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BSI Standards Publication

Industrial communication networks — Wireless communication networks

Part 1: Wireless communication requirements and spectrum considerations

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National foreword

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

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TECHNICAL SPECIFICATION

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Industrial communication networks – Wireless communication networks – Part 1: Wireless communication requirements and spectrum considerations

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORKS –

Part 1: Wireless communication requirements and spectrum considerations

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/TS 62657-1, 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/741A/DTS	65C/749/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 in the IEC 62657 series, published under the general title *Industrial communication networks – Wireless communication networks*, 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- withdrawn,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.

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

INTRODUCTION

The IEC 62657 series has two parts:

Part 1: Wireless communication requirements and spectrum considerations
Part 2: Coexistence management

This part of IEC 62657 provides general requirements of industrial automation and spectrum considerations that are the basis for industrial communication solutions. This Part 1 is intended to facilitate harmonization of future adjustments to international, national, regional and local regulations.

IEC 62657-2 provides the coexistence management concept and process. Based on the coexistence management process, a predictable assuredness of coexistence can be achieved for a given spectrum with certain application requirements.

INDUSTRIAL COMMUNICATION NETWORKS – WIRELESS COMMUNICATION NETWORKS –

Part 1: Wireless communication requirements and spectrum considerations

1 Scope

This Technical Specification provides the wireless communication requirements dictated by the applications of wireless communication systems in industrial automation, and requirements of related context. The requirements are specified in a way that is independent of the wireless technology employed. The requirements are described in detail and in such a way as to be understood by a large audience, including readers who are not familiar with the industry applications.

Social aspects, environmental aspects, health aspects and market requirements for wireless communication systems in industrial automation are described to justify the wireless communication requirements.

This document also provides a rationale to successfully articulate the proposed short-term and long-term solutions. Coexistence management according to IEC 62657-2 is already applied in the short-term solutions.

This Technical Specification describes requirements of the industrial automation applications that can be used to ask for additional dedicated, worldwide unique spectrum. This additional spectrum is intended to be used for additional wireless applications while continuing using the current ISM bands.

This document provides useful information for the automation field professionals who are not familiar with the spectrum and wireless technologies.

Building automation is excluded from the scope because of the different usage constraints (for most non-industrial buildings it is normally difficult for the owner/operator to impose control over the presence and operation of radio equipment).

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 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61784-2, *Industrial communication networks – Profiles – Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3*

IEC 61784-3, *Industrial communication networks – Profiles – Part 3: Functional safety fieldbuses – General rules and profile definitions*

IEC 62443 (all parts), *Industrial communication networks – Network and system security*

IEC 62657-2:2013, *Industrial communication networks – Wireless communication network – Part 2: Coexistence management*

ETSI/TR 102 889-2:2011, *Electromagnetic compatibility and Radio spectrum Matters (ERM); System Reference Document; Short Range Devices (SRD); Part 2: Technical characteristics for SRD equipment for wireless industrial applications using technologies different from Ultra-Wide Band (UWB)*

3 Terms, definitions abbreviated terms and acronyms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62657-2- and the following apply.

3.1.1
automation application
application of measurement and automatic control in the industrial automation domains

3.1.2
availability (performance)
ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided

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

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

[SOURCE: IEC 60050-191:1990, 191-02-05]

3.1.3
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: This is consistent with the definition of coexistence in IEEE 802.15.2-2003.

[SOURCE: IEC 62657-2:2013, 3.1.12]

3.1.4
coexistence management
process to establish and to maintain coexistence that includes technical and organizational measures

[SOURCE: IEC 62657-2:2013, 3.1.14]

3.1.5
cognitive radio system
radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained

[SOURCE: ITU-R SM.2152:2009] [10][1]

3.1.6
conduit
logical grouping of communication assets that protects the security of the channels it contains

Note 1 to entry: This is analogous to the way that a physical conduit protects cables from physical damage (see IEC 62443).

Note 2 to entry: A USB port is considered a conduit, but a USB device (e.g., memory stick) is considered an asset.

3.1.7
Ethernet
communication system according to ISO/IEC 8802-3 and IEEE 802.1D

3.1.8
factory automation
automation application in industrial automation branches typically with discrete characteristics of the application to be automated with specific requirements for determinism, low latency, reliability, redundancy, cyber security, and functional safety

Note 1 to entry: Low latency typically means below 10 ms delivery time.

3.1.9
frequency band
range in the frequency spectrum that is assigned by regulatory organizations for use for specific applications

[SOURCE: IEC 62657-2:2013, 3.1.21]

3.1.10
plant
complete set of technical equipment and facilities to accomplish 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]

3.1.11
process automation
automation application in industrial automation branches typically with continuous characteristics of the application to be automated with specific requirements for determinism, reliability, redundancy, cyber security, and functional safety

3.1.12
reconfigurable radio system
RRS
radio system encompassing software defined radio and/or cognitive radio system

3.1.13
reliability
ability of an item to perform a required function under given conditions for a given time interval

Note 1 to entry: It is generally assumed that the item is in a state to perform this required function at the beginning of the time interval.

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

Note 2 to entry: The term “reliability” is also used as a measure of reliability performance (see IEC 60050-191:1990, 191-12-01).

[SOURCE: IEC 60050-191:1990, 191-02-06, modified – Note 2 to entry has been modified]

3.1.14
shared medium
resource of frequency band in particular area shared by several wireless applications

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

[SOURCE: IEC 62657-2:2013, 3.1.38]

3.1.15
software defined radio
radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard

[SOURCE: ITU-R SM.2152:2009] [10]

3.1.16
wireless application
any use of electromagnetic waves with devices or equipment for the generation and use of radio frequency energy

[SOURCE: IEC 62657-2:2013, 3.1.46]

3.1.17
wireless communication
communication in which electromagnetic radiations are used to transfer information

3.1.18
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.

[SOURCE: IEC 62657-2:2013, 3.1.49]

3.1.19
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.

[SOURCE: IEC 62657-2:2013, 3.1.50]

3.2 Abbreviated terms and acronyms

AGV	Automated guided vehicle
AP	Access point
APDU	Application protocol data unit
BPCS	Basic process control system

CCS	Carbon dioxide capture and storage
CO_2	Carbon dioxide
CP	Communication profile according to IEC 61784-1 or IEC 61784-2
CR	Cognitive radio
CRC	Cyclic redundancy check
DAA	Detect and avoid
DCS	Distributed control system
DECT	Digital enhanced cordless telecommunications
DSL	Digital subscriber line
EC	European Commission
EDGE	Enhanced data GSM environment
EIRP	Equivalent isotropic radiated power
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMI	Electromagnetic interference
EMS	Electromagnetic susceptibility
FSCP	Functional safety communication profiles
GPRS	General packet radio service
GPS	Global positioning system
GSM	Global system for mobile communications
I/O	Input/Output
ID	Identification
IEA	International energy agency
IP	Internet protocol
ISDN	Integrated services digital network
ISM	Industrial, Scientific and Medical
LAN	Local area network
LBT	Listen before talk
LOS	Line of sight
LTE	Long term evolution
MU	Medium utilization factor
NLOS	Non line of sight
OLOS	Obstructed line of sight
PC	Personal computer
PLC	Programmable logic controller
PPE	Personal protective equipment
RE	Renewable energies
RF	Radio frequency
RRS	Reconfigurable Radio System
SDR	Software defined radio
SIL	Safety integrity level
SIS	Safety instrumented system
SOP	Standard operating procedures

SRD	Short range devices
TDMA	Time Division Multiple Access
TS	Technical Specification
UMTS	Universal mobile telecommunications system
USB	Universal serial bus
WIA-PA	Wireless network for industrial automation – process automation
WLAN	Wireless local area network
WRT	Wireless real-time

4 Wireless communication requirements of industrial automation – considerations for regulators

4.1 Worldwide harmonized frequency use

One of the reasons to enable worldwide use of wireless devices is that a wireless component will go through several steps of successive integration before being actually used (into a product, then a machine, then a factory), so the final geographical location of the wireless interface is not necessarily known. Regulation of the utilization of frequency bands is a matter of national sovereignty and has not yet been harmonized worldwide. Even when using the 2,4 GHz ISM band, national device approvals or licenses could be required. Furthermore, it could be necessary in some countries to gain approval for the operation of a wireless network, or to publish details of such a network in advance. Occasionally there are local usage restrictions related to the maximum transmission power that exceed international or regional norms, or a limitation of operation for indoor or outdoor areas. It is therefore important when exporting wireless systems to clarify in advance whether and under what circumstances the devices in question are permitted to be operated in the respective country.

NOTE Normally, manufacturers include such information in their documentation.

4.2 Coexistence management process (see IEC 62657-2)

Standard network solutions with specific performance characteristics (such as time criticality, safety and security) are used in industrial automation applications. The specific performance characteristics needed for industrial automation are identified and provided in Clause 5.

Examples of industrial domains are:

- process automation, covering for example the following industry branches:
  - Oil & Gas, refining,
  - chemical,
  - pharmaceutical,
  - mining,
  - Pulp & Paper,
  - Water & Wastewater,
  - steel;
- electric power, covering for example:
  - power generation (wind turbine, etc.),
  - power distribution (grid);
- factory automation, covering for example the following industry branches:
  - Food & Beverage,
  - automotive,
  - machinery,

- semiconductor.

In industrial automation nowadays there are both wired networks and wireless networks. Examples of these wireless networks are IEC 62591 (WirelessHART®2), IEC 62601 (WIA-PA) and IEC/PAS 62734 (ISA100.11a); all these networks use IEEE 802.15.4 for the process applications. Other examples of wireless networks are specified in IEC 61784-1 and IEC 61784-2 CPs that use IEEE 802.11 and IEEE 802.15.1 for factory automation applications. Unlike separately wired networks, wireless networks share the same media and thus may interfere with each other. Therefore, unless predicable coexistence is assured, operation of multiple wireless networks within the same facility could be problematic, resulting in the failure to meet time critical, safety and security requirements.

Typically, an industrial plant is in a fenced area and all the plant equipment are under the supervision of the plant management who can fully implement a coexistence management process for all the wireless networks of the plant.

In some cases the owner/operator may not be able to control, or may not choose to control, the equipment present. This document can also be used to assist in the identification of the resulting performance limitations.

The coexistence management process represents the activities of the coexistence management system. 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 IEC 62657-2:2013, Clause 5, and provided as described in IEC 62657-2:2013, Clause 6, are used in different phases of the coexistence management process. The coexistence management process consists of the following phases:

- investigation phase (see IEC 62657-2:2013, 7.4.1);
- planning phase (see IEC 62657-2:2013, 7.4.2);
- implementation phase (see IEC 62657-2:2013, 7.4.3);
- operation phase (see IEC 62657-2:2013, 7.4.4).

Robust wireless communication requires the use of a suitable coexistence management system. Such a system could use manual or automated procedures to ensure coexistence as discussed in IEC 62657-2.

Coexistence management should be established whatever spectrum is in use (licensed, unlicensed).

4.3 Concepts for using spectrum in wireless industrial applications

4.3.1 General

This part of IEC 62657 discusses the following concepts and the resulting requirements for using spectrum in wireless industrial applications:

- coexistence management according to IEC 62657-2 in a controlled environment, see 4.2;
- use of suitable available spectrum for wireless industrial applications, see 4.3.2;
- dedicated spectrum for wireless industrial applications, see 4.3.3;
- additional concepts, see 4.3.4.

NOTE The order of the concepts does not mean any ranking or priority.

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[2] 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.

In addition to the coexistence management, combinations of the other concepts can be found in practical applications.

4.3.2 Suitable available spectrum for wireless industrial applications

Several frequency bands are necessary that provide different coverage areas to address all the different operational requirements for wireless industrial applications, sometimes operating simultaneously in parallel and covering very different operational environments.

While the non-critical wireless links could use existing spectrum and comply with existing rules and standards, new frequencies (outside the 2,4 GHz and other SRD bands) need to be identified for the most demanding/critical wireless links in industrial applications. The preference is to have this new spectrum close to or adjacent to bands which are globally already available and for which industrial wireless technology has already been developed.

To address the specific needs for wireless industrial applications, the following requirements and recommendations are identified.

- Specific wireless technologies that are robust in a dynamic and multi-path environment shall be used.
- Frequency bands, which shall be either globally available, or adjacent to such bands, to facilitate the use of similar technology with minimally different operating frequencies.
- Frequency bands should be above 1,4 GHz to avoid interference from welding machines and below 6 GHz due to the quasi optical propagation behavior above this value, the requirement for non-line-of-sight wireless communications and power efficiency as needed for battery powered devices.

Existing solutions for industrial wireless communication use frequencies such as 900 MHz (US only), 1 880 MHz to 1 900 MHz (DECT), the 2,4 GHz ISM-band or the 5 GHz WLAN bands.

Currently, the industrial automation applications use the existing spectrum allocated for generic SRDs. The 2,4 GHz band is a commonly used band and its use is regulated by each country.

For example, in Europe devices with an EIRP of less than 10 mW can be used with no restriction for mitigation techniques. These devices shall comply with ETSI EN 300 440-1 and ETSI EN 300 440-2, while devices with an EIRP of 10 mW to 100 mW can only be used with restrictions. These devices shall comply with ETSI EN 300 328 and CEPT/ERC/REC 70.03. The restrictions in ETSI EN 300 328 require

- an automatic sharing mechanism, which requires the use of listen before talk (LBT) or
- a medium utilization factor (MU) or
- a detect and avoid (DAA) mechanism, also called “listen after talk”.

These restrictions are incompatible with the needs of industrial wireless links.

Security mechanisms shall always be part of the communication architecture of industrial wireless applications to defend the industrial user against attacks. Pervasive action plans (so-called "safe-modes") also exist to take into account intended and unintended interference created by others such as jamming. This may include moving to different frequencies. Cyber security standards for industrial applications are available, such as IEC 62443.

Typically the use of a single common wireless standard by multiple uncoordinated users will not result in interference between them. For example, separate user groups may each establish IEEE 802.11 radio networks in the same space, and conformance to this standard will allow them to coexist to a basic extent. Provisions in some other standards, e.g.

Bluetooth®[3], may also provide some measures to facilitate basic coexistence among certain differing standards. However, the basic level of coexistence provided by these measures will not meet industrial requirements, since they do not guarantee deterministic and managed sharing of the common radio resource. In an industrial context, where many diverse radio networks shall simultaneously meet performance requirements and different levels of priorities shall be satisfied, additional coexistence solutions are required to ensure predetermined and equitable sharing.

An example of a suitable wireless technology for wireless industrial applications is the industrial protocol compliant with IEC 62591 that allows several thousand devices to operate in a meshed network over several years without any collision among themselves. The technical basis for this behavior is a clock synchronized slot assignment, called Time Division Multiple Access (TDMA) technology and a network manager tool in an access point (gateway) that assigns the allowed slots to transmit data.

Non-critical wireless links can use the existing non-licensed bands such as ISM and have to comply with national or regional regulations. Operation in some of the SRD bands is subject to using specific mitigation techniques as mandated by the applicable regulation/standard. These mitigation techniques would apply to any SRD, including those used for industrial applications, as it is obvious that a variety of SRD applications might already be present in the industrial environment.

4.3.3 Dedicated spectrum

4.3.3.1 Critical wireless links in industrial applications

Some industrial applications require a strictly deterministic behavior of the wireless communication links. The availability, reliability, predictability, dependability, immunity and quality of industrial wireless equipment are quite different from many other short range applications. Therefore the short term solution that is based on coexistence management and the spectrum typically used for the mass market generic type of SRD applications may not be adequate for these industrial applications. Coexistence management in the long term should be complemented by an additional dedicated, worldwide unique spectrum.

The candidate frequency bands are not supposed to become generic SRD bands but should be limited to certain specific applications.

This document highlights the need for a new spectrum to be designated that corresponds to the following needs.

- The critical wireless links in industrial applications assume a certain priority in spectrum designation.
- The requested band should be specific for these industrial applications and not be overlapping with the existing SRD bands.
- This new band shall be for worldwide use.

Once the new spectrum has been designated, the development of a harmonized standard for these critical wireless links in industrial applications is needed.

4.3.3.2 Proposed candidate frequency bands

The requirement to use radio systems in an area where electromagnetic emissions occur results in a request of spectrum above 1,4 GHz. The requirements of non-line-of-sight communications and power efficiency result in a request of spectrum below 6 GHz (see also 4.3.2 and 5.3.2).

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[3] Bluetooth® is the trade name of a product supplied by the Bluetooth Special Interest Group. This information is given for the convenience of users of this standard 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.

There exists no specific regulation for industrial applications at the publication time of this part of IEC 62657. Wireless industrial applications that currently exist on the market use the existing spectrum designated for generic devices or some specific short range devices and therefore fall within the scope of any of the existing annexes of REC 70-03 [12]. However, the requirements of critical wireless links in industrial applications cannot be fulfilled when these links operate in these SRD bands; this is why an exclusive (specific SRD) spectrum is required as soon as possible.

4.3.4 Other concepts

4.3.4.1 Geolocation licensing

The dense deployment of wireless solutions can be foreseen to be restricted to well defined areas (building, site, user premises etc.), so that it makes sense to take into account geolocation information as an additional parameter in the shared medium access rules of a wireless device. The aim is to avoid communication overhead and to simultaneously protect possible victim devices. It is requested that the victim devices shall be protected in a way that they do not experience an unfair degradation of service from other devices.

The inclusion of geolocation information is also in line with the ITU definition of the spectrum utilization factor in ITU-R SM.1046-2, which is the product of frequency bandwidth, geometric (geographic) space, and time.

As a prerequisite for interference three conditions have to be fulfilled simultaneously: same location[4], same time, and same frequency. If any of these three conditions is not fulfilled there will be no interference with any possible victim devices.

The proposal is to consider the geolocation of the device to control its transmission characteristics. In a non-crowded area or in owned premises (where radio environment can be managed), a license for a specific band should be obtainable from the relevant national regulator.

A device can obtain information about its current geolocation by several techniques, ranging from simple to sophisticated solutions. Currently this domain experiences further progress and interest because of the discussion about cognitive radio systems.

A first and simple approach is to link the device to a fixed mounted controller, following a master-slave concept. If a slave device is in range and under management of such a controller (master), it is allowed to operate with up to 100 mW employing relaxed timing constrains for its transmissions. Slave devices losing the link to the master shall stop their relaxed operation immediately. The geolocation information is owed to the proposed master-slave concept given in an implicit manner, thus avoiding the need of explicit geolocation information by positioning systems such as GPS, Galileo or Glonass. In addition, it is proposed that slave devices employ an assessment metric of their slave-to-slave and slave-to-master connections (e.g. link quality indication) that can be reported back to the controller and which enables an immediate reactive adaption by the slave device itself in case of interference experienced by victim devices. The controller can be additionally in charge of maintaining proper coexistence and interference management within the user’s premises.

By limiting the range of operation for example to a typical indoor environment, the risk of interference with devices outside the user’s premises is eliminated by the attenuation of surrounding walls. Typical values of attenuation by walls and floors are 10 dB and above, which limits the field strength below the limits of a device operating with less than or equal to 10 mW, which can be operated without timing constraints.

Even without a wall, propagation losses can limit the interference outside of the user’s premises to a certain level, which can be below the limits of a device operating with 10 mW

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[4] Assumes a constant, limited EIRP.

(EIRP) at the border of the user's premises. At 2,4 GHz, the signal will be attenuated by 49,6 dB (accounting freespace attenuation only) at a distance of 3 m.

One can think about many alternatives and more sophisticated solutions based on the inclusion of geolocation.

4.3.4.2 Reconfigurable Radio Systems (RRS)

Reconfigurable Radio Systems (RRS) are expected to become important drivers for the evolution of wireless communications and to bring substantial benefits from reconfigurable flexible and cost-effective architectures for wireless devices to a better utilization of the radio frequency spectrum, thereby helping to mitigate the "spectrum scarcity" problem.

RRS, in particular software defined radio (SDR) and cognitive radio (CR) technologies have been investigated in the commercial, public safety and military areas.

Additional industrial automation requirements are:

- deterministic communication in addition to best effort communication;
- use of the preferred spectrum in the range of 1,4 GHz to 6 GHz (see also 4.3.2 and 5.3.2);
- RRS shall not increase significantly the power consumption (maximum shall not be more than two times the power needed in a non-RRS device);
- joining/registration procedure to a network.

4.4 Market relevance and requirements

4.4.1 General

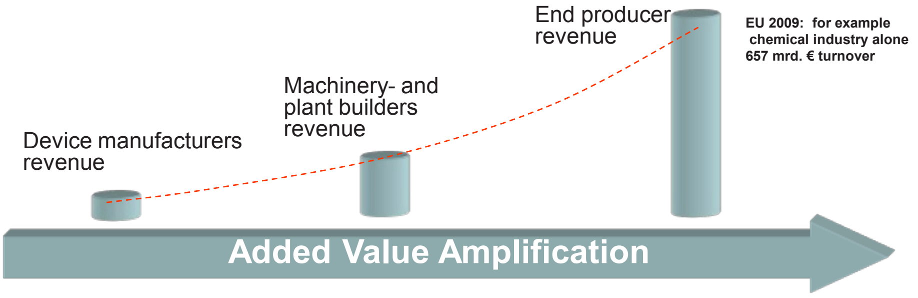
Modern automation applications are increasingly using wireless technology to transfer data. Nowadays the wireless technology is mature and is being increasingly used both within process automation and factory automation. Most wireless communication systems use the license-free Industrial, Scientific and Medical (ISM) frequency bands to transfer process and diagnostics data. Due to various requirements such as transmission speed and the distances to be bridged, several wireless technologies have established themselves on the market.

Industrial production is highly automated compared to other production. The global productivity of industrial production can benefit from using wireless devices.

Examples of industrial production areas are: automotive, chemical, pharmaceutical, machinery, food and beverage.

The market relevance of wireless devices for the industrial automation market can be shown by treating it as the end producer revenue regarding the market where the wireless devices and machines are installed (see Figure 1). In the telecommunications and commercial market, the selling of the device is mostly the end of the revenue, while in industrial automation the wireless devices are the enabler of the revenue of the end producer.

Comparing the number of nodes is not the right approach to judge the importance of the industrial wireless market versus the telecommunications and commercial market.



IEC 0985/14

Figure 1 – End producer revenue

4.4.2 Enabling position of industry equipment

4.4.2.1 Wireless product

A wireless product is typically called wireless field device or wireless device for industrial automation applications. The attribute wireless expresses the presence of a wireless communication interface. Wireless products can be classified in various ways, for example according to the scheme described in Table 1 where they are classified according to the degree of application criticality. Efforts for coexistence management can vary according to the classification described in Table 1.

Table 1 – Application communication requirements

Class	Application	Application communication requirements
Functional safety	Implementation of a safety-related system whose failure could have an impact on the safety of persons and/or the environment and/or the plant	The communication protocol should support functional safety communication and the coexistence manager shall be established in order to fulfill all requirements of IEC 62657-2.
Control	Closed or open loop control	The communication protocol should support a higher availability, reliability, and time-criticality protocol than the one used for other application domains such as consumer industry or telecommunication. The coexistence manager shall be established in order to fulfill most of the requirements of IEC 62657-2.
Monitoring	Process visualization and alerting	No specific add-ons required for the communication protocol. The coexistence manager should be established in order to fulfill at least some requirements of IEC 62657-2.
NOTE 1 This table is copied from IEC 62657-2:2013, Table 1. NOTE 2 The relative terms “most” and “minimum” are based on the graphical description in IEC 62657-2:2013, Figure 3.		

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 the criticality corresponding to its functionality, but the automation application 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.

Further applications ranging from radio bar code readers to voice and video over IP applications can be classified likewise.

4.4.2.2 Wireless machine

A wireless machine is a machine that for the communication function uses a product like a wireless field device (see 4.4.2.1). The manufacturer of a machine can use the wireless products (see 4.4.2.1) to build a machine in a more efficient manner.

4.4.2.3 Improved production

A plant of a manufacturer of products includes the apparatus, machines, instruments, devices, means of transportation, control equipment and other operating equipment in order to have an efficient manufacturing of the intended products. Manufacturers of products use the wireless machines (see 4.4.2.2) and the wireless products (see 4.4.2.1) to improve production by achieving an efficient production compared to a cable based communication network interface.

4.4.3 Cost-benefit aspects and benefits in the application

4.4.3.1 General

When considering whether or not to use an industrial wireless system, it should be considered whether such use is economically viable (taking into account the technical criteria, see IEC 62657-2:2013, Clause 6) and which concrete advantages could be obtained, see 5.1.2.2.

4.4.3.2 Cost-benefit factors

4.4.3.2.1 General

There are numerous possibilities of using industrial wireless systems, and these open up a wide range of benefits. To be able to determine such benefits as a user or operator, it is necessary to look at the various life-cycle phases of a plant and the communication systems that are possibly used. It is useful here to look more closely at the following factors and to use these when comparing wireless systems within an application field, or to compare them with wire-connected alternatives:

- quantitative factors;
- qualitative factors.

All of these factors can be "added up" and compared in a concrete case by the user to determine whether or not the use of a wireless system is practical in the respective case and which system should be used.

4.4.3.2.2 Quantitative factors

The following quantitative factors should be considered.

- Engineering costs, e.g. for planning, device configuration and device programming.

  NOTE 1 This cost factor greatly depends on the respective wireless systems, because more simple systems often only need to be switched on. On the other hand, other – more complex – systems often require extensive device configuration to provide reliable and effective communication.

- Costs of material and devices, e.g. for wire conductors and contact for sensors as opposed to access points and antennas.

  NOTE 2 The projected costs for material and devices are in most cases roughly identical for both types of systems (wireless-based and wire-connected).

- Installation costs, e.g. for assembly (laying of cables as opposed to installing an antenna).

  NOTE 3 Wireless systems often cost less to install when compared to cable-connected systems.

- Operation and maintenance costs, e.g. costs of cleaning, repairs and replacement caused by wear, but also the concomitant costs for downtimes.

  NOTE 4 This item provides the greatest source of savings when using wireless systems.

4.4.3.2.3 Qualitative factors

The following qualitative factors should be considered.

- System availability: the same system availability that can be achieved with a wired communication network may be also achieved with a wireless communication network if the wireless coexistence management is applied.
- Product/process quality: by using additional sensors that would not be economical when wire-connected, additional measured values can be gained and, e.g., the rejection rate in production can be reduced and processes can be optimized.
- Performance of the communication infrastructure: it is achieved by connecting the required number of participants and by using an adequate data rate.
- Expandability/flexibility of the communication infrastructure: i.e. how well can the system be expanded or converted for additional participants.

4.5 Social, health and environmental aspects

4.5.1 General

A suitable wireless communication performance in industrial automation applications enables the industry to solve the requirements regarding social and environmental aspects and obtain the benefits described in 4.5.

There are many potential social and environmental benefits of wireless application for the industry. These benefits include improvement of safety, improvement of the labor environment and health care, resource conservation and reduction of CO_2 emission. Most of these industrial applications deploy mechanism of control and safety applications.

Control and safety applications typically require predictable, deterministic, and repeatable performance, so that their communication services are not interrupted by other less critical applications. Control systems are groups of devices that monitor sensors and other inputs, make control decisions and issue outputs that interact with the real world, e.g. pumps, valves, heaters, traffic lights. Incorrect outputs based on corrupted control can cause harm to people, environment and equipment.

The use of wireless communication helps get more information from the plant and thus achieve an improved control. For example, a production line of plastic bottles can use less material if the precision of the continuous material thickness is stable. This can be achieved by implementing more measurement points in the production line to control the temperature, pressure, fluidity, etc., of the material when transported to the extruder.

4.5.2 Social, health and environmental considerations

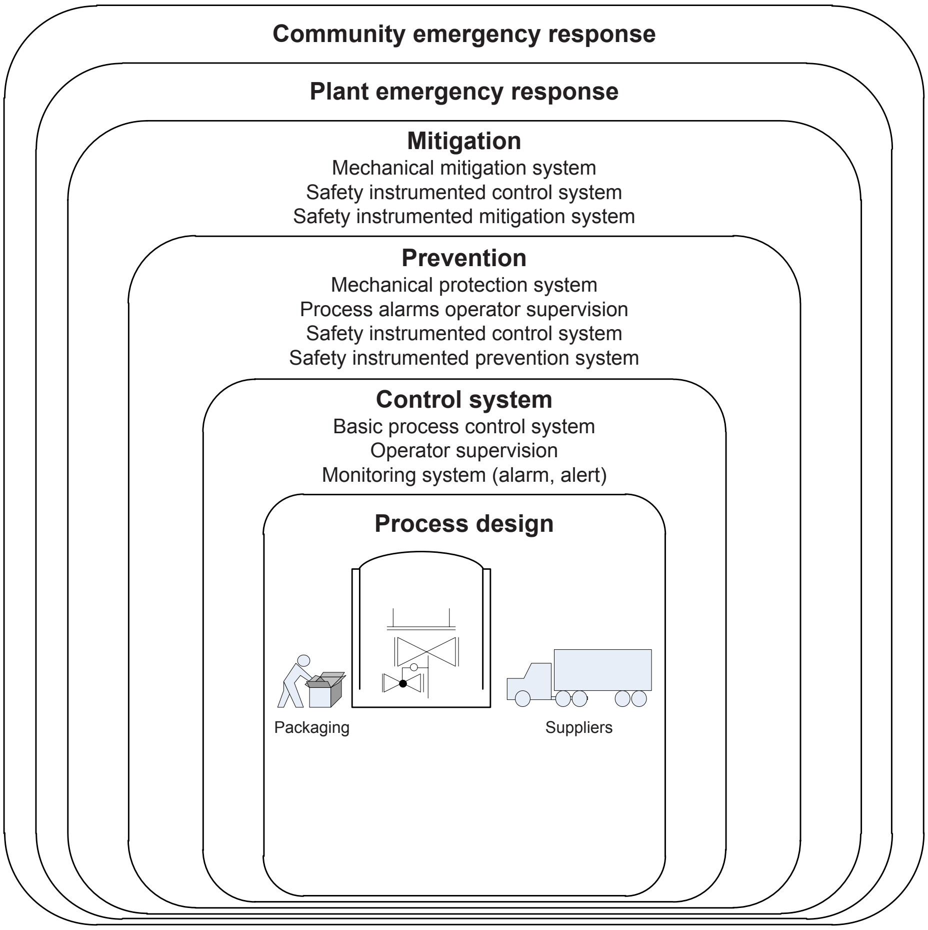
4.5.2.1 Avoiding serious accidents

Accidents which sometimes happen in manufacturing plants bring very serious consequences when the plant handles dangerous material and high energy. These accidents could be prevented by a multi-layers protection system. IEC 61511 specifies the following five layers for the protection of the process industry (see Figure 2): control and monitoring, prevention, mitigation, plant emergency response, and community emergency response. In every layer, wireless technology helps to maintain and to improve the safety level.

The basic process control system (BPCS) is a key layer of protection “which responds to input signals from the process, its associated equipment, other programmable systems and/or operator, and generates output signals causing the process and its associated equipment to operate in the desired manner.” A wireless communication system could be used between the control system and the process, using wireless sensors and wireless actuators. It could be used also for communications with other associated equipment and operators who need alarms to take the required actions.

The safety instrumented system (SIS) performs specified functions to achieve or maintain a safe state of the process when unacceptable or dangerous process conditions are detected. It is used for both purposes of prevention and mitigation. Safety instrumented systems are separate and independent of regular control systems but are composed of similar elements, including sensors, logic solvers, actuators and support systems. A wireless communication system could be used for SIS as well as for BPCS.

The final layers are plant and community emergency response. If a large safety event occurs this layer responds in a way that minimizes ongoing damage, injury or loss of life. It includes evacuation plans, fire fighting, etc. Wireless communication systems help functions such as warning of the evacuation directive and monitoring of the disaster area.



IEC 0986/14

Figure 2 – Typical risk reduction methods found in process plants

4.5.2.2 Improving human safety

In a manufacturing environment there are many machines and equipment which can injure personnel such as press machines and automated guided vehicles (AGV). In such environments, wireless communication allows to have safety systems which could be deployed to ensure human safety.

In some plants where flammable or toxic gases are dealt with, measures using wireless technology such as monitoring leakage of such dangerous gases, announcing the evacuation directives to field operators and confirming the safety of the personnel might be necessary.

4.5.2.3 Improving energy efficiency

Energy efficiency has received an ever growing attention worldwide since it is considered a major lever to help secure a sustainable society in view of climate change, growing population and security of supply. Growing populations and industrializing countries create huge needs for electrical energy.

Wireless communication systems contribute to the establishment of sophisticated energy management systems, which include functions to measure energy consumption and to optimize energy efficiency.

Energy management systems are a fundamental part of the overall solution, since they allow optimized use of energy, general reliability and sustainability of performance. Low-consumption products that function when not needed still consume energy (lamps, motors and electronics on standby, etc.). A 2 °C variation in temperature setting on heating or cooling can consume up to 10 % additional energy, hence small drifts can have significant consequences.

Automation and control are essential for the optimization of energy usage.

- They allow consuming only what is necessary, when and where necessary.
- They allow correcting “bad habits” and improving behavior.
- They can easily be installed in existing sites and improve existing performance.
- They complement energy-efficient end-use products to improve overall usage performance.

Examples of solutions are occupancy detectors and light detectors, timers, variable-speed drives, electric motor systems automation and control, programmable logic controllers (PLCs). Wireless communication systems make these solutions more efficient and more suitable for the intended scope.

4.5.2.4 Improving labor environment

Automation systems can prevent persons from working in dangerous environments, can minimize physical heavy work and can allow the replacement of workers in monotonous activities. However, the necessity for wired connectivity makes tasks difficult in some cases. The wire connection might be impractical because of the cost resulting from the distance to be covered by the wired connection or because of its frequency of usage. In other cases, the wired connection might be not feasible due to the movement of the communicating points.

Wireless communication systems can be used to provide real-time information on the use of personal protective equipment (PPE); for instance, these systems can determine whether each worker is wearing the required PPE, monitor the workers’ presence and warn the worker if PPE is not properly used. They can also be very useful to detect whether a worker enters an area where the worker can be injured (physical protection). For example, they can detect if the worker is on the trajectory of a moving robot arm or of other moving equipment.

Wireless communication systems can solve these problems and improve the labor environment.

4.5.2.5 Reducing CO_2 emission

From a political and scientific viewpoint the global discussion is concentrating on limiting the global warming to a 2 °C increase by the end of the century. In order to reach an acceptable level of likelihood for such a limitation the IEA has developed the 450 μparts/parts (target CO_2 equivalent concentration) scenario. This scenario would result in a reduction of nearly 19 Gt of annual CO_2 emissions compared to a business as usual scenario in 2030. Nearly 45 % of the necessary reduction is seen to be achieved through energy efficiency measures. These can be further broken down to 10 % contribution by industry, 18 % by buildings and 17 % by the transport sector. Additionally the sustainability and conservation of resources need to be considered. Automation itself is a necessary enabler of energy efficiency measures, solutions and systems.

Renewable energies (REs) are those methods of obtaining energy which can operate indefinitely without emitting greenhouse gases, and they are important not only for energy efficiency and decarbonization. REs include hydropower generation, wind power, solar thermal power generation, solar photovoltaic electricity, geothermal power generation, heat pump systems and nuclear generation.

CO_2 (carbon dioxide) capture and storage (CCS) is one of the methods with a large potential to achieve considerable reductions in CO_2 emissions. There are two main potential options to store CO_2, the ocean and geological reservoirs.

In all these solutions, wireless communication systems are very useful.

4.5.2.6 Conserving limited natural resources

Some industrial products contain limited natural resources (for example water, energy, and gold) or need them for the manufacturing of the products themselves. Since these resources are limited, they should be used in an optimal way to achieve a sustainable society.

Automation systems are indispensable for this optimization, and wireless communication systems could help achieve a better optimization.

Examples for achieving the conservation of limited natural resources by using wireless communication systems are:

- waste water treatment systems, where additional information from moving sliders is used to improve the cleaning process and reduce the amount of fresh water in chemical plants;
- smart grids, where the implementation of many measurement devices in a widely distributed control system can reduce the energy consumption, and thus save fossil fuels;
- chemical production processes, where many temporary mounted wireless devices provide data that is only important during start-up and help reducing the amount of raw material.

4.5.3 Health concerns

The transmission power of Bluetooth, WLAN and other wireless systems is at least 10 times to 20 times lower than the transmission power of mobile telephones, which can operate up to 2 W. Industrial wireless modules are also not worn directly on the body and the radiated power absorbed by the body is usually less than 1/1 000th of the transmitted energy. In comparison to a mobile telephone, the radiation exposure from an industrial wireless module is therefore much less, and can be considered to be almost insignificant. The medical risks are correspondingly low.

Additional information is available from national bodies like the Federal Office for Radiation Protection in Germany (Bundesamt für Strahlenschutz), the Safety Code 6 in Canada, the OET Bulletin 65 in the United States, IEEE C95.1-2005 or international standards such as IEC 62479:2010, Annex A, or ICNIRP [24].

Wireless communication is not a problem if kept under the limits shown in 4.5.3.

4.5.4 Other concerns

Wireless technology could be seen as magic as you cannot view, smell, feel, etc. the communication based on electromagnetic fields and consequently it could be seen as not reliable.

There is a concern about battery-powered wireless devices. This is not a problem if batteries are used in accordance with the Directive 2006/66/EC [13] of the European Parliament on batteries and accumulators and waste batteries and accumulators (also known as the Battery Directive) or a similar procedure in other countries.

Wireless communication is not a problem. Wireless technology is well established, it is part of research since decades and widely used in public areas. Battery powering is today well established and evolving using e-mobility.

5 Wireless communication requirements of industrial automation – considerations for automation experts

5.1 Use of wireless communication networks in industrial automation

5.1.1 General

Subclause 5.1 specifies wireless communication requirements dictated by applications of wireless communication systems in industrial automation.

Wired communication systems have been widely deployed in industrial automation for a long time. Although wireless communication systems will not replace all existing wired communication systems, they have special characteristics that wired systems don’t have. These characteristics can provide tremendous benefit for industrial automation systems, but they bring new concerns as well, to be settled before practical deployments. Therefore the essential differences between wireless communication systems and wired communication systems should be well recognized from the point of view of both advantages and concerns. These essential differences are discussed in 5.1.2.

There are many kinds of application areas where wireless communication systems can be utilized in industrial automation. These application areas can be categorized by two aspects. One aspect is the plant layer where the wireless communication system is deployed and the other aspect is the industry type in which the system is deployed. These categorizations are discussed in 5.1.3 and 5.1.4, respectively.

The phase of a plant lifecycle (commissioning, maintenance, operation, etc.), in which the wireless application is used, should also be considered as it possibly has specific requirements.

Wireless communication requirements are best substantiated with practical use cases. Some typical use cases are described in 5.2. Each use case emphasizes multiple essential requirements and provides the background and context for the pertinent requirements.

In order to cover all essential requirements of wireless communication systems with consistency, a categorization of the requirements is useful. Categorized wireless communication requirements are specified in 5.3.3 to 5.3.7.

Table 2 shows the structure of the plant networks used in the application fields.

Table 2 – Structure of the communication networks used in the application fields

Communication networks in industrial automation (5.1.3)	**Application Field (5.1.4)**	
	Process automation (5.1.4.2)	**Factory automation (5.1.4.3)**
Cross-plant wireless network (5.1.3.2)	Use cases (5.2)	
Plant-wide wireless network (5.1.3.3)		
Sensor/actuator wireless network (5.1.3.4)		

5.1.2 Essential differences between wireless and wired communication networks

5.1.2.1 General

Wireless communication has been further developed in a variety of ways within the last few years and has found its way into complex applications of industrial automation. There are persons who have some reservations regarding the use of wireless technologies, because of insufficient or incorrect information. The following contribution is aimed at answering the most significant reservations.

5.1.2.2 Advantages in using wireless communication networks

The most essential property of wireless communication systems is of course that they do not require wires to connect communication nodes to each other. This characteristic not only saves wire material cost but it can also reduce the communication system installation cost and installation time. This property alone enables new applications such as a temporary measurement system for the purpose of process analysis and troubleshooting. Similarly, there are wired communication applications which are technically feasible but not practical on economic grounds, for instance long distance wiring for only a few measuring points.

Since wireless communication systems can be deployed in moving or rotating equipment, they can be used for new applications which could not be conceived with wired communication systems. Mobile wireless equipment carried by field workers is another effective application.

Wireless systems should not be viewed as a general replacement for cable, but when used in a targeted manner they provide significant advantages in a multitude of industrial applications when compared to cable-connected systems. They provide both qualitative benefits such as increased ease of use or increased flexibility during installation, as well as quantifiable benefits such as lower installation and maintenance costs (see Table 3).

Table 3 – Benefits of using wireless systems

Plant networks	Application example	Benefits	Benefits for the user/operator
Cross-plant wireless networks	Remote monitoring	Independent of telephone, internet and network connections	• Low planning effort • Simplified engineering • Higher flexibility • Cost-savings in operation, for connection fees, due to reduced hardware and optimized processes
	Control of water/drainage systems	Uniform communication path (no mixed operation between analog, ISDN, DSL, dedicated line)	
	Operation of mobile processing plants (e.g. water)	Data availability at all times and at all places without temporary cable installation	
	Monitoring of decentralized systems	Decentralized process controller is not required	
	Monitoring of mobile logistics processes (e.g. crane, truck)	Permanent data availability to optimize delivery-chain management	
Plant-wide wireless networks	Shelf access equipment, electrical monorail systems and automated guided vehicle systems	Simplified installation, maintenance-free and greater flexibility in contrast to wire conductors and optical data links	• Can be expanded easily • Increased availability • Higher flexibility • Increased safety for persons • Improved resource planning • Cost savings during installation, in operation and during repairs
	Gantry crane	No need for drag chains, thereby eliminating failures caused by wear	
	Rotary indexing machines, tool changers	Many fewer weak spots caused by wire conductors or loosened plug connections	
	Integration of I/O and serial interfaces (e.g. robots)	Weight reduction due to savings of data cables in cable pathway	
	Building networking	No earth work or laying work required	
	Mobile operation	Very easy to use and saving of additional operating terminals	
	Locating persons and equipment	Position can be localized wirelessly	
Sensor/actuator wireless networks	Monitoring of measuring points (e.g. temperature)	No laying of data cables and often no power lines on the side of the field device	• Can be expanded easily • Increased availability • Higher flexibility • Increased process and product quality due to additional sensors • Cost savings during installation and operation
	Monitoring of mobile measuring stations	No installation and removal of temporary cable installations	
	Rotary indexing machines, tool changers	No weak spots caused by wire conductors or loosened or defective plug connections	
	Plant-wide signal detection	Connection of sensors/actuators that are distributed or difficult to reach, as well as fast retrofitting/conversion	
	Corrosion monitoring, pipe weld monitoring for leakage, vibration monitoring	Physical wiring of the sensor is completely impractical (such as along a pipe elevated 5 m to10 m above the ground)	

5.1.2.3 Concerns in the deployment of wireless systems

Although the wireless systems provide the advantage of not requiring installation of wires, their implementation poses new challenges.

Wireless media have neither well defined confinement nor visible confinement. Therefore the radio propagation path and characteristics strongly depend on the environment conditions and radio interference can come from any direction.

Multiple wireless communication systems need to share a common space as communication medium. A particular frequency band cannot be used in the same space at the same time by multiple communication systems. This issue needs to be solved while maintaining the requirements for industrial automation.

Moreover, the collisions occur at receiver, while the transmitter is typically unable to detect that the corresponding receiver has collisions.

5.1.3 Communication networks in industrial automation

5.1.3.1 General

In individual cases, the requirements, advantages and benefits of wireless systems are highly dependent on the application under consideration. It is advisable for this reason to divide them into fields of application. This allows suitable comparisons among different wireless systems, and also with wire solutions.

Communication networks for industrial automation can be loosely organized around the classical “automation pyramid” (see Figure 3).

The different communication networks are:

- enterprise network;
- plant network;
- fieldbus.

The wireless technology is used to extend these three kinds of networks.

a) Cross-plant wireless networks: networks with a low number of components, with large to very large spatial spread and small or medium volumes of data, for remote maintenance and remote control.
b) Plant-wide wireless networks: networks with a medium number of components, with limited spatial spread and small to very large volumes of data, depending on the requirements of the application.
c) Sensor/actuator wireless networks: networks based on sensor and actuator nodes operating at the field level with very small packets of data and a very high number of components.

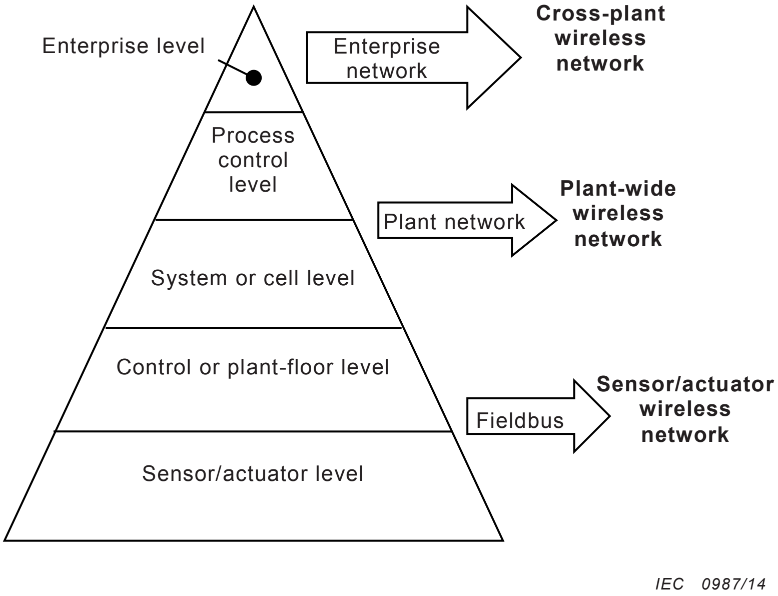


Figure 3 – Wireless communication system interrelated with the automation pyramid

5.1.3.2 Cross-plant wireless network

Primarily, a cross-plant wireless network is concerned with bridging large distances. Remote access can thereby be made to stationary machines and systems as well as to mobile participants, e.g. vehicles. The usable data rate initially plays a subordinate role, whereby efforts are also made even here to achieve bit rates that are as high as possible. A difference can also be made between occasional data exchange, which is often sufficient for remote control applications (e.g. sporadic transfer of measured values), and continuous data exchange which is often required for remote maintenance, even if only for a limited period of time.

In addition to proprietary wireless solutions with ranges of just a few kilometers or satellite-supported communication, GSM, GPRS, UMTS, LTE, EDGE and other wireless solutions are used. The advantages of these systems are worldwide availability, increasing bandwidths and decreasing costs.

5.1.3.3 Plant-wide wireless network

Applications in this field can be divided into four sub-areas.

a) Wireless communication between stationary participants (e.g. two machines or system parts where cabling is at least two times as expensive due to local conditions).
b) Wireless communication to or between mobile participants (e.g. automated guided vehicle systems).
c) Wireless communication for mobile control and monitoring.
d) Wireless communication for localization, i.e. for detecting persons and objects using appropriate transponders.

The requirements for data rate, real-time performance and the maximum number of supported participants can vary widely in these four sub-areas, because they are very closely connected to the application to be implemented. If only a few signals are to be transferred by wireless technology then a decentralized I/O module with an integrated radio interface is usually all that is required. If, on the other hand, a broadband wireless network rollout is required, e.g. to connect several control systems, PC or mobile operator panels, then WLAN would be the suitable wireless system. An additional benefit of this system is the ability to use the wireless network for several applications, e.g. to forward video streams in parallel to control and visualization data.

If there is also an additional need to transmit safety-critical signals then it is essential that the wireless system can support a safety protocol which, e.g. when combined with WLAN or Bluetooth, allows the Industrial Ethernet standards according to IEC 61784-2 and their functional safety profiles according to IEC 61784-3 to be used.

5.1.3.4 Sensor/actuator wireless network

This wireless network is often linked via gateways (protocol converters) to other networks, e.g. Ethernet, because they only need to transfer low volumes of data.

Various wireless networks have established themselves in industrial automation due to the different requirements for factory automation and process automation.

Whilst sensor/actuator networks within factory automation usually use a large number of small packets of data within short distances with a high throughput, the most important aspect of process automation is usually secured wireless transmission over long distances.

For a sensor/actuator wireless network, there have only been a few protocol standards up to now that permit interoperability between devices from different manufacturers.

Process automation applications use protocol standards that are based on IEEE 802.15.4 such as IEC 62591 (WirelessHART), IEC 62601 (WIA-PA), IEC/PAS 62734 (ISA100.11a), or even proprietary protocols.

Factory automation applications use protocol standards that are based on IEEE 802.15.1, IEEE 802.11, or even proprietary protocols.

5.1.4 Application fields

5.1.4.1 General

Industrial automation technologies are quite different for factory automation and process automation, because of the different requirements posed by each of these applications.

5.1.4.2 Process automation

Process automation is mostly characterized by applications within the field of the control, monitoring and diagnostics of heating, cooling, mixing, stirring and pumping procedures.

Often, analog signals of filling level, temperature or pressure monitoring are transferred and evaluated. These evaluated measurements have been made available to automate extraordinary start-up and shutdown operation for continuous process and batch process, and furthermore, they are useful for control of product quality and the switching of products for a batch process corresponding to the manufacturing of a wide variety of products in small quantities. In process automation there are relatively slow changes in measured values; a sampling every 100 ms through several seconds is typical for these applications. This characteristic directly determines the requirements for the reaction speeds of the wireless technologies applied in process automation.

The energy required by wireless and sensor components is correspondingly low and can often be provided by decentralized supply units such as batteries or so-called energy harvesters (e.g. energy is generated from temperature variations, light, machine vibrations or the flow of media).

A large process automation system requires wide wireless transmission ranges.

The size of a process automation system is often many times larger than in typical factory automation plants. A wide range is therefore an important requirement for wireless networks in this field.

The plant structure only changes moderately over time compared to factory automation and therefore the propagation conditions change accordingly.

5.1.4.3 Factory automation

A marked characteristic of factory automation machines and systems is their fast production processes. Often this means machine parts that are in motion within a limited space.

Fast processes require short operation cycles and fail-safe transfer of sensor and actuator signals. Cycle times of less than 10 ms are quite normal. This characteristic of factory automation directly determines the requirements for the wireless technologies.

Fast production processes make the highest demands on wireless solutions.

Due to their limited spatial spread, various wireless networks are often operated within the same small area.

Wireless technologies can cover the most varied range of applications within factory automation. Uses have already been implemented from wireless connection of sensors within an automation cell right up to communication on the field or control level. Diversified wireless solutions thereby provide technologies that are geared towards the respective requirements for range, cycle time and number of participants.

5.2 Industrial automation application requirements (use cases)

5.2.1 General

Subclause 5.2 describes some use cases of wireless communication in industrial applications. One of the purposes is to illustrate the benefits of wireless applications, and the other is to mention technical requirements from an application viewpoint. All major requirements are included in the use cases of 5.2.

5.2.2 Use case 1 – Safety of workers around transporting machines

5.2.2.1 Description

This use case is related to transporting machines used in indoor assembling lines, e.g. in the manufacturing of automobiles or household electric appliances. These unmanned transporting machines are also known as AGV. Some unmanned transporting vehicles, which are controlled through wireless communications, carry parts and components and feed them to stations in the assembly line. The vehicles basically run on dedicated tracks, but in some places the tracks need to cross people’s pathways. A safety interlock mechanism is required in these crossing areas in order to assure the safety of workers.

Light curtains, laser scanners or radar scanners ahead of a vehicle on the pathway detect the entering of persons in the crossing area. This event is reported to a safety logic solver, which recognizes the situation and decides to stop the vehicle which is approaching the crossing area. Wired connectivity to the vehicle is not practical because it moves on the track, so the communication between the logic solver and the vehicle is implemented using wireless communications.

5.2.2.2 Consequence of losing the function

If the communication of a request to stop a vehicle fails, the vehicle might enter the crossing area occupied by persons. As a result, the transporting vehicle may cause severe injuries to personnel. The vehicle itself may be damaged. Moreover, any kind of accident affects the continuity of production line operations, with production losses.

5.2.2.3 Critical requirements

In cases where the communication system stops working, such condition should be detected and the vehicle shall suddenly stop, even if it has not received any request to stop from the logic solver.

One serious case of failure is the case where the error detection mechanism cannot detect the error which changed the content of a request. In this case, the vehicle might interpret the message as if no request to stop was received under healthy communication conditions, and this may cause an accident.

Mechanisms with a certain level of complexity and corresponding error detection capability such as CRC are usually employed in the safety-communication system to detect errors, but they are not sufficient by themselves. In order to meet the required safety levels, such as the SIL levels specified in IEC 61508, the bit error rate should be less than a certain level depending on the residual error rate of the error detection mechanism. Enough immunity against EM interference is necessary for the communication system to keep the bit error rate below the acceptable level.

The communication delay is also important. If the reaction time from detection of an event by the light curtain to the stopping of the vehicle is shorter than the process safety time, which is the acceptable maximum delay of reaction for the target process, then an accident can happen.

5.2.3 Use case 2 – Level monitoring and alarming in a tank farm

5.2.3.1 Description

This use case is for a tank farm where several huge tanks are installed in an area of several square kilometers. These tanks may contain dangerous material such as combustible material and toxic material. Level monitoring and its related alarming are very important to prevent leakage of content.

A tank farm occupies a widespread area, so wiring is very costly especially when it is only for level monitoring.

Wireless communication circumvents the problems caused by the large electro-potential differences that can occur across communicating equipment during lightning events near or over a tank farm.

A wiring in tank farms to lower the electro-potential differences is not needed anymore if the communication is provided by wireless devices that do not need external power.

A wireless communication is very effective in such cases.

5.2.3.2 Consequence of losing the function

In cases where the monitoring and alarm functions don’t work correctly because of communication errors, an overflowing of the tank content could happen.

Leakage of toxic content may affect the workers’ health and it could also cause serious environmental issues. Overflow of combustible content could cause explosions or fire disasters. These accidents cause damage to manufacturing assets and loss of materials, with huge financial losses as a consequence.

Optimization of inventory is another important aspect of level monitoring. Since some materials stored in tanks are very expensive, minimizing such inventory saves production costs.

5.2.3.3 Critical requirements

In order to properly cover the area of a tank farm a long range radio is required. In some cases there are several metal structures between communication nodes, and this may cause attenuation and multi-path distortion. Therefore better propagation performance is required. Individual tanks may have a very large structure that can be an obstacle to the radio propagation. In these cases, where a line of sight to the location of the level sensors may not be feasible, it is possible to circumvent the obstacles using a mesh topology.

5.2.4 Use case 3 – Field worker support with mobile wireless equipment

5.2.4.1 Description

Field workers of the process industry cover wide areas of outdoor plant sites for the purpose of patrol or maintenance. These field workers need to reference standard operating procedures (SOP) documents in order to execute their task such as process operation and equipment maintenance. If they do not have intelligent communication means, they need to carry heavy binders of SOP. A maintenance person might need instruction manuals of equipment which include graphical information. Wireless communication systems are useful for these applications, because a wired connection is not practical for mobile field workers.

A person checking process conditions might need information about a DCS system, such as loops configurations and historical trend data, to recognize process conditions by measured values. To provide such information a wireless access to the DCS is used. In this case communication delays should be short enough to provide fresh data indicating the current process conditions.

Sometimes voice communication between field workers and engineers in the control room is useful. The engineer in the control room has easy access to a large amount of information and can advise field workers who have limited information. Even video information could be used to support field activities. Video data, which is captured by a field worker and is sent to the control room, can help engineers grasp the situation and provide directions.

In emergency situations, a wireless communication system contributes to the safety of field workers. Besides providing voice communication, a real time location system helps in recognizing the worker’s location, movement and status.

5.2.4.2 Consequence of losing the function

In the cases where the wireless communication system fails, the efficiency of field work decreases tremendously and the safety of field workers can be seriously compromised.

5.2.4.3 Critical requirements

The wireless communication system should cover the whole area where the field workers may travel. In order to achieve the appropriate radio range a mesh topology may be required.

The graphics, pictures, and streaming of voice and video demand substantial wireless communication bandwidth.

The wireless communication equipment which is carried by field workers should be light and with sufficient autonomy, therefore power consumption should be minimized to reduce the battery weight and to prolong the battery life.

5.2.5 Use case 4 – Vibration monitoring and analysis of rotating machines

5.2.5.1 Description

This use case is related to condition-based maintenance. Since the vibration pattern of most rotating machines changes with deterioration, the monitoring of vibrations can be used to determine the maintenance time for rotating machines. In some cases a wired connection to the vibration sensor is not practical because of its movement. In other cases there are so many points to be measured that wiring is not acceptable in term of cost. A wireless communication system can be used to resolve these issues.

5.2.5.2 Consequence of losing the function

If condition monitoring through wireless communications is not available, the maintenance work is compelled to be based on an estimated time schedule. This typically means that the frequency of maintenance is increased while the risk of unexpected shutdowns due to undetected equipment degradation is also increased.

5.2.5.3 Critical requirements

The data size of vibration patterns is usually relatively large. In some cases real-time monitoring is needed to provide alarming. Therefore, substantial bandwidth and real-time performance is required.

5.2.6 Use case 5 – Oil wellhead monitoring and control

5.2.6.1 Description

This use case is related to oil wellheads which are scattered in wide oil fields. The pressure and the flow rate of crude oil spouting change depending on the condition of the oil field. In order to control the total production volume of oil from several wellheads, valves installed at each wellhead should be adjusted according to the condition indicated by flow rate, pressure and temperature.

Oil wellheads are usually scattered and unmanned. Visiting every wellhead to check its condition and to adjust it is time consuming and inefficient. The installation of a wired communication system is not practical because wellheads are scattered in a large area. Therefore, a wireless communication system can be an effective solution. The condition of each wellhead can be monitored remotely. Even the adjustment of valves can be performed remotely. Therefore, the frequency of physically visiting a wellhead can be greatly reduced.

5.2.6.2 Consequence of losing the function

If the wireless communication is not available, the frequency of wellhead visits increases and the optimization of production rates cannot be achieved.

5.2.6.3 Critical requirements

Enough radio range is required to connect to distant wellheads. Usually a line of sight is possible but disrupting climatic conditions should be taken into account.

Since wellheads are located in far and unmanned places, the frequency of visits to replace batteries for wireless equipment shall be kept to a minimum. Therefore, the power consumption of the wireless system shall be minimized.

Appropriate security measures shall be in place because the wireless network spreads into an open and wide area and malicious persons can easily obtain physical access to the network.

5.2.7 Use case 6 – Some applications for factory automation, with a large number of nodes

5.2.7.1 Description

This use case is a generic application in indoor manufacturing such as for automobiles or for household electric appliances. Usually the set-up of a manufacturing production line changes more frequently compared to a set-up in the process industry. The refurbishment of the communication system of a production line is much less when the communication system is based on a wireless technology instead of a wire technology.

5.2.7.2 Consequence of losing the function

If the function of a wireless communication system is lost, critical parts of the production line (e.g., robot work cell) cannot continue to operate.

5.2.7.3 Critical requirements

The density of wireless components in a manufacturing shop floor is usually very high, with many wireless applications overcrowding the same area. In addition, the wireless traffic is much higher in the manufacturing than in the process industry. Therefore, the coexistence of multiple wireless communication systems shall be guaranteed.

5.3 Wireless communication network requirements

5.3.1 Timing and real-time

5.3.1.1 Common requirements

All the systems involved in industrial automation pose some constraints regarding the response time, i.e. the time between the presentation of a set of inputs (stimulus) and the presentation of the required behavior (response), including the availability of all associated outputs. Obviously, how fast the response time has to be depends on the characteristics of the controlled plant.

In regulation tasks, delays appear as dead times, which additionally may be affected by jitter (variable delay). In sequential tasks, delays slow down plant operation, possibly beyond what the plant may tolerate. Clearly, the delay and jitter due to the wireless network shall be less than the value that affects the required system response time. In addition, time synchronization among wireless devices is also required. Time synchronization prevents mutual disturbance of the communications and the use of timestamps added to the transmitted data allows the time behavior of a station to be decoupled from the communication delay and jitter. Time synchronization can be achieved by allocating transmission slots to stations and making them all follow a time-driven message transmission schedule. Implemented this way, time synchronization is beneficial to avoid collisions, to have a correct response time and a better bandwidth utilization.

If industrial applications require results in a bounded time then the industrial automation system shall be a deterministic or real-time system. Consequently, a communication system used in this industrial automation system shall provide the required data transfer in bounded time including repetitions needed to correct transmission errors.

5.3.1.2 Wireless real-time requirements

5.3.1.2.1 Basic principles of performance indicators

A wireless real-time (WRT) communication network is a wireless communication network that performs real-time communication.

Users of WRT communication networks have different requirements for different applications. In order to satisfy these requirements in an optimal way WRT communication networks will exhibit different performance.

Performance indicators (specified in 5.3.1.2.3) shall be used to specify the capabilities of a WRT end device and a WRT communication network as well as to specify the requirements of an application. Performance indicators will be used as a set of interaction means between the user of the WRT device and the manufacturer of the WRT device and network components. Subclause 5.3.1.2.2 specifies the application requirements view.

Performance indicators represent

a) the capabilities of a WRT end device,
b) the capabilities of a WRT communication network, and
c) the requirements of an application.

A consistent set of performance indicators (specified in 5.3.1.2.3) is used to represent the WRT capabilities. Some of the performance indicators are interdependent; in this case some indicator values depend on the value of others to provide a consistent set.

NOTE 1 The interdependence is due to physical or logical constraints, which cannot be violated. For example the indicators "WRT-Throughput” (which would use 90 % of the total bandwidth) and "Throughput non-WRT” (90 %) cannot happen at the same time because that would describe a transmission load of 180 %.

No general boundary values to specify WRT performance are specified for the indicators in this document, but device suppliers need to specify boundary values for a specific product if they claim to be compliant to this document.

Technology specific devices shall specify

a) the selection of performance indicators out of possible performance indicators defined in 5.3.1.2.3 relevant to a given device, optionally with their individual limits or ranges,
b) the interdependence between performance indicators,
c) optionally, lists with consistent performance indicators values.

   Each of the lists has one or more leading performance indicators. The leading performance indicators are preset to a fixed value (typically optimized to have the best overall performance). The other performance indicators in the list are shown with their related consistency limits,

d) optionally, a more comprehensive representation of the relation between performance indicators (Figure 4 shows an example of a graphical representation).

The supplier of WRT end devices and WRT communication networks shall provide at least one consistent set of performance indicators.

NOTE 2 A set of lists with consistent performance indicators is only given when interdependence between performance indicators exists.

NOTE 3 Applications can have requirements where one particular indicator has higher importance than all the others. Such applications will find useful the opportunity to select the consistent indicator list with the relevant leading indicator. Other applications can have requirements where several indicators are of equally high importance. For such applications, a graphical or otherwise more comprehensive representation of the relation between consistent indicators is more appropriate. Figure 4 is an example of a graphical representation of consistent indicators given by a device.

NOTE 4 WRT end devices are designed under the discretion of the manufacturer of such a device. Therefore no assumption could be made on how many WRT end-stations (network interfaces) are built in one device. In order to achieve comparable performance indicators from the application perspective the performance indicators are built on WRT end-stations, not on WRT devices.

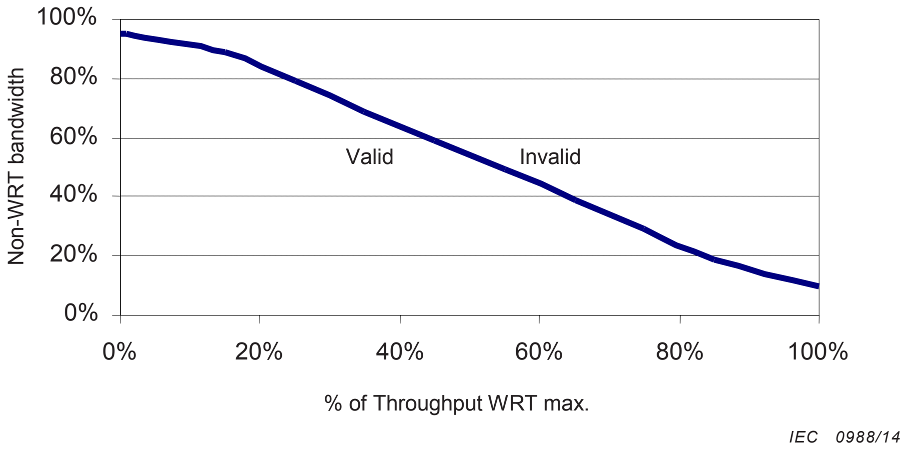


Figure 4 – Example of graphical representation of consistent indicators

5.3.1.2.2 Application requirements

The capabilities of a WRT communication network are specified in 5.3.1.2.3 as indicators. The indicators are used to match application requirements to the capabilities of components compliant to one or more devices.

Subclause 5.3.1.2.3 introduce performance indicators with respect to a WRT communication network that can be used in a best-practice way for industrial automation applications.

The characteristic parameters representing the performance indicators are specified in IEC 62657-2:2013, Clause 5. The values or value ranges of the characteristic parameters allow to assess a WRT communication network with respect to the real-time performance and the coexistence capability. These characteristic parameters are as follows:

- transmission time, according to IEC 62657-2:2013, 5.2.50;
- update time, according to IEC 62657-2:2013, 5.2.53;
- data throughput, according to IEC 62657-2:2013, 5.2.10.

For these characteristic parameters statistical values shall be used in order to describe the requirements or to characterize a wireless communication system. Relevant statistical parameters are either a mean value, or a mode to specify the center and standard division, or a percentile P95 to specify the variation of the characteristic parameter.

The specification and assessment of wireless communication systems is the subject of ongoing research activities which includes also parameters such as availability, synchronicity, and redundancy recovery time. The objective is the development of a measure for an application oriented, wireless technology independent, quantitative specification of application communication requirements and an assessment of wireless communication solutions.

5.3.1.2.3 Performance indicators

5.3.1.2.3.1 Delivery time

Delivery time shall indicate the time needed to convey an APDU containing data (message payload) that has to be delivered in real-time from one node (source) to another node (destination). The latency is measured at the interface between the application process and the (fieldbus) application entity.

NOTE 1 The term latency is a synonym of the term delivery time used in IEC 61784-2.

The maximum latency shall be stated for the following two cases:

- no transmission errors, and
- one lost frame with recovery.

NOTE 2 If a permanent failure occurs, the latency of a message is the redundancy recovery time (see 5.3.1.2.3.6).

Calculation of the maximum latency shall include the transmission time as well as any waiting time (for an example backoff delay, see IEEE 802.15.4 or a clear channel assessment observation time, see ETSI EN 300 328:2012, 4.3.2.5.2.2).

NOTE 3 The waiting time depends on the WRT network concept and the application load which is generated by the other nodes in the WRT network and the non-WRT traffic at that time.

5.3.1.2.3.2 WRT-Throughput

WRT-Throughput shall indicate the total amount of APDU data (by octet length) on one link per second.

5.3.1.2.3.3 Non-WRT bandwidth

The non-WRT bandwidth shall indicate the percentage of bandwidth which can be used for non-WRT communication on one link. Additionally the total link bandwidth shall be specified.

NOTE The indicators WRT-Throughput and non-WRT bandwidth are related to each other.

5.3.1.2.3.4 Time synchronization accuracy

Time synchronization accuracy shall indicate the maximum deviation between any two successive node clocks.

5.3.1.2.3.5 Non-time-based synchronization accuracy

The non-time-based synchronization accuracy shall indicate the maximum jitter of the cyclic behavior of any two nodes, using triggering by periodical events over the network for establishing cyclic behavior.

NOTE This factor accounts for coherency of data or actions triggered by the event, and it is a measure of the coherency spread.

5.3.1.2.3.6 Redundancy recovery time

Redundancy recovery time shall indicate the maximum time for an item to recover from failure and become fully operational again in case of a single permanent failure.

NOTE If a permanent failure occurs, the latency of a message is the redundancy recovery time.

5.3.1.3 Process automation requirements

The most critical requirements are in the field of control, where the time constants are in the range of 100 ms to some seconds. On the other hand, as stated in 5.1.4.3, applications within the field of the monitoring and diagnostics of heating, cooling, mixing, stirring and pumping procedures usually have longer time constants, in the range of seconds to minutes. Consequently the requirements about the update time (see IEC 62657-2:2013, 5.2.53) of the wireless network are on the same order of magnitude. In particular, relative long update times allow the use of message retries to increase robustness and allow the implementation of fully interconnected (mesh) network topology. With regard to time synchronization, accuracy in the order of one millisecond is needed to apply low power consumption strategies based on time division medium access.

5.3.1.4 Factory automation requirements

In factory automation, discrete, stepwise manufacturing dominates (for example, assembling a product from many different parts). Factory automation production lines have cycle times which may vary from 1 s (one product produced and tested per second) to 1 min. In addition, these applications are characterized by a high node density, with an average density requirement of more than one wireless device/m^3. Typically most of the I/O signals are digital and the events are typically separated in time (asynchronous) and individually relevant, resulting in a large number of telegrams, with a worst case equal to two times the number of I/O per production cycle. This means that thousands of packets may be exchanged across the network each second. For this reason, the requirements of network response time for factory automation are much more stringent than those of process automation. In particular, such a short response time is usually met by adopting star topologies and a high data rate. Regarding time synchronization, accuracy in the order of a few microseconds may be needed to satisfy low jitter requirements.

5.3.1.5 Cross-plant requirements

Cross-plant data transfers are mainly used to supply chain management and production scheduling purposes and are based on aggregation of data coming from a lower plant layer. For this reason, timing requirements (latency, synchronization accuracy) are less stringent than those for the plant-wide layer, in the order of tens of seconds or more.

5.3.1.6 Plant-wide requirements

Plant-wide data transfers are mainly intended for performance analysis and maintenance purposes; they are based on aggregation of data coming from a lower plant layer. For this reason, timing requirements (latency, synchronization accuracy) are less stringent than those for the sensor/actuator plant layer, in the order of seconds. An exception is wireless communication to or between mobile participants (e.g. automated guided vehicle systems), whose requirements are comparable with those at the sensor/actuator level.

5.3.1.7 Sensor/actuator requirements

Control loops are implemented at the sensor/actuator layer; for this reason time latency is a crucial parameter at this level.

The timing requirements (latency, synchronization accuracy) can be very stringent; in factory automation requirements in the order of a few ms are typical, with a jitter in the order of a few μs.

5.3.2 Bandwidth and bit rate

5.3.2.1 Common requirements

In order to understand bandwidth and bit rate requirements it is useful to define the data delivery model (i.e. traffic characteristics) of a wireless communication system used in industrial automation. Generally, two different data delivery models are used:

- Cyclic (periodic or time triggered) data. Here the data coming from or going to the field has a cyclic behavior, thus showing well defined bandwidth requirements, both deterministic and predictable. In addition, cyclic data freshness is an important parameter, since newer data make obsolete the old one, i.e. the time to live is short. This model is used for control, where the data regarding the control input quantities is acquired periodically all at the same time and then dispatched before the next step.
- Acyclic (aperiodic or event triggered) data. This kind of traffic, which spans over all the plant layers, is usually generated by unattended events, as for example alarms. Typically there may be bursts of events; this fact requires the use of a priority service in order to allow as soon as possible the solution of the most critical events. Clearly, there is a strict relationship among the bandwidth available to the user, the actual bit rate and the timing performance of the wireless communication solution.

To solve a large part of the industrial automation applications it is required to get a worldwide available dedicated spectrum with at least 76 MHz bandwidth, but this spectrum does not necessarily have to be contiguous. This amount of spectrum is based on the assumption of a typical number of devices per plant and a typical data traffic. The assumptions and the evaluation of the required amount of bandwidth are given in ETSI/TR 102 889-2. The scale of the network is shown in 5.3.3.

The typical data traffic for cyclic and acyclic transmission of data and alarms can for example be combined in one channel out of several channels in this 76 MHz band.

The desired spectrum of 76 MHz bandwidth shall be available above 1,4 GHz in order to reduce the impact of non-intentional radiators such as arc welding machines, to allow for large area covering, and to guarantee low cost and multi-vendor radio availability. Multiple (in the order of ten) channels shall be available to ensure robustness to interferences and coexistence with other co-located wireless communication solutions. The actual number of available channels depends not only on the bit rate but also on the spreading/modulation technique. For example, frequency hopping systems are based on a high number of narrowband channels, while direct sequence spreading techniques are based on a few wideband channels.

5.3.2.2 Process automation requirements

Wireless stations employed in process automation usually exchange a few bytes per data (consider that the value of each quantity may be represented by a 4-byte floating point number) with a relative long cycle time (maybe on the order of seconds or slower). In fact, most of the signal processing is performed at the sensor level and only useful information is sent via the wireless channel. For this reason, bandwidth requirements for process automation are less severe than those for factory automation. Usually a bit rate of hundreds of kbit/s is sufficient, resulting in a required frequency range in the order of at least 34 MHz according to ETSI/TR 102 889-2:2011, Table 1.

5.3.2.3 Factory automation requirements

Most of the wireless devices used in factory automation are digital I/O points, thus exchanging a very few bytes per transaction. However, the node density can be very high and the cycle time very short, thus requiring a high user bandwidth. In particular, a short cycle time on the order of a few ms limits the available time “over the air”, requiring a raw bit rate of no less than 1 Mbit/s. For this reason, the available bandwidth shall be at least 42 MHz according to ETSI/TR 102 889-2:2011, Table 1.

5.3.3 Radio propagation conditions, geographic coverage and scale of the network

Propagation conditions influence the robustness of a wireless communication system as well as the interference of other wireless communication 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.

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.

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

Three application classes can be logically identified in a plant:

- cell (or subunit) automation;

- factory hall (or plant subunit) automation;
- plant level wide automation.

The cell automation is a part of a production line in an automotive plant or a discrete manufacturing plant or a subunit in a process automation plant (for example, a reactor with a local control to which sensors and actuators are connected). Typically a cell automation requires lower range communications (for example, a 10 m to 30 m range) but is more demanding for latency and robustness, and the cell is capable of living with fast movements, integrated antennas and many obstacles (nearly complete shielding). One such cell has one wireless system with an average of 30 devices. Up to 10 such cells can be in close proximity, so that their interference area overlaps.

The factory hall automation is a whole production line or moving applications (for example, moving through a factory hall in discrete manufacturing such as automated guided vehicles, rail hanging power screwdrivers), or a whole production unit in process automation.

A factory hall (or plant subunit) has the following characteristics:

- it covers a larger area (e.g. 100 m × 100 m). This is solved by an industrial WLAN or a mesh type technology (TDMA schemes used) to safely cover a larger area;
- it uses systems composed of an average of 100 devices and still requires low latencies:
  - up to 5 such independent systems can be within range of each other (are within "interference" range);
  - the area related local device density at 150 m interference range therefore is approximately (5 × 100 devices) / (150 m × 150 m) or 0,022 devices per m^2 at 100 m interference range.

The plant level wide automation covers areas of variable size, up to the whole plant, typically with an industrial mesh technology that has the following characteristics.

- It could cover large areas such as 1 km × 1 km and typically is implemented with a mesh technology to increase robustness against typical industrial influences (moving obstacles, interference/coexistence).
- One such mesh system can have up to 1 000 connected devices, where each device only covers a smaller range (e.g. 100 m) and consequently the mesh covers all the area, without using excessive power.
- There may be up to 5 independent such mesh networks operating in parallel in the whole plant.
- Each mesh network uses a maximum of 50 devices and the devices of the different mesh networks can be in range of each other (are within "interference" range).
- The area related local device density at 100 m interference range therefore is approximately (5 × 50 devices) / (100 m × 100 m) or 0,025 devices per m^2 at 100 m interference range.

Mesh networks operating in parallel use overlapping, preferably in the same frequency band, to get maximal flexibility of coexistence management, to increase spectrum efficiency and to have the same needed spectrum properties such as industrial-interference-free, power efficiency (range) and compensation for damping by obstacles.

All of these three application classes are operated in parallel (partially or completely overlapping interference area), and often by different operators and connected to different control systems.

Each of the many wireless systems has to be allowed to switch on and off and vary the number of connected active devices and data amount transferred, depending on the needs of the many different production cells/subunits/lines in order to maximize individually production, quality, safety and do service, troubleshooting and installation work on the productions units.

5.3.4 Power consumption

5.3.4.1 Common requirements

Industrial networks typically require uninterrupted service, especially for the control applications. In this case, on the wired network section, alternative paths shall be provided through redundant network design. As a result, these networks are designed with redundancy for fault-tolerance as the basic requirement. Unfortunately, this fact has a negative impact on energy consumption as the redundant network consumes energy even if it is on stand-by mode.

Possible solutions are the shutdown approach (i.e. to put components to sleep), the, slowdown approach (i.e. adaptation of the transmitting rate to the real needs), and the coordination approach (i.e. network-wide management and global solutions for energy efficiency).

On the wireless sections, the need for uninterrupted service introduces further requirements. First, more access points (APs) are needed to enforce full network coverage and suitable approaches have to be taken to maximize the network lifetime, i.e., the time of the first node failure. This is a common used measure that reflects the fact that in a wireless network the failure of a single node can determine network partitioning and interrupt any further service. Wherever network nodes are battery operated, there is a potential for network partitioning due to one or more nodes with a shortage of battery supply. As a result, in all industrial automation networks including battery-operated nodes, any means to reduce the nodes' power consumption has to be taken.

Generally speaking process automation applications are less demanding, while factory automation applications are more demanding just because of the typical traffic of the relevant applications.

In addition, even if the target of the energy efficiency requires a significant reduction of the power consumption in all parts of a plant, cross-plant and plant-wide applications are less critical because they are usually mains powered.

The most critical situations are at the sensor/actuator level, especially where only battery operated solutions are feasible.

5.3.4.2 Sensor/actuator requirements

Typically, sensor/actuators networks made up of battery-operated nodes feature a major need for protocols able to optimize power consumption, so as to prolong the lifetime of the nodes and thus that of the network as a whole, while also meeting end-to-end delay requirements. The requirement on power consumption often clashes with the need for real-time support, which comes out as these networks may be used for control and monitoring applications. This results in a periodic soft real-time traffic that requires a way to enforce a minimum data delivery speed so as to meet delay constraints.

Low-power processors and very small memories are typically used for nodes in sensor/actuator networks. This, however, does not solve the problem, as the amount of energy consumed by the communications in these networks may be significantly higher than that required for processing.

This fact implies a tradeoff among the frequency spectrum used for the wireless transmission, the transmission range and the power consumption. In particular, the lower the frequency range, the longer the covered distance in a single hop with the same transmission power. Furthermore, if the application allows for a multi-hop network, the path loss dependence from the distance makes this approach more energy efficient with respect to a single hop network.

5.3.5 EMC

5.3.5.1 General

Many kinds of electrical equipment and radio equipment are installed, and sources of radio frequency wave are increasing all over the plant or factory. In plants and factories, cases in which several electrical equipment and radio equipment coexist side by side are increasing.

Electromagnetic compatibility (EMC) includes electromagnetic interference (EMI) and electromagnetic susceptibility (EMS). The effects of EMS shall be examined.

5.3.5.2 Common requirements

It is necessary for the equipment to keep normal performance under some specific electromagnetic environment.

For example, an arc welding machine and a wire electric discharge machine are used for fusion joining metals, or an arc furnace is used for dissolving steel manufacture or specialty steel.

The interfering wave from a welding machine includes both a conduction wave and an emission wave. The wireless system needs to give special consideration to the interfering emission wave. A welding machine is often used for temporary building construction work, and it may cause non-reproducible failure.

It is well known that a microwave oven affects wireless LAN system in the home environment. Similar disturbances can be observed when microwave machines are used e.g. in the sterilization process in a food processing plant.

Before using a wireless system it is necessary to conduct a site survey in order to identify whether there are noise sources. Then, if noise sources are identified, the following actions shall be taken into account during the design of the wireless system and its configuration.

- Design of wireless network and locations for wireless equipment.
- Selection of radio frequency and its power.
- Installation of shields for the identified noise sources.

These actions shall be part of the coexistence management according to IEC 62657-2.

5.3.6 Functional safety

5.3.6.1 Common requirements

The common requirements describe the very strict requirements for the field, i.e. at the plant layer “sensor/actuator”. Signals for functional safety of machines and systems are being transmitted more and more over networks. Functionally safe communication can be implemented not only over networks using cables, but also over wireless paths. This allows one to extend the communication to mobile parts and thus solve important issues as the one described in the use case in 5.2.2. For example, functionally safe communication can be established between the central system controller and a safety input/output module on a mobile transport system. The implementation of a functional safety communication is usually based on the use of a safety transmission protocol whose safety mechanisms are independent of the transmission physics. Functional safety communication profiles (FSCPs) for fieldbuses are specified in IEC 61784-3.

Any wireless network is susceptible to interference and less than 100 % reliable even if it uses a harmonized or exclusively-licensed band. Suitable measures shall be part of the equipment to prevent accidents caused by the failure of a wireless link.

5.3.6.2 Additional requirements for specific applications

The issue here is that for each specific application the safety communications shall not be executed with delays beyond the time limits that are specified for that application. Beyond those time limits, the lack of information would result in a serious safety problem for the personnel and the machinery, or would result in a safe state, that means the loss of normal operation.

For the process applications these time limits may generally be in the range from 100 ms to several seconds over a large area. For the factory automation these time limits may generally be in the range of milliseconds over a small area.

As clarified for the use cases described in 5.2, a compromise here is not acceptable: missing the functional safety requirements may result in loss of production, and above all in physical harm to people or loss of human life.

5.3.7 Security

5.3.7.1 General

A secure network system keeps confidentiality, integrity, and availability. Wireless systems are faced with unauthorized access or eavesdropping. These threats may happen due to inappropriate operation and unintended accident. A wireless network is more likely to be exposed because the medium of wireless communication is air and it can be accessed more easily compared to wired media.

Adequate design and preparation are required in order to keep a wireless network secure and trustworthy. At first, it is productive to consider security within each network level and protocol layer in a plant or a factory. After that the solution is the usage of a logical conduit according to IEC 62443, which already ensures security between layers. Security considerations shall be applied throughout the entire wireless system life cycle.

5.3.7.2 Access control

Access control is an important function to protect against invasion by unauthorized access. Access control shall be in place to manage the user account and wireless equipment.

The credentials associated with the user account shall determine the role and authority for that user account. Management of a unique ID depending on each equipment or device for joining a network system securely is recommended.

5.3.7.3 Encryption

A secure wireless system shall use encryption techniques. There are many kinds of encryption technologies and specifications. The appropriate selection shall be done according to the confidentiality requirements. A key shall be used for joining a network securely when new equipment and devices are installed.

5.3.7.4 Key management

When setting up an industrial wireless network, the cryptographic keys for later secure communication shall be set up. The established keys shall be resilient to attacks and flexible to dynamic update.

Key management can be described as static and dynamic. The static schemes assume a static and short-lived network.

The dynamic schemes assume long-lived networks, and adopt dynamic re-keying for sustained security and survivability. There are other key classifications such as symmetric or asymmetric.

Only trusted devices shall be allowed to join a network. A key management scheme shall support the joining and leaving of devices in the network. The joining process can be done manually or automatically. Each device can be pre-installed with a private key which supports its authentication with the authentication server.

5.3.7.5 Other considerations

Jamming interferes with proper communication. Countermeasures should be established to guard against someone entering areas near a wireless system (physical security), or to hide the presence of wireless system itself (e.g. Faraday cave).

5.3.8 Availability, reliability

The availability and reliability of the wireless network shall meet with the requirements of the application.

The communication protocols shall provide reliable data communication, and preserve the determinism of real-time data communication. In cases of fault, removal, and insertion of a component, communication protocols shall provide deterministic recovery times.

The reliability of a wireless communication network can be increased by channel hopping to provide a level of immunity against interference from other RF devices operating in the same band, as well as robustness to mitigate multipath interference effects. In addition, the use of selective channel utilization facilitates coexistence with other RF systems by detecting and avoiding using occupied channels within the spectrum. Selective channel utilization can also enhance reliability by avoiding the use of channels with consistently poor performance.

The required availability can be achieved by

- increasing reliability of the elements,
- improving maintenance and
- using redundancy.

Plants rely on the correct function of the automation system. Plants tolerate a degradation of the automation system for only a short time, called the grace time. The network recovery time should be shorter than the grace time since the application typically needs to perform additional tasks (related to protocol and data handling, waiting for the next scheduled communication cycle, etc.) before the plant is back to the fully operational state. Applications can be distinguished by their grace time, as Table 4 shows.

Table 4 – Examples of application grace time

Applications	Typical grace time s
Uncritical automation, e.g. enterprise systems	20
Automation management, e.g. manufacturing, factory automation	2
General automation , e.g. process automation, power plants	0,2
Time-critical automation, e.g. synchronized drives	0,020

Some plants have stricter requirements when they are required to operate continuously, having no idle period during which the plant may be maintained or reconfigured. In this case, the grace time holds for the stricter requirement, for instance dictated by the hot-swapping of parts of the equipment.

Automation systems may contain redundancy to cope with failures. Methods differ on how to handle redundancy, but their key performance factor is the recovery time, i.e. the time needed to restore operation after occurrence of a disruption. If the recovery time exceeds the grace time of the plant, protection mechanisms initiate a (safe) shutdown, which may cause significant loss of production and plant operational availability.

NOTE 1 Even though safety is not directly addressed, high reliability is a desirable feature in a safety system.

A key characteristic of recovery is its determinism, i.e. the guarantee that the recovery time remains below a certain value as long as the basic assumptions (single failure at a time, no common mode of failure, less than maximum system extension) are met.

Redundancy within the network considers the presence of more network elements than necessary for operation, in order to prevent loss of communication caused by a failure. To this effect, more than one path between any two end nodes shall be used.

It is possible to construct a nearly infinite range of topologies from the nodes and functions.

Examples of redundant topologies are:

- meshed network (providing multiple path interconnecting field devices);
- parallel network (by using the same spectrum or different spectrum).

According to the requirements of the availability of the wireless communication network the redundancy modes should be selected.

- Backup mode

  In the backup mode, only one of the redundant paths is selected as on-service while the other paths are on stand-by.

  If the on-service path becomes unavailable, one of the paths that is on stand-by backs it up.

  During the elapsed time from the loss of the on-service path to the beginning of the operation of the backup path, messages can be lost, therefore the channel is considered in a disconnected state.

  NOTE 2 In IEC 60050-191:1990, 191-15-03, this kind of redundancy is named “stand-by” or “passive” redundancy. The term “dynamic redundancy” is also used.

- Alternate (active) mode

  In the alternate mode, redundant paths are used alternately, at random or according to regular patterns.

If it is detected that one of the redundant paths is in a disconnected state, that path stops being used while other paths continue being used alternatively.

This mode allows checking the availability of the components continuously and therefore increases diagnosis coverage.

- Parallel (active) operation

  In the parallel operation, messages are transmitted via all available redundant paths.

  The receiving end node selects one of the received messages.

  NOTE 3 The term “static redundancy” or “work-by” is also used.

Faults are detected through error detection mechanisms that detect only a percentage of the faults. The coverage is the probability that diagnosis mechanisms detect an error within a time that allows recovery before other mechanisms take action to protect the plant or before the plant suffers damage.

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