission time values, the statistical parameter can be ascertained from the sample. Changes in statistical parameters, depending on the presence of other radio applications, are a measure of the strength of influence on the radio solution. For this relative evaluation, distribution parameters are adequate instruments, e.g. the percentile. The percentile P95 is a common value (see Figure 18). In 95 % of all transmissions this value is not exceeded. Experience shows that the P95-value is a sensible compromise between the required sample size and significant information. Other statistical distribution parameters can, however, also be consulted. These distribution parameters (e.g. percentile P95) are not identical with the availability of the plant.

A maximum value of transmission time would be necessary in order to get an absolute result on coexistence by comparing this time value with a limit required by the application. However, the maximum value of a certain measurement is not equivalent to the absolute maximum transmission time. The measured maximum value has a certain probability that can be calculated if the functional equations of the curves in Figure 25 and Figure 26 are known. The reliability of the calculation depends on the sample size of the measurement on which the functional equations are based.

Besides this, the maximum value for transmission time can be analytically appraised, taking for all time segments the maximum value. This maximum value is not suitable to evaluate coexistence because,in this case, for the time segments influenced by other radio applications, the maximum value shall be taken as well.

5.2.51 Transmitter spectral mask

The power spectral density envelope can be characterized by a number of specific points creating the transmitter spectral mask as shown in Figure 19 for an IEEE 802.15.4 system. This is a reasonable simplification for the coexistence management. Specific transmitter spectral masks are defined by a standard document. This document considers not only the power in the intended channel but also in the adjacent and alternate channels. The power spectral density shall be less than the limits specified through the transmitter spectral mask. The spectral profile of the transmitter radiated power can be used to emphasize the quality of equipment with respect to coexistence if the transmitter spectral mask is markedly smaller than required by the related standard.

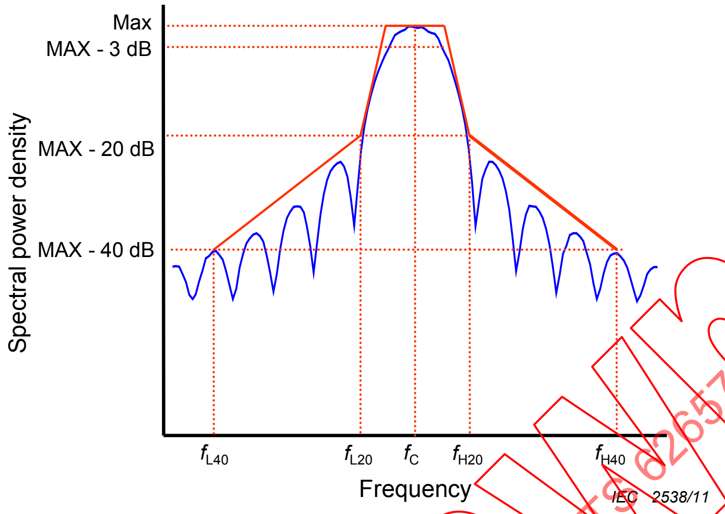


Figure 19 – Transmitter spectral mask of an IEEE 802.15.4 system

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

5.2.52 Type of antenna

Wireless devices can use different kind of antenna to collect or radiate electromagnetic waves. Examples include omni-directional antennas, directional antennas, antenna arrays and PCB antennas. The antennas can be integrated into the equipment (internal) or antenna connectors are available to mount antennas externally. If equipment 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 communication link and the sensitivity to interferences.

5.2.53 Update time

The update time can be used for evaluation in case of automation application with cyclic transfer. The cyclic transfer of a position detection system might serve as an example.

The update time is the interval from the delivery of the last user data byte of the packet of a producer, from the communication interface of a consumer to the automation application, until the delivery of the last user data byte of the following packet of the same producer.

The interferences described in 4.4 result in distributions of the transmission time. Coexistence exists as long as the transmitted packets keep a limit value for the distribution of the update time given by the automation application.

The update time is a random variable. Figure 20 shows an example of distribution functions of the update time. For a relative assessment, i.e. whether a radio application interferes more or less, the standard deviation can be consulted as a distribution parameter.

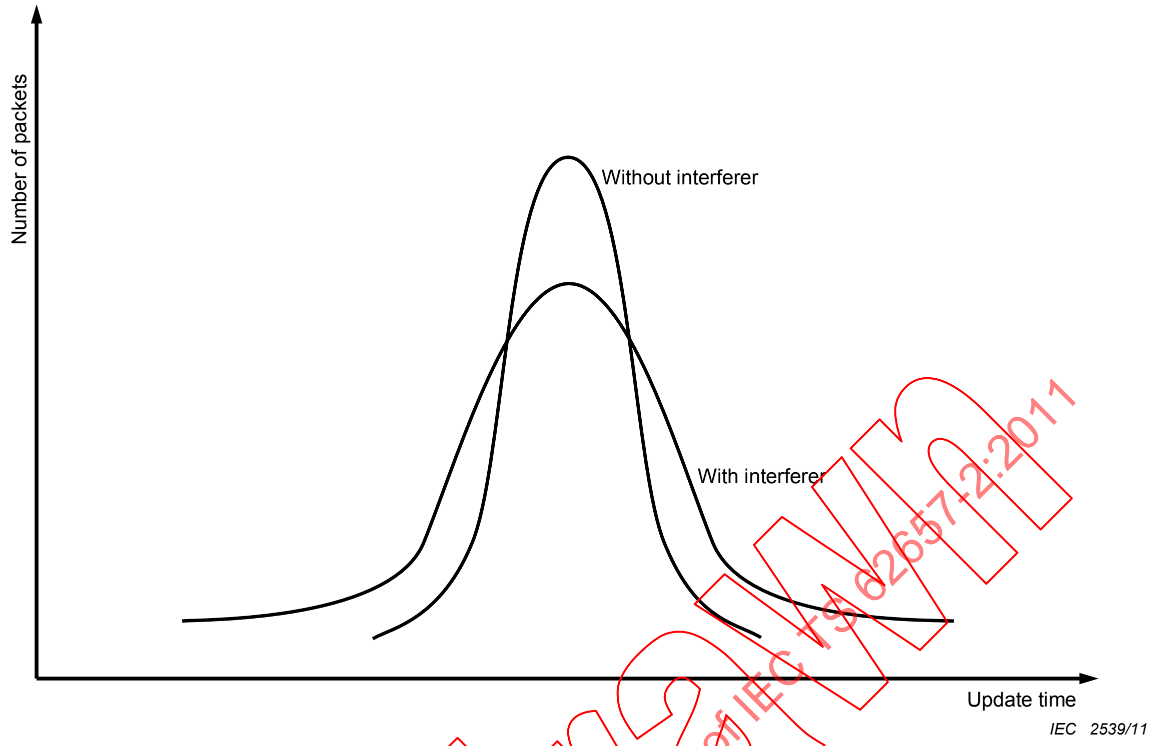


Figure 20 – Example of distribution functions of the update time

A maximum span of the update time, also called jitter, would be necessary in order to get an absolute result on coexistence by comparing this time value with a limit required by the application. However, the maximum span of a certain measurement is not equivalent to the absolute maximum span of update time. The maximum span has a certain probability that can be calculated if the functional equations of the curves in Figure 20 are known. The reliability of the calculation depends on the sample size of the measurement on which the functional equations are based.

5.2.54 Used frequency bands

The number of frequency bands that can be configured, or that are actually used, are part of the essential parameters of a coexistence management.

5.2.55 Wireless devices

The number of wireless devices has an impact on communication load and medium utilization. The fewer wireless devices which are communicating within the wireless system, the lower are the probability of collisions.

5.2.56 Wireless networks

This parameter describes wireless networks operating in the same area. All networks shall be considered, independently of technology or used frequency spectrum. The medium utilization of these networks shall be described.

5.2.57 Wireless technology or standard

Most wireless equipment will use a standardized basic technology which sometimes already predefines some of the parameters listed in this subclause. Therefore, the values or the domain for a number of parameters are implicitly defined by naming the wireless technology or standard.

NOTE It is planned to provide filled templates for the most important wireless standards.

The frequency band shall be provided explicitly since this allows a first general categorization of a wireless solution. Furthermore, the modulation scheme shall be specified. The kind of modulation, or the coding of the symbols before physical transmission, might help to avoid interferences of the wireless solutions. Moreover, the communication requests are transferred differently onto the communication medium, meaning that one and the same communication load can lead to different channel occupation ratios.

Implementations that use a basic technology might, for certain parameters, be much better than the basic standard. A wireless implementation may also only use a subset of a reference wireless standard and therefore not all parameters may be relevant. Moreover, there are wireless technologies that do not follow a certain standard.

Examples of standards specifying a wireless communication network are IEC 62591 [9] and future IEC 62601 [10].

6 Coexistence management information structures

6.1 General

This clause specifies structuring of coexistence management parameters according to usage dimensions. The principle is depicted in Figure 21. The parameters explained in Clause 5 are selected and structured in this clause, forming a template. This template can be used to described a specific object by assigning values or value ranges to the parameters. Thus, the information can be deployed within the wireless coexistence management process.

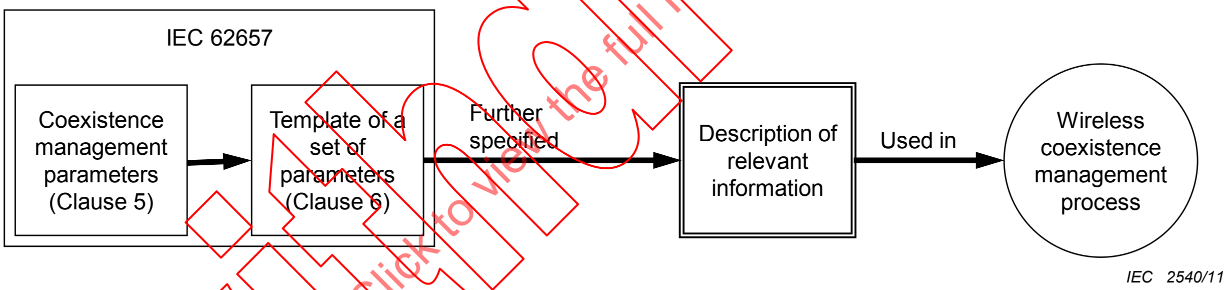


Figure 21 – Principle for use of coexistence parameters

Four sets of parameters are specified for the wireless coexistence management process. They are used to describe

- the general characteristic of plant common to all wireless network solutions (see 6.2),
- the application communication requirements of each automation application (see 6.3),
- the characteristic of each wireless system- and device–type (see 6.4),
- the characteristic of each wireless communication solution (see 6.5).

6.2 General plant characteristic

Subclause 6.2 specifies the set of parameters that characterizes the plant in general with respect to all wireless communication applications. Figure 22 shows the relation between the definition and specification in this document and the use of them.

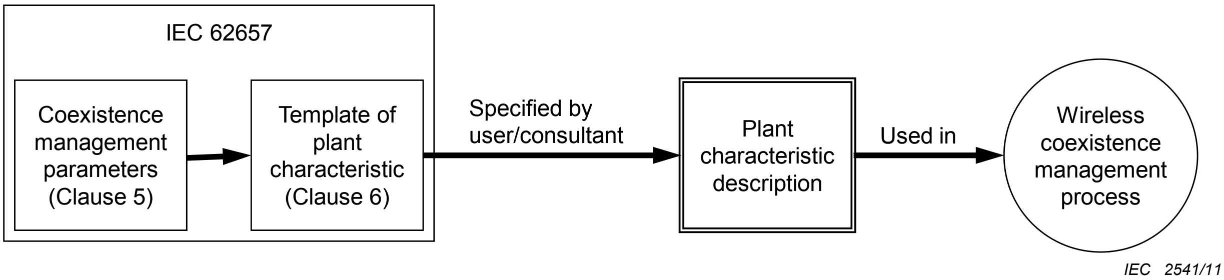


Figure 22 – Parameters to describe the general plant characteristic

The parameters in Table 3 shall be used to describe the propagation conditions and the interference potential within a plant.

Table 3 – List of parameters used to describe the general plant characteristic

Parameter name	Reference	Content
Characteristic of the area of operation	5.2.7	Characteristic of the area of operation
Wireless networks	5.2.56	List of wireless solutions (including all parameters according to 6.5.2) in the plant
Geographical dimension of the plant	5.2.15	Geographical dimension of the plant
Limitation from neighbours of the plant	5.2.19	Description of limitations from neighbors of the plant
Natural environmental conditions	5.2.26	Description of natural environmental conditions
Other frequency users	5.2.28	List of other frequency users including detailed description
Radio propagation conditions	5.2.35	Description of radio propagation conditions
Regional radio regulations	5.2.39	List of relevant regional radio regulations
Future expansion plan	5.2.14	Description of possible future expansions of the plant

Most of the parameter values can be provided by the plant owner. However, for some parameters, expertise of wireless experts is required. If such expertise is not available within the organization of the plant, it is strongly recommended to consult external expertise.

Textual descriptions can be used for these parameters if it is not feasible to provide qualitative value. In these cases, the textual description shall be as specific as possible. Graphics and pictures can support such descriptions.

In addition to the listed parameters organi,ational elements can be used. The wireless networks for instance can be tagged by an identifier and organized in a list.

6.3 Application communication requirements

6.3.1 Overview

Application communication requirements are mostly quantitative requirements specifying the required conditions and the required characteristics of wireless communication solutions at the communication interface. These requirements shall be met in order to achieve the purpose of the automation application.

By definition, coexistence is the state in which all applications using wireless communication fulfill their requirements. These requirements are usually related to business goals and take into account, in addition, a number of conditions such as safety of persons, efficient use of resources or hazard conditions.

In order to fulfill these goals, the wireless communication solution shall meet the application communication requirements in terms of reliability and real time capability, considering the industrial conditions and the characteristics of wireless systems that influence those requirements.

Figure 23 shows the relationship between the definition and specification of parameters in this specification and its use in order to describe the application communication requirements.

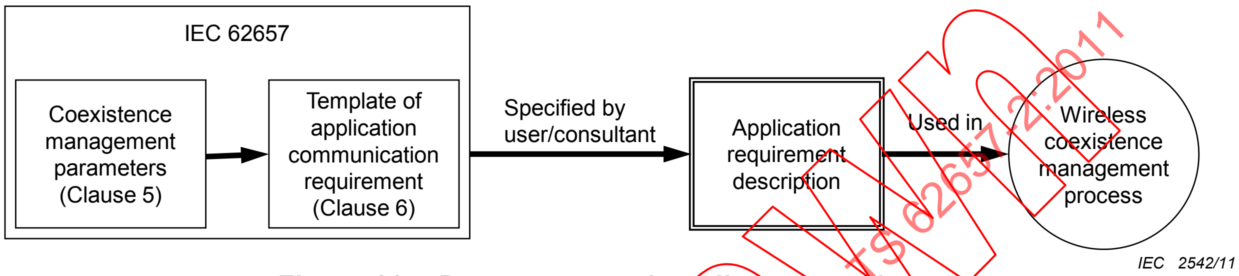


Figure 23 – Parameters to describe automation communication requirements

Application communication requirements can be divided into requirements that influence the behaviour of a device or network and performance requirements that shall be met by the wireless solution in order to ensure the purpose of the automation application.

6.3.2 Requirements influencing the characteristic of wireless solutions

The set of parameters in Table 4 are application communication requirements that influence the performance of wireless solutions and thus the coexistence state. The values of these parameters shall be collected.

Table 4 – List of parameters used to describe the requirements influencing the characteristic of wireless solutions

Parameter name	Reference	Content
Communication load	5.2.8	Required communication load
Initiation of data transmission	5.2.17	Required initiation of data transmission
Length of user data per transmission interval	5.2.18	Required length of user data per transmission interval
Positions of wireless devices and distances between them	5.2.31	Required positions of wireless devices and distances between them
Purpose of the automation application	5.2.33	Description of the purpose of the automation application
Relative movement	5.2.40	Required relative movement
Security level required	5.2.43	Required security level
Spatial coverage of the wireless communication network	5.2.44	Required spatial coverage of the wireless communication network
Transmission interval	5.2.49	Required transmission interval
Wireless devices	5.2.55	Required wireless devices

6.3.3 Performance requirements

Performance requirements describe the time and error behaviour necessary to achieve the purpose of the automation application.

The set of parameters in Table 5 shall be used to describe the required performance.

Table 5 – List of parameters used to describe performance requirements

Parameter name	Reference	Content
Data throughput	5.2.10	Required values for data throughput
Reliability required	5.2.41	Required values for reliability
Transmission time	5.2.50	Required values for transmission time
Update time	5.2.53	Required values for update time
Response time	5.2.42	Required values for response time

As described in 5.2, these parameters are random variables. Statistical parameters such as mean value, percentile, standard deviation or span (jitter) shall be used to express the requirements.

6.4 Characteristic of wireless communication system and device type

6.4.1 Overview

Subclause 6.4 specifies sets of parameters that characterize the model of a network or device. These parameters are not those of a particular implementation of a wireless communication system or device; that is called a wireless communication solution. Figure 24 shows the relationship between the definition and specification in this specification and its use.

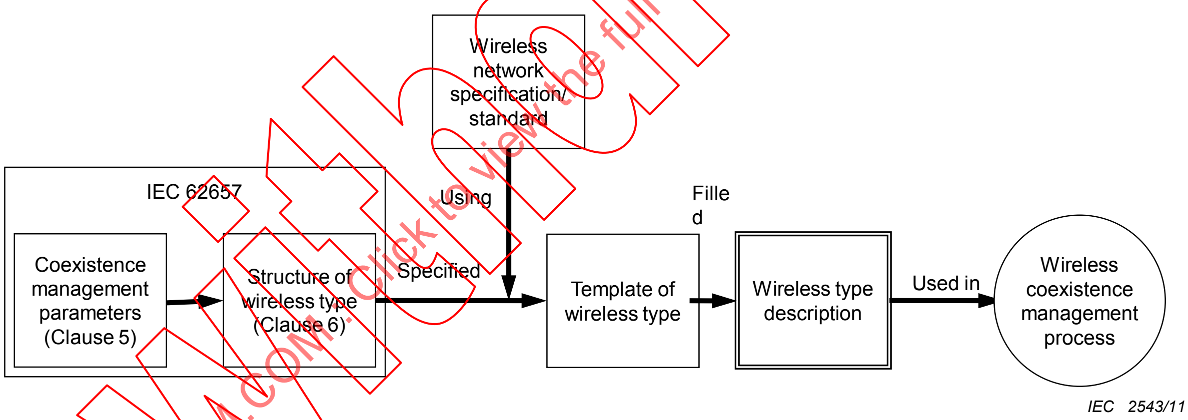


Figure 24 – Parameters to describe network and device type

Almost all parameters are specified in standards or specifications for wireless communication systems. However, a particular wireless network or device might have better or worse performance than specified. Furthermore, specifications sometimes allow value ranges for parameters. The values and value ranges of the following parameters shall be provided together with the wirelefss product. References can be used for parameters whose values or value ranges can be found in specifications or standards.

In this clause we differentiate between common network parameters and specific device parameters.

6.4.2 Characteristic of wireless communication system type

The type of wireless communication system shall be characterized using the parameters given in Table 6.

Table 6 – List of parameters used to describe the wireless communication system type

Parameter name	Reference	Content
Wireless technology or standard	5.2.57	Reference to a specification or standard with which the wireless system is compliant
Regional radio regulations	5.2.39	List of regional radio regulations with which the wireless system is compliant
Topology	5.2.46	Possible implementable topologies
Wireless devices	5.2.55	Maximum possible number of active devices
Infrastructure components	5.2.16	Possible or required infrastructure components
Centre frequency and Bandwidth or Centre frequency and Cut-off frequency or Radio channel	5.2.6, 5.2.4 or 5.2.6, 5.2.9 or 5.2.34	Centre frequencies and bandwidths, centre frequencies and cut-off frequencies or radio channels that are used, or that can be selected
Frequency hopping procedure	5.2.13	Possible frequency hopping procedures
Modulation	5.2.25	Possible modulations
Bit rate of physical link	5.2.5	Possible bit rates of a physical link
Transmission interval	5.2.49	Maximum transmitter sequence
Transmission gap	5.2.48	Minimum transmission gap
Maximum dwell time	5.2.20	Maximum dwell time
Medium access control mechanism	5.2.24	Possible medium access control mechanisms
Mechanisms for adaptivity	5.2.23	Possible mechanisms for adaptivity
Security level required	5.2.43	Functions for ensuring security level

Parameter options shall be provided by value ranges or lists of values.

6.4.3 Characteristic of wireless devices type

6.4.3.1 General

The parameters of a wireless device can be distinguished in transmitter and receiver parameters.

6.4.3.2 Transmitter parameters

The spectral energy radiated by a device can be measured with a spectrum analyser. An example of a measurement is shown in Figure 25. The blue line illustrates the power spectral density of a transmitter. A simplified representation is the transmitter spectral mask which is overlaid in Figure 25 (see red coloured line).

NOTE Depending on the specific technology or standard, different parameters are used to describe the frequency spectrum and the power level.

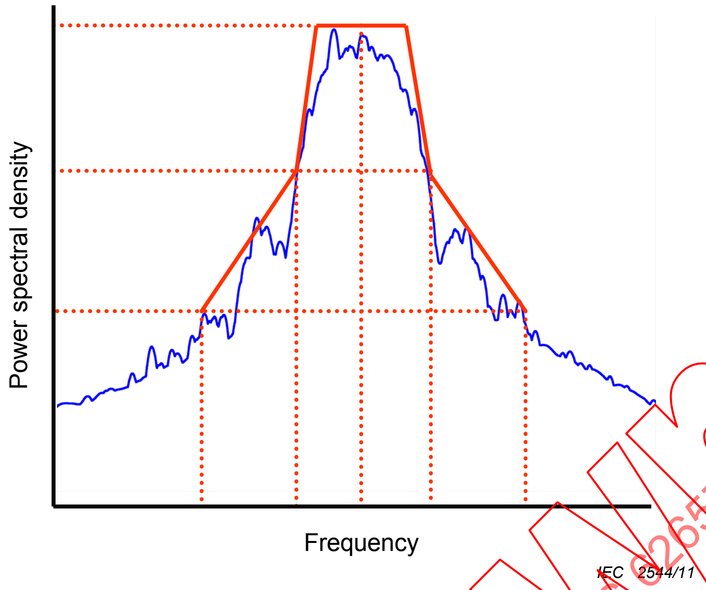


Figure 25 – Power spectral density and transmitter spectral mask of a DECT system

While frequency and power are originally determined by the wireless device or system, the utilization of the spectrum in time also depends on the communication requests of the application. In Figure 26 the principle medium utilization in time and frequency is depicted. It can also be recorded using a spectrum analyser. The yellow colour in Figure 26 shows the area of the centre frequencies with the highest power level. Relevant parameters describe the time of a transmission and the time between two consecutive transmissions. In certain circumstances, it is of interest as to whether the time refers to one radio channel or to several.

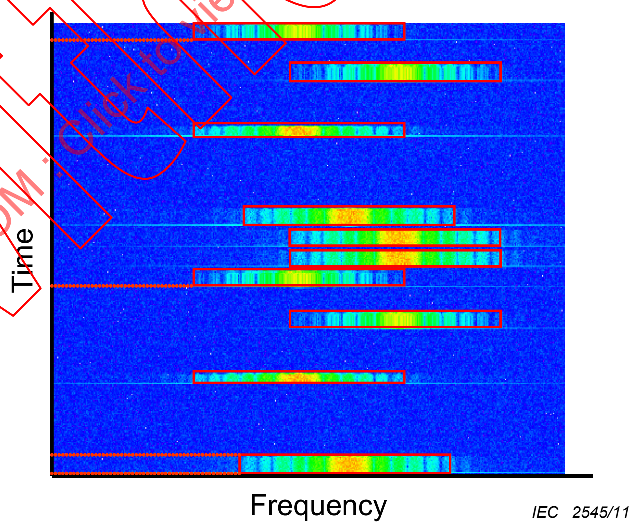


Figure 26 – Medium utilization in time of a DECT system

The values or value ranges of a device type may be better than the values specified for the network type. Therefore, the transmitter parameters in Table 7 shall be used to characterize a wireless device type.

Table 7 – List of parameters used to describe transmitter of a wireless device type

Parameter name	Reference	Content
Wireless devices	5.2.55	Model of wireless device
Type of antenna	5.2.52	Possible antenna types
Effective radiated power (EIRP, ERP)	5.2.12	Possible effective radiated power values
Total radiated power (TRP)	5.2.47	Possible total radiated power values
Power spectral density	5.2.32	Description of power spectral density
Radio channel	5.2.34	Possible centre frequencies and bandwidths, centre frequencies and cut-off frequencies or radio channels
Transmission interval	5.2.49	Maximum transmitter sequence value
Transmission gap	5.2.48	Minimum transmission gap value
Duty cycle	5.2.11	Maximum duty cycle value
Maximum dwell time	5.2.20	Maximum dwell time value

6.4.3.3 Receiver parameters

The receiver parameters in Table 8 shall be used to characterize a wireless device type.

Table 8 – List of parameters used to describe receiver of a wireless device type

Parameter name	Reference	Content
Adjacent channel selectivity	5.2.1	Value of adjacent channel selectivity
Receiver sensitivity	5.2.38	Possible values of receiver sensitivity
Receiver maximum input level	5.2.37	Value of receiver maximum input level
Receiver blocking	5.2.36	Value of receiver blocking

6.5 Characteristic of wireless communication solution

6.5.1 Overview

Subclause 6.5 describes the characterization of wireless communication solutions which are implementations of wireless systems and devices. In contrast to the description of network and devices types, here the parameter values refer to a certain installation within a plant.

Figure 27 shows the relationship between the definition and specification of parameters in this specification and its use of them. Based on a wireless type description of a certain network or device type, and with respect to the structure presented in 6.5, the wireless network and device solutions can be described.

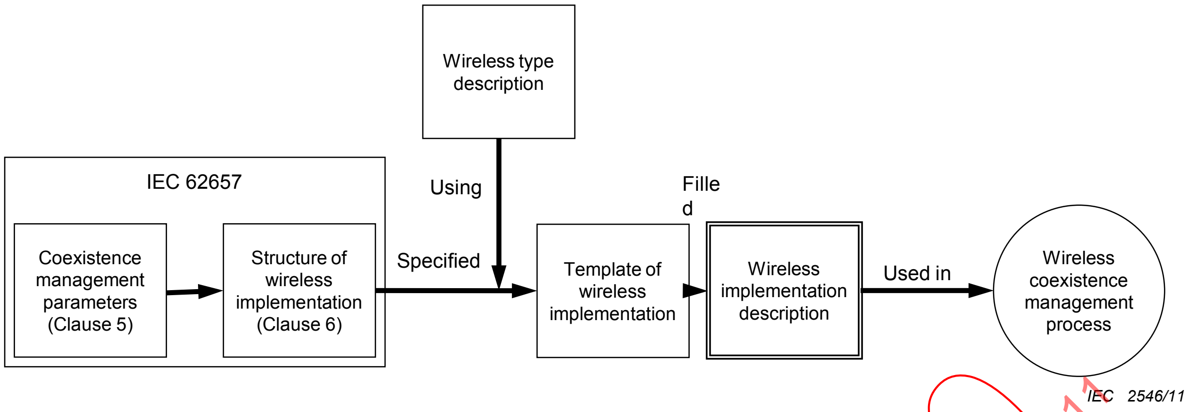


Figure 27 – Parameters to describe network and device type

6.5.2 Wireless network solution

The wireless network solution shall be characterized using the parameters in Table 9, in addition to the parameters of the network type.

Table 9 – List of parameters used to describe wireless network solution

Parameter name	Reference	Content
Wireless system type	6.4.2	Reference to a wireless system type described with parameters according to 6.4.2
Topology	5.2.46	Implemented topologies
Wireless devices	5.2.55	Number of active devices
Infrastructure components	5.2.16	Number and type of implemented infrastructure components
Centre frequency and Bandwidth or Centre frequency and Cut-off frequency or Radio channel	5.2.6, 5.2.4 or 5.2.6, 5.2.9 or 5.2.34	Configured centre frequencies and bandwidths, centre frequencies and cut-off frequencies or radio channels
Frequency hopping procedure	5.2.13	Configured frequency hopping procedures
Modulation	5.2.25	Configured modulations
Bit rate of physical link	5.2.5	Configured bit rates of physical link
Transmission interval	5.2.49	Maximum transmitter sequence
Transmission gap	5.2.48	Minimum transmission gap
Maximum dwell time	5.2.20	Maximum dwell time
Medium access control mechanism	5.2.24	Configured medium access control mechanisms
Mechanisms for adaptivity	5.2.23	Configured mechanisms for adaptivity
Security level required	5.2.43	Configured functions for ensuring security level

6.5.3 Wireless devices solution

The wireless device solution shall be characterized using the parameters in Table 10, in addition to the parameters of the network and device type.

Table 10 – List of parameters used to describe transmitter of a wireless device solution

Parameter name	Reference	Content
Wireless system type	6.4.2	Reference to a wireless system type described with parameters according to 6.4.2
Wireless device type	6.4.3	Reference to a wireless device type described with parameters according to 6.4.3
Type of antenna	5.2.52	Implemented antenna types
Effective radiated power (EIRP, ERP)	5.2.12	Configured effective radiated power values
Total radiated power (TRP)	5.2.47	Configured total radiated power values
Power spectral density	5.2.32	Description of power spectral density
Radio channel	5.2.34	Configured centre frequencies and bandwidths, centre frequencies and cut-off frequencies or radio channels
Transmission interval	5.2.49	Maximum transmitter sequence value
Transmission gap	5.2.48	Minimum transmission gap value
Duty cycle	5.2.11	Maximum duty cycle value
Maximum dwell time	5.2.20	Maximum dwell time value

The receiver parameters of a device is mostly specified by the wireless device type. Only the receiver sensitivity can be configured, see Table 11.

Table 11 – List of parameters used to describe receiver of a wireless device solution

Parameter name	Reference	Content
Receiver sensitivity	5.2.38	Configured values of receiver sensitivity

7 Coexistence management process

7.1 General

7.1.1 Overview

The coexistence management process includes technical and organizational activities in order to establish and to maintain the coexistence state of all wireless solutions in a plant. The coexistence parameters specified in Clause 5, and provided as described in Clause 6, are used in different phases of the coexistence management process. The overall process starting from the decision to establish such a process is depicted in Figure 6. The coexistence management process consists of following phases:

- investigation phase (see 7.4.1);
- planning phase (see 7.4.3);
- implementation phase (see 7.4.4);
- operation phase (see 7.4.5).

The coexistence management process represents the activities of the coexistence management system.

NOTE As all these phases belong to the coexistence management, in the following text the term 'coexistence' is omitted in front of the phase name.

The investigation phase is initiated when changes are discovered or when a new wireless system shall be installed.

In the planning phase, the resource allocation plan is developed or modified based on the coexistence parameter values.

In the implementation phase, new wireless communication solutions are installed and the configuration of existing wireless communication solutions is modified in accordance with the resource allocation plan.

In the operation phase, the condition of wireless communication systems is monitored to detect problems related to coexistence and changes of environmental conditions.

7.1.2 Suitable documentation method

For an efficient processing of coexistence management, related to the complexity of the local situation, the application of a suitable documentation method is advisable. The documentation should at least include the following content and may be administered with software tools:

- storage of information about numerous wireless communication systems and devices, including information about their spatial position and their radio parameters (for example in a data base);
- plausibility check of the recorded data;
- administration of information concerning the status of the known wireless applications;
- access to this information and their administration for all parties involved in the project (if necessary, even for those located in other countries) subject to access authorizations;
- visualization of the collision risk and the occupation of the frequency bands in an intuitive comprehensible form (for human beings);
- experiences of the company in handling the wireless applications;
- optionally visualization of the positions of the wireless applications.

7.1.3 Documentation

Inventory results, information on the wireless applications, results of analyses and measurements and the particulars of installation and approval shall be documented. The scope of the documentation should correspond to the application class. It is recommended to support the documentation by a suitable documentation method. The requirements on such a method are described in 7.1.2.

7.1.4 Application of tools

The essential steps to administer radio frequencies can be supported with suitable tools.

7.2 Establishment of a coexistence management system

7.2.1 Nomination of a coexistence manager

For effective control of the coexistence management process, a central responsibility is required. For this purpose, one or more central contact persons (coexistence managers) shall be assigned. The area of responsibility of the coexistence manager shall be determined individually for each enterprise. Thus, a coexistence manager may be responsible for the whole company, for one or more locations, or for business divisions and departments, depending on the company organization. The crucial factor is to ensure the efficiency of the process.

Whatever the approach adopted by the specific company, it may be considered as belonging to one of two main options:

- based on the relevance of the problem;
- independent of the relevance of the problem.

In the first case, the coexistence manager is chosen from the divisions mostly affected by potential collisions. Often the IT and the automation divisions are the ones concerned.

In the second case, the neutrality of the responsible division is emphasized. Hence, for example, the coexistence manager could be chosen from the “facility management” division administrating the company resources, because the frequency spectrum is to be considered a limited and therefore a valuable resource.

Internal processes and the organization of a company are the decisive factors to choose either of the two strategies. In each individual case the decision shall be made subject to the respective conditions. Here it is important to ensure the efficiency of the process. The coexistence manager shall have basic knowledge about automation applications and the characteristics of wireless systems. The coexistence manager shall have the authority to take the necessary measures to fulfill the defined tasks.

7.2.2 Responsibility of a coexistence manager

The coexistence manager shall be responsible for the following activities:

- establishment of communication channels within the company;
- establishment of a committee, consisting of contact persons of all company divisions using wireless systems;
- establishment of an obligation to register wireless communication systems in the location(s) of interest in the company;
- inventory of wireless applications and, if necessary, commissioning of external or internal service providers to accomplish the inventory;
- release or rejection of newly registered wireless applications and, where necessary, generation of requirements for the use of wireless applications based on the agreed decisions of the internal committee;
- development and coordination of specifications and regulations to implement and operate wireless applications;
- documentation of information about the operational wireless applications, of the decisions of the coexistence management committee and of the accomplished examinations (if necessary, commissioning external or internal service providers to keep these documents)

7.2.3 Support by radio experts

A coexistence manager shall have basic knowledge of radio technologies and associated radio compatibilities. A specialist knowledge is required to promote qualified decisions regarding the use of wireless applications which involve considerable risks. If a coexistence manager does not have the specialist knowledge, he shall be assisted by a radio expert.

The following typical tasks require the assistance of a radio expert:

- inventory;
- analysis of radio robustness;
- metrological testing of radio robustness;
- preparation of a draft decision memo for the use of radio technologies;
- determination of strategies for the use of radio technologies in the future;
- controlling the adherence to the agreed specifications.

7.2.4 Training

The coexistence manager and, if necessary, other members of the committee shall be trained at regular intervals. This training serves to update the knowledge of the persons concerned and to communicate the following information: