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Requirement Profiles in ZDKI

Technical Group 1

“Applications, Requirements and Validation”
of the Accompanying Research – Reliable wireless communication in industry (BZKI) in the BMBF Funding Programme “ICT 2020 – Reliable Wireless Communication in Industry” (ZDKI)

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1 Purpose of the document

This document describes a methodology for formal specification of requirement profiles for reliable wireless communication. Starting with a general approach, elements and attributes for description of profiles are defined. Requirement descriptions from the literature, from technical committees and from standardization organizations were analysed and, with the aid of the profile description, requirement profiles were specified. The requirements of the collaborative projects in the BMBF funding programme “ICT 2020 – Reliable Wireless Communication in Industry” were taken into account on the basis of published documents.[1] On that basis, the collaborative projects were assigned to the specified requirement profiles. The target parameters and their value ranges were thus defined more closely for the individual collaborative projects. Demarcations and market segments addressed thus become visible.

This document is also the basis for a general validation strategy for the radio solutions examined and their component parts.

2 Definitions, abbreviations and symbols

2.1 Definitions

2.1.1 Requirement profile

Semi-formal description of the requirements of a use case (type or class) with low granularity, with the aid of a quantity of influencing parameters and characteristic parameters whose values or value ranges are simultaneously valid.

2.1.2 Requirement specification

Formal or semi-formal description of an application (instance or object) with high granularity, with the aid of a quantity of influencing parameters and characteristic parameters whose values or value ranges are simultaneously valid.

2.1.3 Use case

Informal description of a class of applications.

2.1.4 Application profile

Semi-formal description of use cases with the aid of application-related influencing parameters.

2.1.5 Environmental profile

Semi-formal description of the environment of an application with the aid of environment-related influencing parameters.

2.1.6 Ability profile

Formal description of a communication system with the aid of a quantity of application-related, equipment-related and system-related influencing parameters and characteristic parameters whose values or value ranges are simultaneously valid.

1 The present version does not yet specify requirement values for the profiles of all parameters. These are to be added gradually in the course of the project work following publication of the methodological procedure in the ZDKI group.

2.2 Abbreviations

BMBF	Bundesministerium für Bildung und Forschung (Federal Ministry of Education and Research)
CEPT	European Conference of Postal and Telecommunications Administrations
EIRP	Equivalent Isotropically Radiated Power
ICT	Information and Communications Technologies
ISM	Industrial, Scientific and Medical Band
LOS	Line of Sight
NLOS	Non Line of Sight
OLOS	Obstructed Line of Sight
SIL	Safety Integrity Level
ZDKI	Reliable Wireless Communication in Industry

2.3 Symbols

A	Availability
$ai(to)$	Availability in observation time
c	Correctness
Co	Data content
Me_{Rxi}	Message received
Me_{Zxi}	Message transmitted
MLR	Message loss rate
N_{LP}	Number of lost messages
N_{RM}	Number of received messages
N_{Rx}	Number of correctly received messages
N_{Tx}	Number of transmitted messages
SN	Sequence number
T_{Tmax}	Maximum limit of transmission time
to	Observation time
t_R	Response time
t_T	Transmission time
t_{TI}	Transfer interval
t_U	Time of error-free data transmission

3 Concept

3.1 General

Requirements for radio communication systems are needed in various phases of the product and system life cycle. In the research into fundamental processes, algorithms and system modules such as is conducted in the collaborative projects in the BMBF funding programme “ICT 2020 – Reliable Wireless Communication in Industry”, the degree of detail and accuracy required is not the same as that in the planning of a real individual system. Even the scope of a requirement specification for product development is not needed. Nevertheless, value ranges or sets of values are to be specified for key parameters which are to be achieved by the radio systems into which research is conducted. A common understanding of the meaning of central terminology is absolutely essential for the exchange of technical information between the collaborative projects. Furthermore, the clarification of categories and the relationships between them assists in the understanding of simultaneously achievable values of parameters and mutually exclusive limits.

In the following sections, the sub-systems to be taken into account in a requirement description are first discussed. Section 4 describes how profile specifications can be developed on that basis. Relevant parameters which are to be used for the profile specification are then collated. As the profile specification is an abstract of a large number of concrete individual cases, the parameters used for it are also abstracted. In this way, a logical device stands for the initiation of the communications processes of a distributed application function with a logical end point. That is the abstraction of physical devices which can implement several logical devices, each with a different number of application functions and a different number of logical end points.

Using the parameters, application profiles for the ZDKI collaborative projects are specified in section 10, and environmental profiles in section 10.7. These are grouped together into requirement profiles in section 11.3.1, and the assignment to the ZDKI collaborative projects is made in section 14. Finally, the specification of ability profiles is dealt with in section 13.

Where appropriate, attention is drawn to the possibility of more detailed specifications.

3.2 Wireless industrial automation

In the context of reliable wireless communication in industry, an automation application is characterized by the spatial distribution of application functions (detection, measurement, and open and closed loop control) (Figure 1).

Wireless communication functions of a radio communication system are to ensure cooperation between the application functions for optimum performance of a production process.

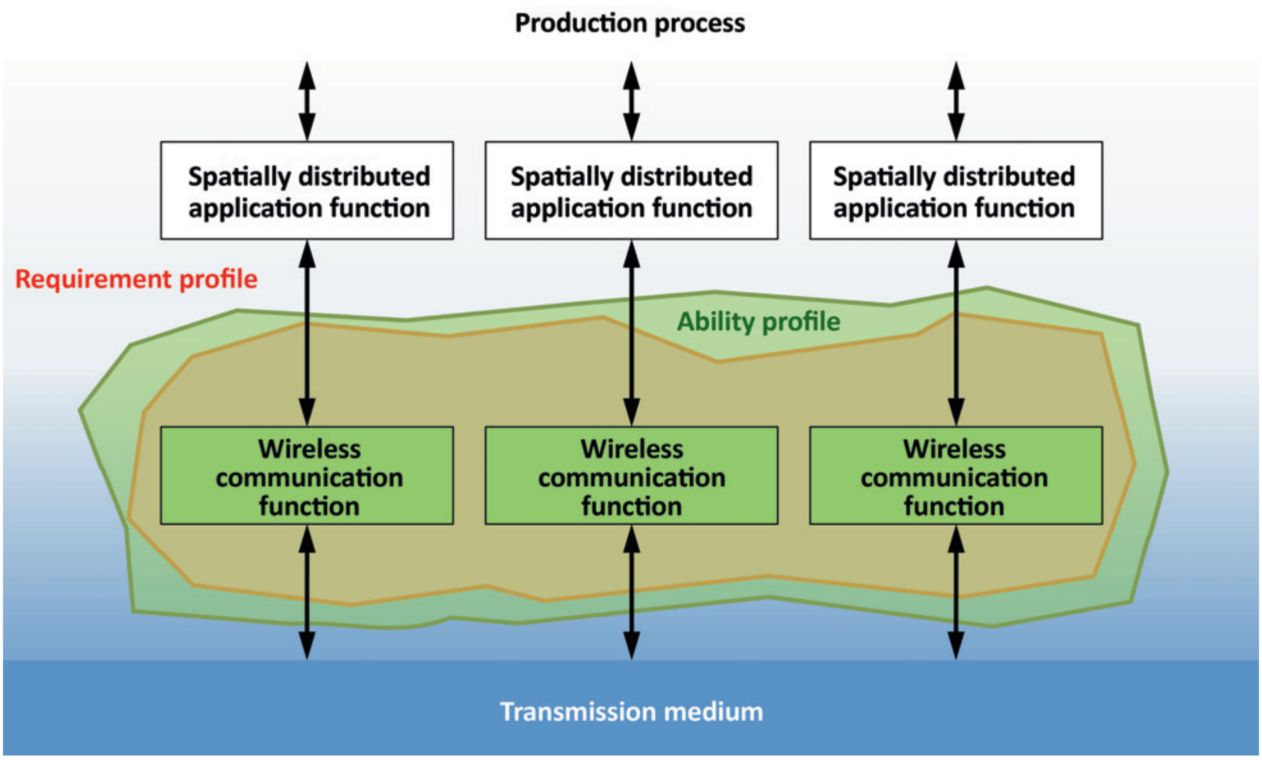

Figure 1: Requirement profile of a spatially distributed automation application covered by the ability profile of a wireless communication system

The spatial distribution of the application functions results from the production process. The production process and its environment also determine the requirements for the wireless communication system. These requirements are to be described with the aid of requirement profiles. A requirement profile is the quantity of required values for a defined set of parameters. The quantity of assured values in that parameter set and the parameters of the radio communication system constitute the ability profile.

The decision as to whether a wireless communication system fulfils the requirements of an automation application can be facilitated by comparing the requirement profile and the ability profile. Figure 1 shows graphically that the requirement profile of a spatially distributed application is covered by the ability profile of a radio communication system.

As the first step towards the derivation of profile descriptions, the area under consideration in radio-assisted industrial automation as presented in Figure 1 is described with the aid of a class diagram (Figure 2).

The class of "wireless industrial automation" is composed of the sub-classes "distributed automation application", "radio environment" and "wireless communication system". Between the sub-classes there are relationships which will be specified in the further course of the deliberations. Furthermore, the "wireless industrial automation" has an interface to the production process, which is not of direct relevance to the following observations and will therefore not be taken into account here.

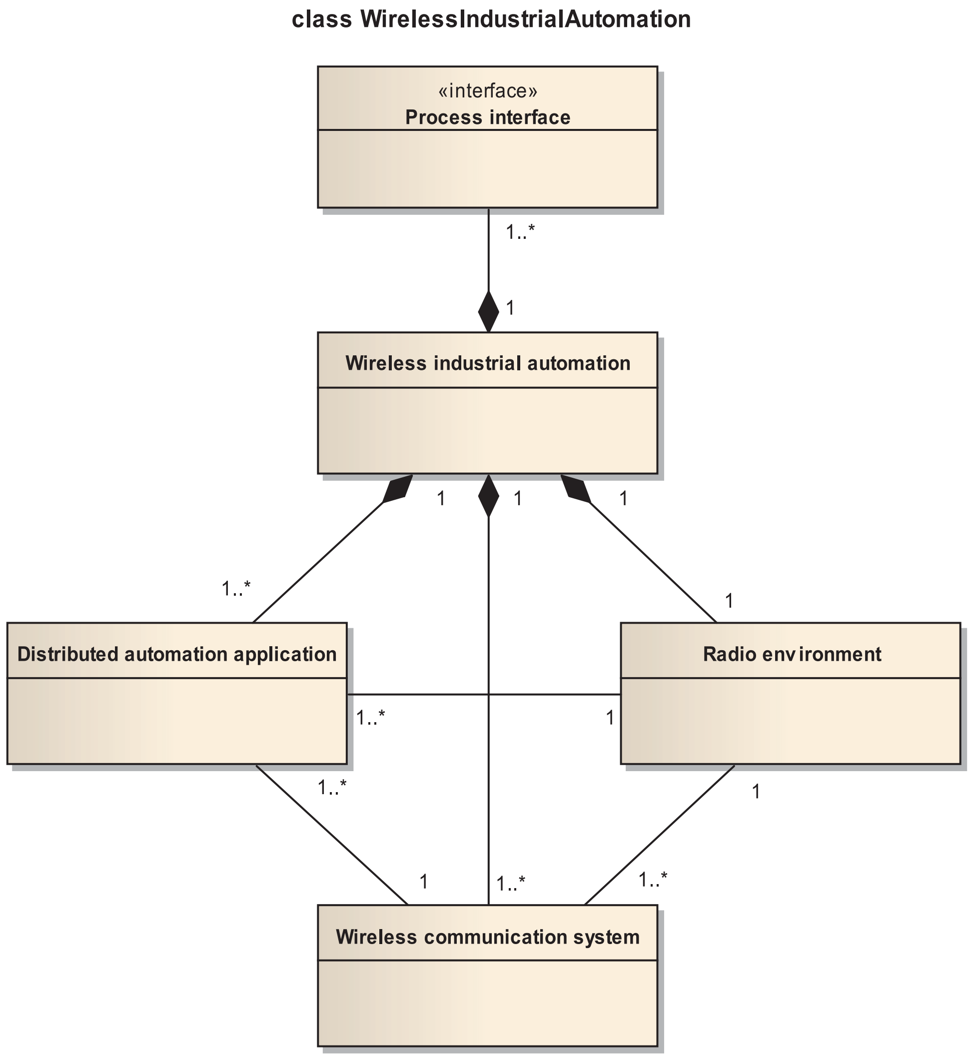

Figure 2: Class model of the area under consideration in radio-assisted industrial automation

3.3 Distributed automation application

Figure 3 presents an abstract view of a distributed automation application as a system model. The distributed automation applications are elements of the system and their relationships constitute logical links. These logical links are to be mapped to physical links in a communication system. The application function has an interface for that purpose. As all time and error characteristic parameters refer to that interface, it is known as the reference interface. The distributed automation application is specified with the aid of relevant attributes which also include attributes of the application function, the logical link and the reference interface.

The process interface is included for the sake of completeness only.

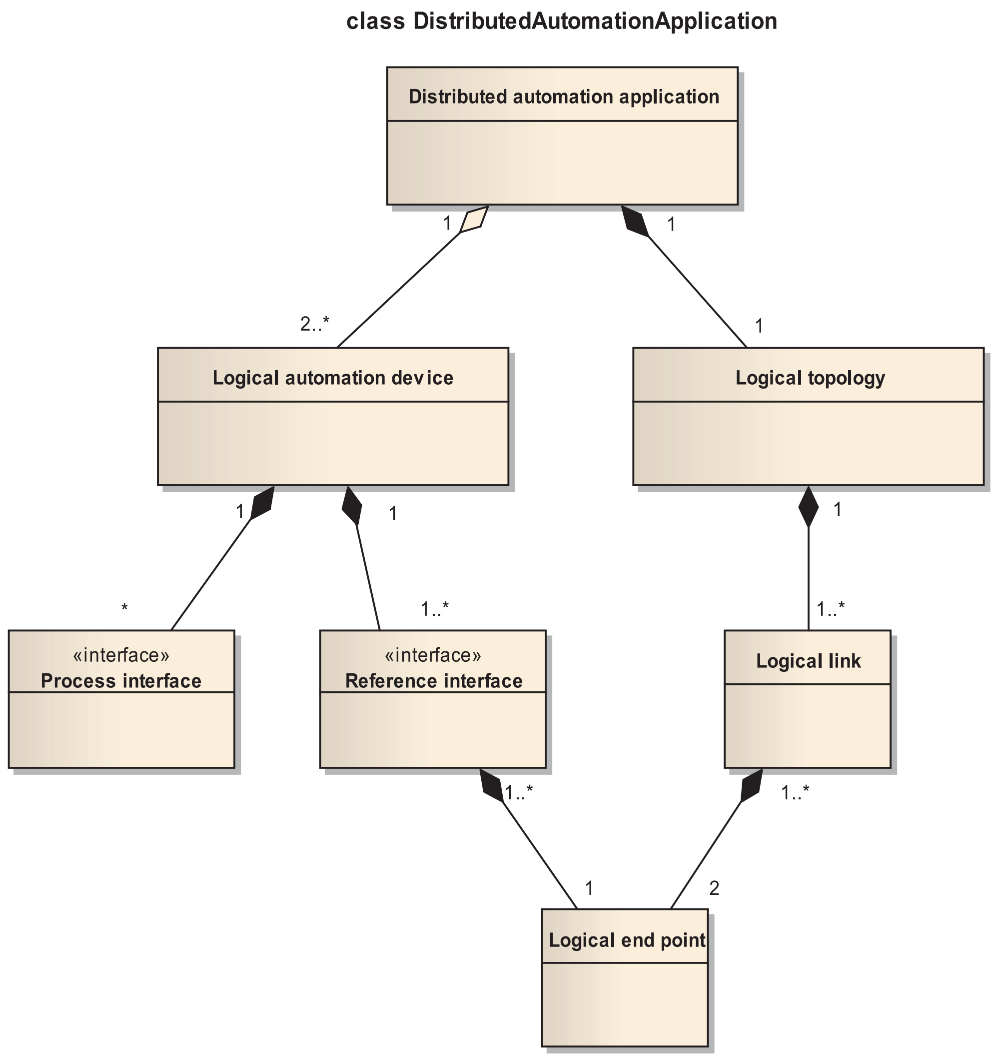

Figure 3: System model of the distributed automation application

3.4 Wireless communication system

Figure 4 shows an abstract model of a wireless communication system. The wireless communication function and the network function are elements of the system. Both elements have a virtual radio interface to the wireless environment. The physical link uses that interface to establish a relationship between wireless communication functions and network functions. This physical link implements the transmission necessary for a logical link.

For that purpose, the wireless communication function has a reference interface to the distributed application function.

The wireless communication system is specified with the aid of relevant attributes which also include attributes of the wireless communication function, the network function and the physical link.

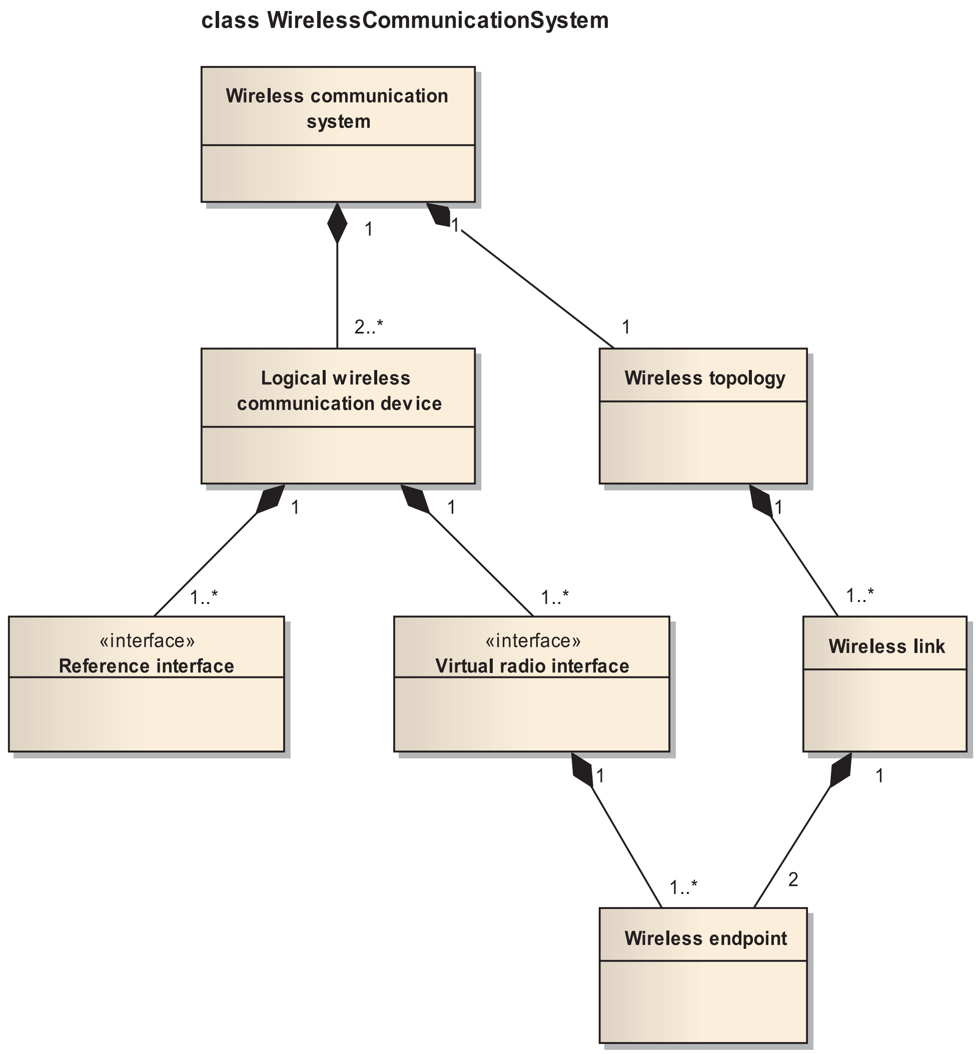

Figure 4: System model of a wireless communication system

3.5 Radio environment

Figure 5 shows a system model of the radio environment. The relevant elements are active and passive environmental influences. Passive environmental influences characterize the propagation conditions of the electromagnetic waves. The passive environmental influences have a link via an external interface to the wireless communication system. That interface is known as the virtual radio interface.

The active environmental influences constitute radio signals which are apt to impede wireless communications. These can be other wireless communication systems or other radio applications, e.g. ISM applications. The active environmental influences have a relationship with the passive environmental influences, and, on a higher level, with the wireless communication system which uses the radio environment.

The radio environment is specified with the aid of relevant attributes which also include the attributes of the passive and active environmental influences. These include attributes of the virtual radio interface, the propagation conditions, other wireless communication systems and other radio applications.

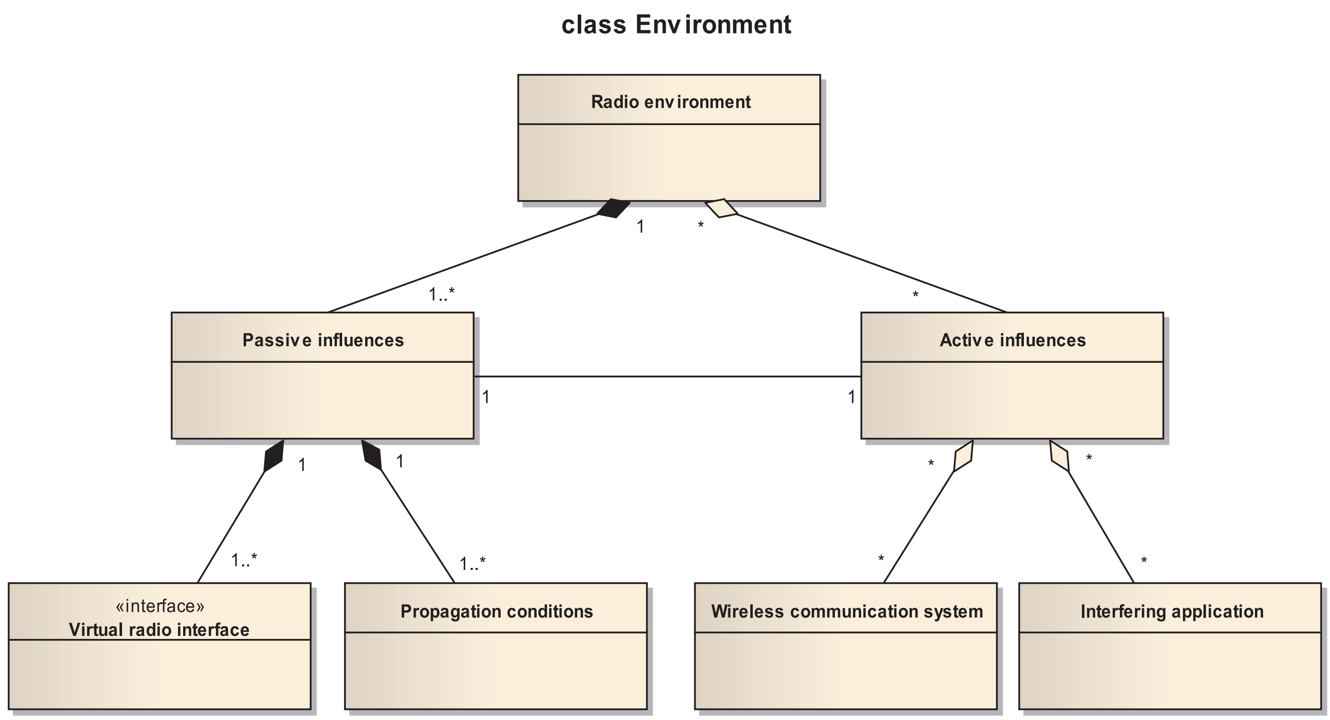

Figure 5: System model of the radio environment

4 Profiles

In this section, with the aid of Figure 6, the relationships between the various parameter sets and profiles and the requirement specification are discussed.

Starting with the parameter sets with which distributed automation applications and radio environments are described, application profiles and radio environment profiles can be deduced. Account is taken in that process of the fact that application-related parameters such as the spatial distance have an effect on the radio environment.

The quantity of all the required values or value ranges for the parameters of time and error characteristics, for the application profile and the radio environment profile, form the requirement profile. It is to be noted that all the values apply simultaneously. This means that it is not a question of setting out maximum requirements for individual parameters, but rather of developing the wireless communication solution with a view to the entire set of values.

The ability profile comprises the quantity of all assured values and/or value ranges for the characteristic parameters and profiles, with the wireless communication solution being defined by a large number of assured parameter values. These parameters may be product characteristics or configuration parameters.

The values for the time and error behaviour of the wireless system (characteristic parameter values) are closely dependent on the values of the parameter sets and profiles, and are therefore only valid in combination with the latter. The characteristic parameters, parameters in the parameters sets and profiles are described below.

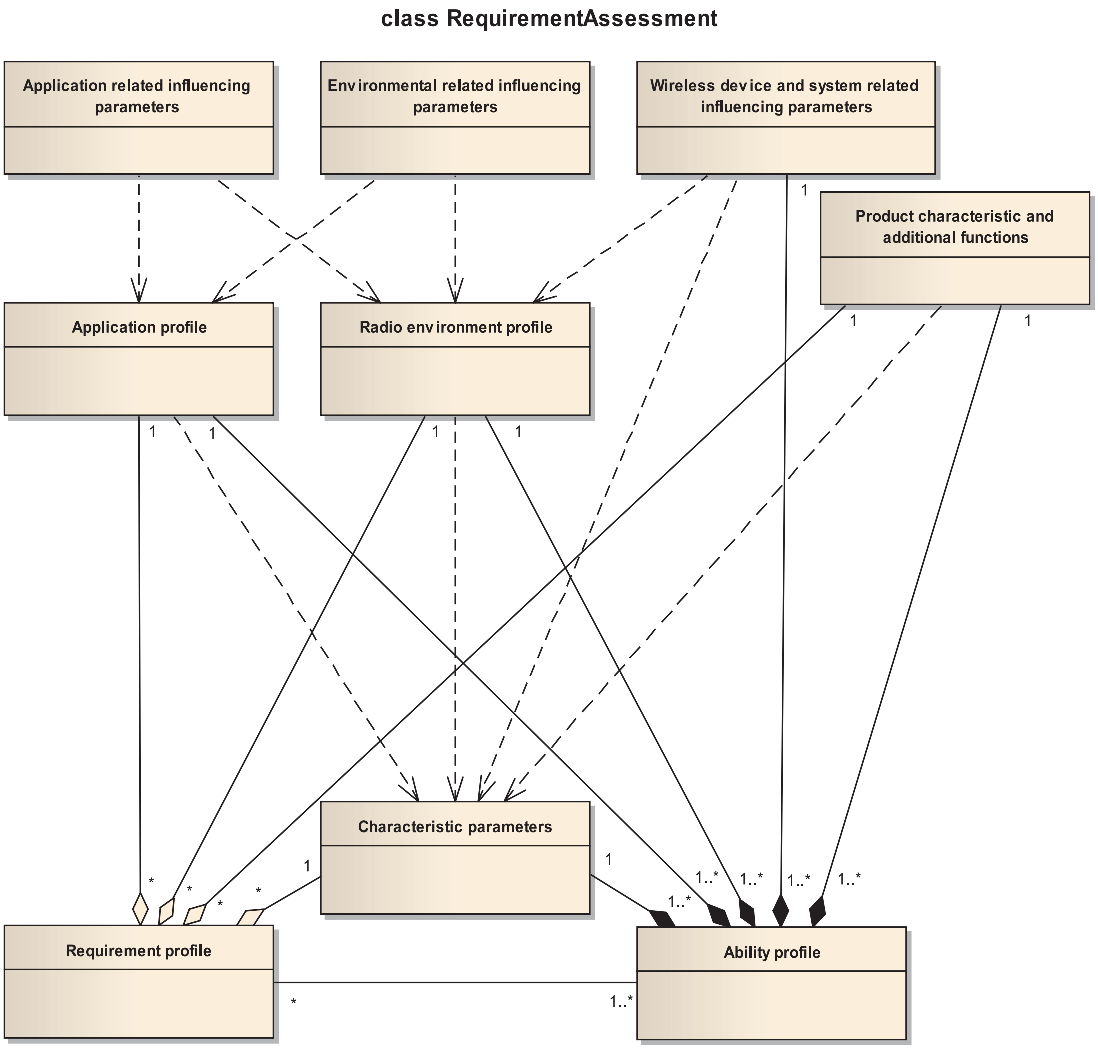

Figure 6: Relationships between various parameter sets and profiles for the requirement specification for wireless communication

5 Characteristic parameters

5.1 Explanatory notes

The characteristic parameters for description of the time and error behaviour of wireless systems must have a relationship with the automation application. Parameters such as the bitrate of radio transmission, transmission power or bit error probability have no meaning for the application. They can be drawn upon for individual components of the wireless communication system. An extrapolation of the effects on the characteristic parameters would then have to be performed.

The characteristic parameter values are determined in relation to the reference interfaces of the logical automation devices involved. As the characteristic parameter values exhibit statistical fluctuations, suitable statistical parameters are used for evaluation. These parameter values are dependent on the scope of sampling and/or on the observation time. Consequently, those factors are also to be stated.

Characteristic parameters from [3] as set out below are used for an unequivocal assessment of the time and error behaviour of wireless solutions.

The variables which have an impact on the values of the characteristic parameters mentioned above are examined in sections 6, 6.4 and 8.

5.2 Transmission time

The transmission time is a fundamental characteristic parameter which can be used for assessment of the availability and real time capability of a wireless system. In that context, it is of interest to know how long the transmission of user data from the source (e.g. a sensor) to the target (e.g. a controller) takes. A uniform understanding of this period of time requires precise stipulation of the start and end of measurement. According to [3], the transmission time is the period from handover of the first discrete component of the user data (bit or octet) at the interface between the application and wireless communication of a source and the handover of the last discrete component of the same user data at the interface between the wireless communication and application of a target (see Figure 7). The type of the interface between the wireless communication and application and its characteristics are always to be stated on publication of the characteristic parameter values, as there is no standardized application interface. In Figure 7, the arrows are waiting times until transmission or processing. The boxes are time slots for transmission or processing.

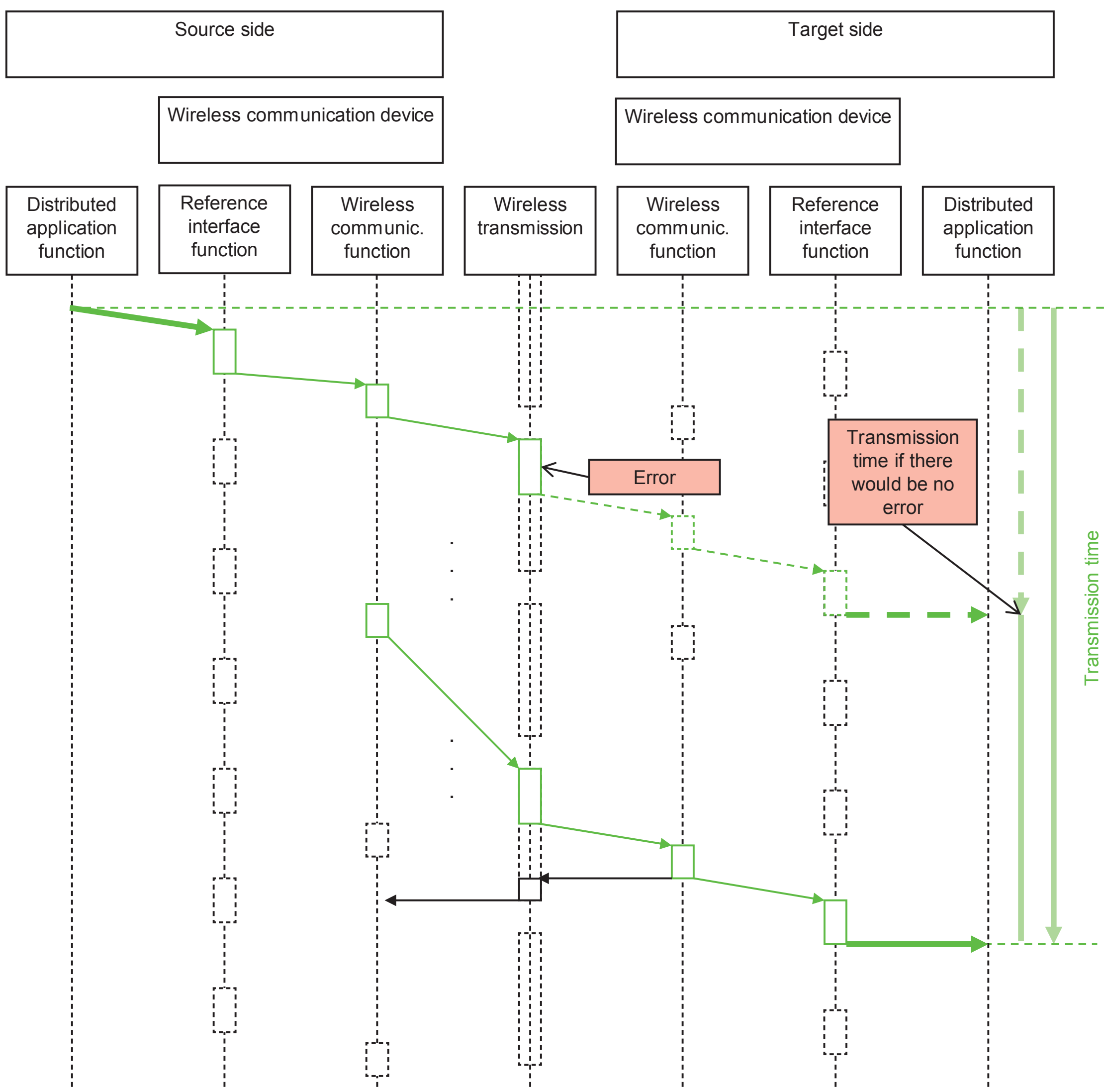

Figure 7: Definition of transmission time

The transmission time is suitable as a characteristic parameter for real time capability, especially for applications with an aperiodic communication requirement. The time of provision of the user data at the target can be assessed independently of the time between two transmissions. The transmission time can also be used for assessment of the availability.

As shown in Figure 7, the values for transmission time fluctuate. They cannot fall below a certain minimum, but mostly adopt a value close to that minimum. The value which occurs most frequency, the modal value, is better suited than the mean value as a measure of tendency for the transmission time. A sensible spread parameter for the transmission time is percentile P95, the maximum value for 95% of all transmissions. The maximum value for the transmission time can be greater than the modal value by powers of ten, and is therefore unsuitable as a parameter for assessment.

5.3 Update time

In an ideal case, the update time is equal to the transfer interval (see Figure 8). That means that the user data transmitted is taken on at the reference interface of the target in the same intervals as it is handed over at the reference interface of the source. The update time is defined as the period from handover of the last discrete component of the user data from a source at the reference interface of a target and handover of the last discrete component of the directly following user data transmitted by the same source. In Figure 8, the arrows are waiting times until transmission or processing. The boxes are time slots for transmission or processing.

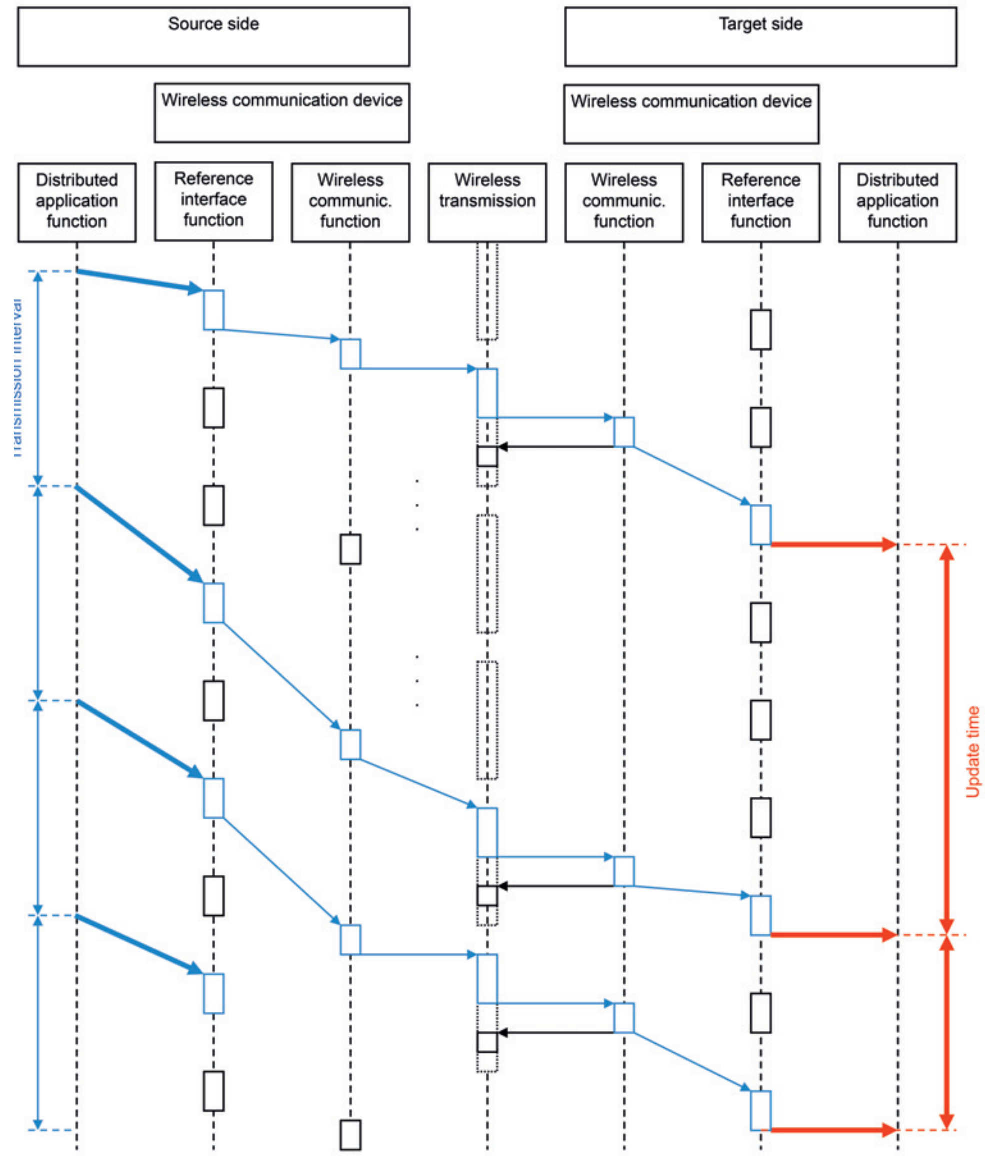

Figure 8: Definition of update time

The update time is especially suitable for assessment of the timeliness and the determinism of applications with a periodic communication requirement.

As shown in Figure 8, the values of the update time fluctuate. On average, the value of the update time corresponds to that of the transmission interval. The mean value of the update time is therefore suitable as a measure of tendency. Statement of the standard deviation is appropriate as a spread parameter.

5.4 Start-up time

A further interface of the wireless communication system, the power supply, is used for determination of the start-up time. The start-up time is defined as the period between switch-on of the wireless communication system or triggering of the reset function and achievement of a steady state.

The starting event for measurement on switch-on of the wireless communication system is the achievement of a steady level of rated voltage at the radio devices. On triggering of a reset function, a start signal is to be provided by the wireless communication system.

The steady state is specified as the correct receipt of 10 successive data transmissions at the reference interface of the target.

The start-up time is used for assessment of real-time capability, especially after temporary disturbances or on short-term departure from the state of coexistence.

The same statistical parameters as for the transmission time are suitable for assessment of the start-up time.

5.5 Data throughput

The data throughput is the number of user data transmitted per unit of time at the target from the communication function to the application function. The data throughput is important when large quantities of data, such as large parameter records, programs or files are transmitted.

On average, the value for data throughput corresponds to the quotient of the user data length and transfer interval. The mean value of the data throughput is therefore suitable as a measure of tendency. A statement of the standard deviation is appropriate as the spread parameter.

5.6 Number of correctly received messages

A message Me_{Rxi} is deemed to have been received when it has been handed over to the application at the reference interface of the target. The number of received messages (N_{RM}) results from the following equation:

$$N_{RM} = \sum_{i=1}^{n} Me_{Rxi} \quad (1)$$

As, however, falsifications of the contents and repetitions of the transmission which are not identified or corrected by the error protection mechanism can occur, the data received are to be checked for these. Promptness is also one of the conditions for a correctly received message. Consequently, the definition of correctly received messages presented below takes account of the data content (Co), the sequence number (SN), the transmission time t_T (Me_{Rxi}) and the addresses (Ad).

$$N_{RM} = \sum_{i=1}^{n} Me_{Rxi} \quad (2)$$

$$where \begin{cases} c(Me_{Rxi}) = 1, if\ Co(Me_{Rxi}) = Co(Me_{Txi}) \wedge SN(Me_{Rxi}) > SN(Me_{Rxi-1}) \wedge t_T(Me_{Rxi}) \leq T_{Tmax} \\ \wedge\ Ad_{SCR}(Me_{Rxi}) = Ad_{SCR}\ \wedge\ Ad_{TGT}(Me_{Rxi}) = Ad_{TGT} \\ c(Me_{Rxi}) = 0, else \end{cases}$$

N_{Rx} consequently designates the number of correctly received messages, to which the following applies:

- The content of the received data Co (Me_{Rxi}) agrees in a bit comparison with the content of the transmitted data Co (Me_{Txi}). There are no bit errors or symbol errors. The correctness of a received message is designated as C (Me_{Rxi}). A simple CRC test is not sufficient in this respect.
- The sequence number of each received message SN (Me_{Rxi}) must be greater than the sequence number of the previously received message SN ($Me_{(Rxi-1)}$). Messages which have been overtaken are therefore assessed as false.
- The value of the transmission time t_T (Me_{Rxi}) must be smaller than a specified limit T_{Tmax}
- The address of the source Ad_{SCR} (Me_{Rxi}) in the message must be identical to the source address of the logical link. The parameters by which the address is defined (node addresses, port, end point) depend on the relevant request.
- The address of the target Ad_{TGT} (Me_{Rxi}) in the message must be identical to the target address of the logical link. The parameters by which the address is defined (node addresses, port, end point) depend on the relevant request.

Depending on the requirements, the formula may be adapted or further parameters (e.g. update time) added. If a message is correctly received, the system is in the up state. A detailed information about more message types are in [8].

5.7 Number of lost messages

A message is deemed to be lost when user data handed over at the reference interface of the source are not handed over at the reference interface of the target.

The number of lost messages is used in the assessment of availability and calculation of the message loss rate.

5.8 Availability

The availability (A) is a measure of the ability of a unit to perform a required function during a given period of time. Applied to the function of a wireless communication system, the availability (A) is the ratio of the time of error-free data transmission (uptime: t_U) to an observation time (t_O):

$$A = \frac{t_U}{t_O} \quad (3)$$

Assuming that the source transmits a number of packets N_{Tx} periodically within the observation time t_O with a transfer interval t_{TI} and that the wireless system is considered to be error-free for the time of the transfer interval for each packet received, the availability can be determined as follows:

$$A = \frac{N_{Rx} t_{TI}}{N_{TX} t_{TI}} = \frac{N_{Rx}}{N_{TX}} \qquad (4)$$

For any observation time t_{Oi}, the dependence of the availability ai on the number of lost packets N_{LP} can be represented as follows:

$$a_i(t_O) = \frac{\Delta N_{Rxi}}{\Delta N_{TXi}} = \frac{\Delta(N_{Txi} - N_{LPi})}{N_{TXi}} = 1 - \frac{\Delta N_{LPi}}{\Delta N_{TXi}} = 1 - \frac{\Delta N_{LPi} t_{TI}}{\Delta N_{TXi} t_{TI}} = 1 - \Delta N_{LPi} \frac{t_{TI}}{\Delta t_{oi}} \qquad (5)$$

The equation in formula (5) makes it clear that the relationship between the transfer interval and the observation time is of importance. The closer the observation time approximates to the transfer interval, the more detrimental are the effects of packet losses on the availability. On the other hand, with a long observation time, accumulated packet losses and therefore temporary drops in availability are not detected.

5.9 Message loss rate

Message loss ratio (MLR) is, according to [2] IEV 371-08-07, the ratio of the number of lost messages to the total number of messages sent.

$$MLR = \frac{N_{LM}}{N_{Tx}} \qquad (6)$$

6 Application-related influencing parameters

6.1 Explanatory notes

In this section, influences which result from the distributed automation application are described. With the resulting influencing parameters, the requirements and conditions from the application point of view can be specified.

A distributed automation application is taken here to mean a system of spatially distributed logical automation devices which have to communicate with each other in order to implement an application.

A logical automation device is the abstraction of the implementation of distributed application functions. Two application functions are assumed for each logical device as the data source, each with a logical end point, the source of a logical connection. One application function initiates periodic communication requests and the other aperiodic communication requests.

6.2 Distributed automation application

6.2.1 Description

A meaningful term or a brief phrase should be selected as the designation for the distributed automation application. A brief description in text form can give an impression of the application and contribute to a better understanding of the necessary communications infrastructure. The environment in which the application is used should also be characterized in a brief text. Photos or plans can assist by illustrating the scenario.

6.2.2 Spatial dimension of the application

The spatial dimension of the distributed application specifies the area in which the logical devices are spatially distributed. This facilitates the estimation of the maximum transmission distances to be overcome and the device density.

The influencing parameter is a list of the values for the length, width and height of the area.

The unit for all values is the metre.

6.2.3 Number of logical automation devices

Together with the spatial dimension, the number of logical automation devices determines the device density of the automation application, and thus its channel occupation. It is assumed in this connection that all devices can be active at the same time.

6.2.4 Distance between logical automation devices

This influencing parameter specifies the maximum distance to be overcome by the wireless transmission of data.

The dimensional unit is the metre.

6.2.5 Relative movement between logical automation devices

This influencing parameter specifies the maximum relative speed between two logical automation devices and their maximum distance apart. It provides an impression of the dynamics of the propagation conditions.

The influencing parameter is a list of the variables of speed in metres per second and distance in metres.

6.2.6 Logical topology

This influencing parameter describes whether a logical automation device transmits user data simultaneously to several other logical automation devices. It can have a value of point-to-point or multi-point.

6.3 Logical automation device

6.3.1 User data length

The user data length specifies the number of information units which are handed over for transmission at the reference interface of the source.

The influencing parameter is a list with a minimum and a maximum value. It is stated separately for the periodic and aperiodic application functions.

The dimensional unit is the bit.

6.3.2 Transfer interval

The transfer interval specifies the period of time between two initiations of data transmissions at the source. A time value is stated for periodic transmission. For aperiodic transmission, a mean value, a standard deviation and a distribution function or limits for a random period can be stated. Aperiodic transmission may also take place once only, for example on start-up.

The unit of time is the second.

6.3.3 Reference interface

For an unequivocal definition of characteristic parameters, reference points to which the characteristic parameter values refer are to be stipulated. From the point of view of an automation application, this is the interface between the distributed application function and the wireless communication function. This interface is known as the reference interface. There are neither recommendations nor standards for the design of a reference interface. Wireless systems provide various serial ports and protocols, and also function or storage interfaces in a physical radio device.

The reference interface can be described with the aid of standard references or by specification of a hardware interface and software services.

6.4 Logical link

6.4.1 Information security

This parameter describes the protection objectives of information security for a logical link, such as authenticity, integrity, confidentiality, availability and non-repudiability.

Information security can be described with the aid of standard references or by a specification.

6.4.2 Functional safety

This parameter describes the functional safety of a logical link, for example as a Safety Integrity Level (SIL).

Functional safety can be defined with the aid of standard references, by standardized levels or by a specification.

7 Environment-related influencing parameters

7.1 Explanatory notes

This section describes influences with which the conditions of the environment in which the wireless communication system is deployed can be specified. In contrast to line-based communication, the operational environment of radio-based communication has an extremely large impact on time and error behaviour. A distinction is made between passive environmental influences and active environmental influences.

Passive environmental influences change the output signal from the transmitter on its way to the receiver. The signal propagation and obstacles reduce the power still available at the receiver. Multi-path propagation resulting from reflections changes the form of the signal, and thus also its amplitude and phase angle.

In the case of active environmental influences, signals from other wireless applications are responsible for changes in the signal from the transmitter at the receiver. The useful signal is overlaid or the receiver is overdriven..

7.2 Passive environmental influences

7.2.1 Characterization of the operational area

The operational area indicates whether the wireless network is used

- inside buildings (indoor),
- outside buildings (outdoor), or
- partly inside and partly outside buildings (indoor/outdoor)

The parameter can adopt one of the values of indoor, outdoor or indoor/outdoor.

The characterization of the operational area can be assisted by technical drawings, sketches or photos. Details of obstacles and reflective surfaces are also helpful.

7.2.2 Dimensions of the operational area

In the case of applications in buildings, the dimensions of the operational area can lead to conclusions as to the propagation conditions. The operational area includes the spatial dimension of the application (section 6.2.2), but can also be larger. That is the case when conditions in the operational area influence the wireless transmission, e.g. by multi-path propagation, moving objects or other radio applications.

The influencing parameter is a list of the values of the length, width and height of the area. The dimensional unit for all values is the metre.

7.2.3 Line of sight

This influencing parameter describes the light of sight between the logical automation devices. It can have the values

- line of sight – LOS,
- non line of sight – NLOS, or
- obstructed line of sight – OLOS.

The disturbance in OLOS is especially a result of obstructions projecting into the Fresnel zone of the radio channel.

7.2.4 Moving objects

This influencing parameter describes the presence of moving objects in the operational area, such as passenger traffic, driverless transport systems, cranes, robots or other large objects which can influence the propagation of the radio signals. The influencing parameter is a list of the values of the number of moving objects and maximum speed. A brief verbal description can be added

7.2.5 Natural ambient conditions

The natural ambient conditions which can influence the propagation conditions include temperature, air pressure and humidity. The influencing parameter is a list of the values of temperature in degrees Celsius, air pressure in bar and relative humidity in %.

7.3 Active environmental influences

7.3.1 Explanatory notes

Specifications of wireless communication technologies and wireless communication standards set down a series of parameter values from which the occupancy of the channels can be estimated. But other radio applications also have to be taken into account as active environmental influences. These include ISM applications which, for example, use high frequency radiation for drying or welding, and also sources of electromagnetic influences such as frequency converters, spark erosion machines or electrical drive motors.

For the active environmental influences, the channel occupation can be described with the aid of the parameters listed below.

7.3.2 Frequency band of the wireless application

The frequency band is the area in the frequency spectrum which is assigned by regulatory authorities to particular wireless applications. It is defined in terms of the lower and upper frequency limits. The influencing parameter is consequently a list of the values of the lower and upper frequency limits. The unit for all values is the hertz.

7.3.3 Frequency channel of the wireless application

The frequency channel is part of the frequency band, which is used by a wireless communication system in accordance with a specification (standard or device specification). A frequency channel is defined by the centre frequency and bandwidth or by lower and upper frequency limits. Specifications of wireless technologies and wireless standards allocate channel numbers to frequency channels for easier identification.

In wireless communication systems which use several radio channels alternately for transmissions, a regulation sets out the use of the radio channels. The maximum dwell time on one frequency channel is also an indication for use in frequency hopping processes.

Modulation methods and mechanisms for adaptively provide information on robustness, channel occupation and the account taken of other wireless communication systems.

7.3.4 Use of frequency spectrum time by the wireless application

The use of the frequency spectrum in terms of time is first and foremost determined by the wireless application. Wireless technologies or standards with addressing and data back-up measures also have an influence on transmitter on time and transmitter off time. The use of channel time can be specified by stating the times concerned or also by the duty cycle.

7.3.5 Transmission power of the wireless application

The transmission power is stated as equivalent isotropically radiated power (EIRP). It is the product of the output power and the antenna gain. With integrated antennas, it is the only accessible power parameter. EIRP is a theoretical value related to an isotropic antenna, an ideal spherical radiator.

The unit is the dB.

7.3.6 Spectral mask of the wireless application

The spectral mask is a graphical description of the maximum values of the spectral power density in relation to the frequency.

8 Device and system-related influencing parameters

8.1 Explanatory notes

The implementation of a wireless communication system determines the time and error behaviour of the wireless communications by device and system-related influencing parameters. The required values of these influencing parameters are not directly demanded by the user, but rather result from the device and system specification. Examples of these parameters for wireless devices are modulation, bitrate of the physical link and medium access control, and for wireless systems security mechanisms, the number of physical wireless links, physical topology and others.

For the listing and definition of these influencing parameters, attention is drawn to [4]. Only two influencing parameters which are of significance for the environmental profile are listed below.

Over and above the influencing parameters, there are further boundary conditions which are to be observed and set down in the ability profile of the wireless system (see section 13).

8.2 Antenna system type

The properties of a radio channel are also determined by the type of the antenna system. Account is to be taken of this type in channel modelling.

This parameter can adopt the following values: omnidirectional antenna, pillbox antenna, PCB antenna, chip antenna, antenna array, slotted waveguide or radiating cable.

8.3 Frequency band of the wireless system

The passive environmental influences are dependent to a great degree on the frequency range in which the radio transmission takes place.

The frequency band is described as a list of the lower and upper frequency limits.

The unit for the values is the hertz.

9 Product properties and additional functions

Apart from the influencing parameters which have a direct effect on the time and error behaviour of a wireless system, there are product properties which should be taken into account in the development of industrial radio devices. These include properties such as the following:

- Energy requirement
- Autarkic energy supply
- Frame size
- Degree of protection
- Usability in potentially explosive atmospheres
- Product price
- Operating costs
- Climate classification
- Temperature range
- Shock and vibration resistance
- Weight

Furthermore, together with automation and communication functions, additional functions may also characterize the wireless system, such as:

- Plug & Play functions
- Functions for graphical display of the communication status to the user
- Functions for communication management
- Functions for synchronization of the distributed applications
- Localization functions

10 Application profiles for ZDKI

10.1 Explanatory notes

The application profile is a set of required values for application-related influencing parameters and characteristic parameters which applies to a class of applications. An application profile is specified by a verbal description and by a table with the set of values for the parameters. The application profiles specified for ZDKI are listed below.[2]

10.2 Machine or manufacturing cell including welding system

This application profile describes the requirements and conditions for machines or discrete manufacturing processes in manufacturing cells. The processes follow a cycle which finally also determines the product output. In consequence, the wireless communication system must be able to serve the communication requirements of that output

2 The topic of availability and reliability is still under discussion in BZKI Technical Group 1. The parameters of “information security” and “functional safety” are the province of BZKI Technical Group 6 and are still under discussion.

reliably. The measurement and control data to be transmitted are short. The number of wireless devices and therefore the number of logical links is modest. Moving wireless devices, for instance in the form of sensors, are possible. The extent of the network corresponds to the size of the machine.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	tbd	s
Update time (t_{UMean}, t_{USD})	tbd	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	-	bit/s
Minimum availability	tbd	%
Maximum packet loss rate	tbd	%
Maximum spatial dimension of the application (length, width, height)	tbd	m
Maximum number of logical automation devices	16	pcs.
Maximum distance between logical automation devices	10	m
Relative movement between logical automation devices (maximum speed, maximum distance)	5 10	m/s m
Logical topology (value from list)	Multi-point	-
Maximum user data length	2 * 8	bit
Minimum transfer interval	$100 * 10^{-3}$	s
Reference interface (value from list)	tbd	-
Information security (value from list)	tbd	-
Functional safety (value from list)	tbd	-

Table 1: Application profile for machine or manufacturing cell including welding system

10.3 Manufacturing workshop including crane and store

This application profile describes the requirements and conditions in a manufacturing workshop. A large number of different wireless devices can be distributed in the workshop and be part of a common network. In consequence, there may be a long distance between two wireless devices. Information on status or measured values is transmitted through each of the logical links as a floating-point number with additional information. Wireless devices on cranes or trolleys are movable. The time requirements mostly result from the reaction times which are to be complied with for the purposes of functional safety.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	tbd	s
Update time (t_{UMean}, t_{USD})	tbd	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	-	bit/s
Minimum availability	tbd	%
Maximum packet loss rate	tbd	%
Maximum spatial dimension of the application (length, width, height)	tbd	m
Maximum number of logical automation devices	50	pcs.

Continuation on following page

Parameter	Value	Unit
Maximum distance between logical automation devices	100	m
Relative movement between logical automation devices (maximum speed, maximum distance)	1,5 100	m/s m
Logical topology (value from list)	Point to point	-
Maximum user data length	64 * 8	bit
Minimum transfer interval	$250 * 10^{-3}$	s
Reference interface (value from list)	tbd	-
Information security (value from list)	tbd	-
Functional safety (value from list)	tbd	-

Table 2: Application profile for manufacturing workshop including crane and store

10.4 Robot arm

Robot arms, for instance in the automotive industry, are as a rule installed in a fixed position but fitted with components which can be rotated and bent in various planes. As a result of the great freedom of movement and constant motion of the individual components, the stresses on the cable harnesses and slip rings are very high. Modern production lines however require fault-free communication – with stringent time requirements in addition. A further aspect is the required flexibility in manufacturing, which leads in some cases to the use of highly complex interchangeable tools. These are incorporated in the communication system of the manufacturing line, meaning that their time requirements fundamentally correspond to those of a wire-based field bus. Apart from normal digital and analogue data, nowadays safety-related I/O data are frequently transmitted through field bus or Ethernet systems (e.g. PROFIsafe). The protocol requires very short latency times, as otherwise the application is stopped for safety reasons.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	tbd	s
Update time (t_{UMean}, t_{USD})	tbd	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	-	bit/s
Minimum availability	tbd	%
Maximum packet loss rate	tbd	%
Maximum spatial dimension of the application (length, width, height)	tbd	m
Maximum number of logical automation devices	2	pcs.
Maximum distance between logical automation devices	10	m
Relative movement between logical automation devices (maximum speed, maximum distance)	6 10	m/s m
Logical topology (value from list)	Point to point	-
Maximum user data length	4 * 8	bit
Minimum transfer interval	$1 * 10^{-3}$	s
Reference interface (value from list)	tbd	-
Information security (value from list)	tbd	-
Functional safety (value from list)	tbd	-

Table 3: Application profile for a robot arm

10.5 High bay store and storage and retrieval vehicles

High bay stores are a fundamental part of contemporary storage logistics. The stores accommodate bins, boxes or pallets, and the storage positions have to be occupied and vacated in a short period of time. Handling is performed by storage and retrieval vehicles which move along the aisles between the bays. A warehouse consists of a large number of aisles with a length of up to 100 m (and more). The bays are typically made of metal, and the radio properties (reflections, shadowing) are highly dependent on the degree of filling and the type of filling of the store. The storage and retrieval vehicles can be controlled by a central PLC. The advantages relative to decentralized stored program controllers on the operator control units are primarily lower costs – but with more stringent timing requirements. In order to avoid drag lines which are susceptible to wear, wireless technology is often used in this application as an alternative to field bus cables. Movement commands are transmitted and acknowledged by radio. Delay times lead to incorrect positioning. The storage and retrieval vehicles simply move past the target position.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	tbd	s
Update time (t_{UMean}, t_{USD})	tbd	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	-	bit/s
Minimum availability	tbd	%
Maximum packet loss rate	tbd	%
Maximum spatial dimension of the application (length, width, height)	tbd	m
Maximum number of logical automation devices	3	pcs.
Maximum distance between logical automation devices	100	m
Relative movement between logical automation devices (maximum speed, maximum distance)	10 100	m/s m
Logical topology (value from list)	Point to point	-
Maximum user data length	64 * 8	bit
Minimum transfer interval	$20 * 10^{-3}$	s
Reference interface (value from list)	tbd	-
Information security (value from list)	tbd	-
Functional safety (value from list)	tbd	-

Table 4: Application profile for high bay stores and storage and retrieval vehicles

10.6 Film wrapper

Film wrappers are a kind of cutting machine consisting of an unwinder, longitudinal cutter and a wrapping station. The cut strips are wrapped alternately on two sides with several wrapping levers. Each wrapping side can contain several wrapping levers which are adjustable in relation to the material travel direction, each of which is fitted with a reel drive motor and a positioning motor.

In addition to the cable carriers, busbars are also used for electricity supply to the machines. In this case, communication can be effected by radio. The transmission usually encompasses position data for control of the reel and cutting mechanisms, which can be moved at a maximum of 10 m/s.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	tbd	s
Update time (t_{UMean}, t_{USD})	tbd	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	-	bit/s
Minimum availability	tbd	%
Maximum packet loss rate	tbd	%
Maximum spatial dimension of the application (length, width, height)	tbd	m
Maximum number of logical automation devices	20	pcs.
Maximum distance between logical automation devices	10	m
Relative movement between logical automation devices (maximum speed, maximum distance)	10 10	m/s m
Logical topology (value from list)	Multi-point	-
Maximum user data length	4 * 8	bit
Minimum transfer interval	$20 * 10^{-3}$	s
Reference interface (value from list)	tbd	-
Information security (value from list)	tbd	-
Functional safety (value from list)	tbd	-

Table 5: Application profile for film wrapper

10.7 HiFlecs profile A

The following use cases can be assigned to the HiFlecs requirement profile A:

- Component handling
  Handling of large components, e.g. from the aviation or shipping industries. Handling is to be performed by several (two to four) driverless vehicles, which each move along their own tracks and are controlled in their relative positions in such a way that no force is applied to the component which is being transported.

- Marriage in automobile manufacture
  Joining of chassis and bodywork. This process requires communication between the vehicle which carries the chassis and the vehicle which carries the bodywork. In the course of the motion, the chassis and bodywork are moved closer to each other so that they can then be bolted together. The positions of these two motions have to be precisely controlled, as deviations can result in damage.

- Shuttles in packaging machines
  In new kinds of packaging machines, one or more rail-guided shuttles transport the material inside machines or between several machines. The position control of the shuttles is to be effected by the wireless system.

The most prominent feature of this requirement profile is a very short transmission time with a maximum data length of over 100 octetts. The time interval between the transmit requests and the number of automation devices are by contrast moderate.

The parameters in table 6 refer to the process data.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	$150 * 10^{-6}$	s
Update time (t_{UMean}, t_{USD})	$5 * 10^{-3}$	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	$200 * 10^{3}$	bit/s
Minimum availability	tbd	
Maximum packet loss rate	$5 * 10^{-7}$, no 2 packets in sequence	
Maximum spatial dimension of the application (length, width, height)	70 x 50 x 10	m
Maximum number of logical automation devices	32	ocs.
Maximum distance between logical automation devices	50	m
Relative movement between logical automation devices (maximum speed, maximum distance)	5 50	m/s m
Logical topology (value from list)	Point to point or point to multi-point	-
Maximum user data length	1024	bit
Minimum transfer interval	$5 * 10^{-3}$	s
Reference interface (value from list)	PROFINET, CAN	-
Information security (value from list)	Authenticity, integrity	-
Functional safety (value from list)	-	-

Table 6: Application profile for HiFlecs A Project

10.8 HiFlecs Profile B

The following use cases can be assigned to the HiFlecs requirement profile B:

- Industrial plant with distributed drive technology
  In an extended plant, 50 to 100 transport axes are equipped with distributed frequency converters and controlled by rotational speed or position. With the radio connection in place of a wire-based field bus system, the installation work can be reduced and simplified, and at the same time the flexibility of the plant can be increased with regard to the topology and spatial arrangement of the machine. With the use of distributed drive controllers, only the wiring of the three-phase mains connection for power supply and possibly a 24V control voltage is necessary.

- Robot cell with product feed and removal through the peripheral axes
  In a plant with robot cells, the robot control and machine control are integrated with approx. 10 to 15 robotic and peripheral axes. The machine can be flexibly combined with shuttles at the periphery of the robot, for instance to perform feed and removal of the products and transport the material to various manufacturing cells. The shuttles make temporary radio contact with the manufacturing cell. When distributed drive controllers are used, it is only necessary to wire up the 3-phase mains connection for power supply and possibly provide a 24 V control voltage.

- Warehousing systems with storage and retrieval devices or shuttle systems
  Automation and drive solutions with horizontal and vertical handling technology are used in the systems. At the periphery, drives for horizontal conveyors are used, although they are not considered further here. In a standard system around 200, but in some cases up to 500, drive motors are mounted decentrally on the moving components of the handling systems, and for the most part move in the aisles between the bays. A handling system consists of 4 – 6 drive axes which are activated by position and/or speed controllers. Shuttles and storage and retrieval devices have fundamentally similar requirements for field bus systems, topology and installation. With the wireless links instead of a wire-based field bus system, retrofitting of the systems in a warehouse is easier.

Apart from the large number of logical links and the large distance between the end points, the large quantity of parameters and other data (100 MByte) which have to be transmitted in a short time (30 s) constitute the major technical challenge. The requirements for the maximum length of process data, the transfer interval and the transmission time are relatively minor.

The parameters in table 7 refer to the process data.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	$1 * 10^{-3}$	s
Update time (t_{UMean}, t_{USD})	$1 * 10^{-3}$	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	$400 * 10^{3}$	bit/s
Minimum availability	tbd	
Maximum packet loss rate	tbd	
Maximum spatial dimension of the application (length, width, height)	1000 x 500 x ?	m
Maximum number of logical automation devices	1000	pcs.
Maximum distance between logical automation devices	500	m
Relative movement between logical automation devices (maximum speed, maximum distance)	6 250	m/s m
Logical topology (value from list)	Point to point or point to multi-point	-
Maximum user data length	400	bit
Minimum transfer interval	$1 * 10^{-3}$	s
Reference interface (value from list)	EtherCAT, CAN	-
Information security (value from list)	Authenticity, integrity	-
Functional safety (value from list)	Typically SIL2, max. SIL3	-

Table 7: Application profile for HiFlecs Profile B

10.9 HiFlecs Profile C

The following use cases can be assigned to the HiFlecs requirement profile C:

- High bay store
  In high bay stores, the individual storage locations are approached automatically by shuttle vehicles for storage and retrieval. The shuttles (1 or more) traverse longitudinally in a warehouse row. The shuttles are controlled by a central PLC which issues traversing commands to the shuttles.

- Robot cells with interchangeable tools (Variant A, Variant B, Variant C)
  In these application scenarios, wireless data transmission is to take place to turntables and robots which were previously connected by slip rings. The major challenges are the torsion movements on robot arms and the change of tools with the tool data connected within the system.

In variant A there is a point to point connection, and the aim is to replace multi-hybrid cables and multiple couplings with wireless communication.

In variant B there is a star topology connection from a central point to several (3-4) robots.

In variant C there is a mesh/tree topology connection from a central point to several robot cells.

Use cases which are assigned to requirement profile C have high requirements for the data length, transfer interval and transmission time of the process data with an average number of subscribers. The subscribers in these applications exhibit a high level of mobility. Speeds up to 10 m/s and distances between the wireless devices of 250 m can be achieved.

The parameters in table 8 refer to the process data.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95})	$0{,}5 * 10^{-3}$	s
Update time (t_{UMean}, t_{USD})	$1{,}5 * 10^{-3}$	s
Response time (t_{RMode}, t_{RP95})	-	s
Data throughput (R_{Mean}, R_{SD})	$3{,}2 * 10^{6}$	bit/s
Minimum availability	tbd	
Maximum packet loss rate	No 3 packets in succession	
Maximum spatial dimension of the application (length, width, height)	250 x 100 x 6	m
Maximum number of logical automation devices	100	pcs.
Maximum distance between logical automation devices	250	m
Relative movement between logical automation devices (maximum speed, maximum distance)	10 250	m/s m
Logical topology (value from list)	Point to point or point to multi-point	-
Maximum user data length	1600	bit
Minimum transfer interval	$0{,}5 * 10^{-3}$	s
Reference interface (value from list)	PROFIBUS, PROFINET	-
Information security (value from list)	Authenticity, integrity, confidentiality	-
Functional safety (value from list)	SIL 1 - 3 (if safety devices or guards are fitted) - Otherwise SIL 4	-

Table 8: Application profile for HiFlecs Profile C

11 Environmental profiles for ZDKI

11.1 Explanatory notes

The environmental profile is a set of required values for influencing parameters which is applicable to a class of environments. The values of the environmental profile are however not only determined by the environment-related influencing parameters, but in part also by application-related and device-related influencing parameters. An environmental profile comprises passive environmental influences and active environmental influences.

11.2 Passive environmental influences

The values of passive environmental influences can be used as a basis for the measurement of a radio channel and the creation of a radio channel model. A radio channel model represents a formal specification of passive environmental influences, which can also be designated a passive environmental profile. As a radio channel model can be used for validation of wireless solutions, it is suitable for assuring a passive environmental profile.

Table 9 shows the value sets for passive environmental influences specified for ZDKI.

The channel model is specified with a value list of the time and frequency-dependent amount and phase of the transmission factor.

Influencing parameter	Profile 1	Profile 2	Profile 3
Characterization of the operational area	Machine, indoor	Manufacturing workshop, indoor	External facility, outdoor
Dimensions of the operational area (length, width, height)	10 m x 10 m x 10 m	100 m x 25 m x 10 m	-
Line of sight	NLOS	OLOS	OLOS
Number and maximum speed of moving objects in the operational area	1 5 m/s	10 1,5 m/s	-
Natural ambient conditions (Maximum temperature, maximum air pressure, maximum humidity)	Indoor climate	Indoor climate	High humidity or precipitation
Maximum distance between logical automation devices	10 m	100 m	1000 m
Relative movement between logical automation devices (maximum speed, maximum distance)	5 m/s 10 m	1,5 m/s 10 m	-
Frequency band (lower and upper frequency limits)	5,8 GHz; 2,4 GHz	5,8 GHz; 2,4 GHz	5,8 GHz; 2,4 GHz
Antenna system (value from list)	Omnidirectional antenna	Omnidirectional antenna	Omnidirectional antenna

Table 9: Passive environmental influences for ZDKI

11.3 Active environmental profile

11.3.1 General

The active environmental influences include wireless communication applications working in the same channel area, ISM applications and electromagnetic interference. The active environmental profiles specified here, also known as interference profiles, are intended to facilitate uniform, application-oriented and reproducible coexistence studies. Starting with industrial coexistence scenarios, the following interference profiles are examined:

- Periodic exchange of process data by Bluetooth
- PROFINET IO communication by WLAN
- Periodic exchange of process data by WISA
- Video transmission by WLAN
- Bluetooth inquire
- WLAN probe request

For the interference profiles of the wireless communication systems, the radio devices involved, the logical links, the user data length and the transfer interval are specified. For the wireless technology used, the use of the medium is described. Other wireless applications (e.g. ISM applications) are described in general terms.

The specifications of the interference profiles can be implemented in a uniform and reproducible manner by real devices, by emulation, or with simulation models.

11.3.2 Periodic exchange of process data by Bluetooth

In the following section, the interference profile for the periodic exchange of process data by Bluetooth is described. In that context, the channel occupation of three parallel Bluetooth wireless communication systems as shown in Figure 9 is considered. The Bluetooth wireless communication system does not have an adaptive frequency hopping (AFH) process. The channel occupation is 10% on average, randomly distributed per frequency channel and between the frequency channels.

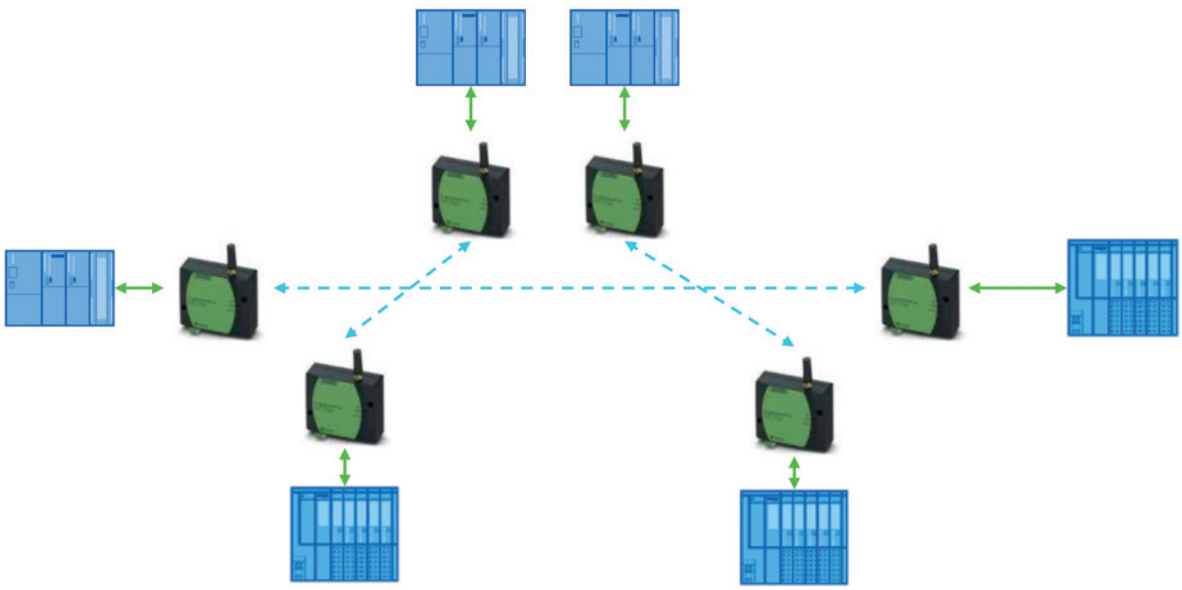

Figure 9: Periodic exchange of process data by Bluetooth

The Bluetooth wireless communication system uses the physical layer defined in IEEE 802.15.1 [7]. The spectral mask with the limits as set out in [7] is presented in Figure 10, with the Figures referring to a resolution bandwidth of 100 kHz.

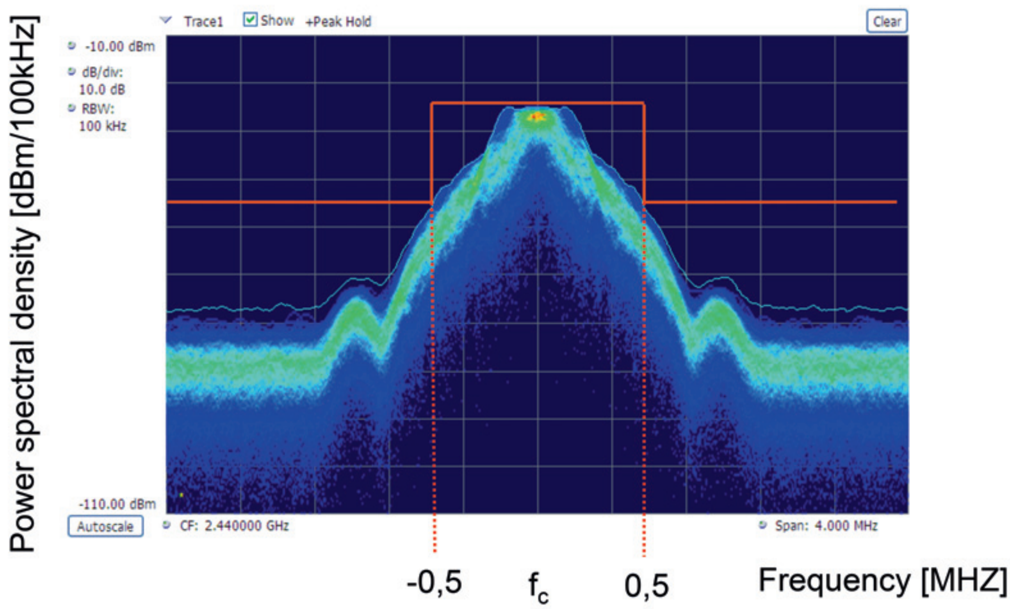

Figure 10: Spectral mask to IEEE 802.15.1

The Bluetooth wireless communication system uses 79 frequency channels in the 2.4 GHz ISM band. Figure 11 shows the spectrum of Bluetooth with all 79 frequency channels, and the lower and upper guard bands marked in red.

In automation technology, Bluetooth packet types DM1, DM3 or DM5 with Forward Error Correction and CRC checksums are used. The user data content depends on the packet type and can be 240 bit for DM1, 1490 bit

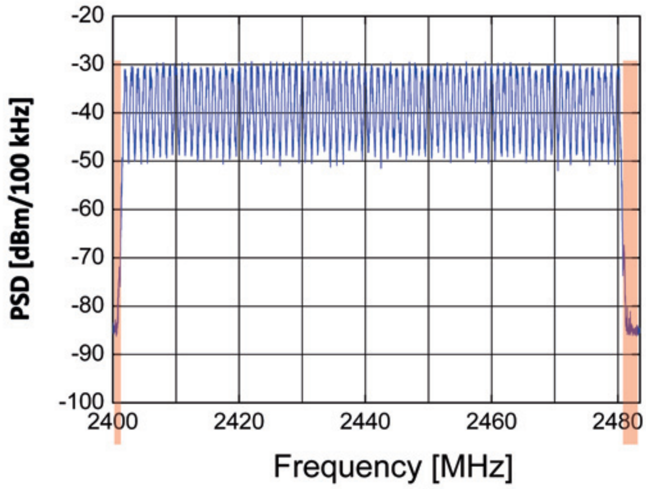

Figure 11: Spectrum of the Bluetooth wireless communication system

for DM3 and 2740 bit for DM5 packets. As the user data content, a UDP packet with a user data content of 48 bytes is transmitted, as is the case with PROFINET IO realtime communication. For periodic exchange of process data by Bluetooth, a transfer interval of 16 ms is used by the application. Together with the Bluetooth packets for data transmission, management packets of a fixed length (e.g. POLL, NULL) are transmitted at fixed times so that synchronization between master and slave is preserved.

In Bluetooth, the time between the start of two packet transmissions is an integer multiple of 625 µs. As Bluetooth uses the Time Division Multiple Access (TDMA) process, the time is divided into slots with a length of 625 µs. The data transmission for a transfer interval of 16 ms is shown in table 10.

Time [ms]	Channel	Frequency [MHz]	Transmission direction	Packet length		Packet type
				[bit]	[µs]	
0.000	65	2,467	Master → Slave	1000	1000	User data
1.875	65	2,467	Master → Slave	166	166	ACK
2.500	47	2,449	Master → Slave	166	166	Management
5.000	78	2,480	Master → Slave	166	166	Management
7.500	26	2,428	Master → Slave	166	166	Management
10.000	69	2,471	Master → Slave	166	166	Management
12.500	0	2,402	Master → Slave	166	166	Management
15.000	10	2,412	Master → Slave	166	166	Management
17.500	40	2,442	Master → Slave	1000	1000	User data
18.125	40	2,442	Master → Slave	166	166	ACK
20.000	65	2,467	Master → Slave	166	166	Management
22.500	05	2407	Master → Slave	166	166	Management
25.000	73	2475	Master → Slave	166	166	Management
27.500	58	2460	Master → Slave	166	166	Management
30.000	36	2,438	Master → Slave	1000	1000	User data
31.875	36	2,438	Master → Slave	166	166	ACK

Table 10: Data of a section for the Bluetooth interference profile

11.3.3 PROFINET IO communication by WLAN

In this section, the interference profile for PROFINET IO communication by WLAN is described. In that context, the channel occupation of a WLAN wireless communication system consisting of an access point and 10 clients, as shown in Figure 12 is considered. As application data, PROFINET IO data are transmitted between the controller and the distributed automation components (ET200).

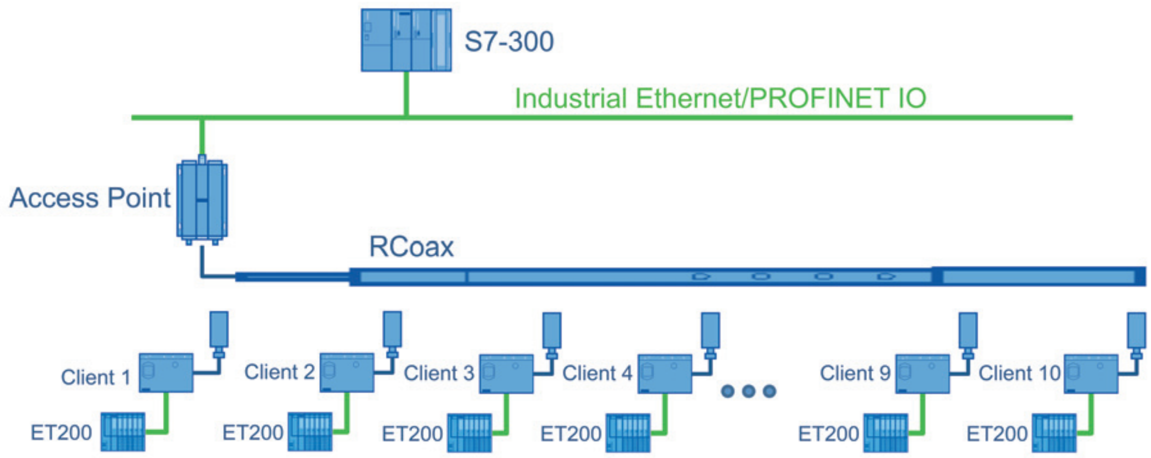

Figure 12: PROFINET IO communication by WLAN

The WLAN wireless communication system as specified in IEEE 802.11g [8] works on 13 frequency channels in the 2.4 GHz frequency band. Only the values of the spectral masks with the limits for spectral power density across a frequency range are defined in [8]. The spectral masks presented in [8] have only limited suitability for emulation of the radio signals of the WLAN wireless communication system. The values of the spectral mask of the transmitter merely correspond to the maximum values of spectral power density. This behaviour is made clear by the measurement results for spectral power density for the IEEE 802.11g WLAN wireless communication system in Figure 13.

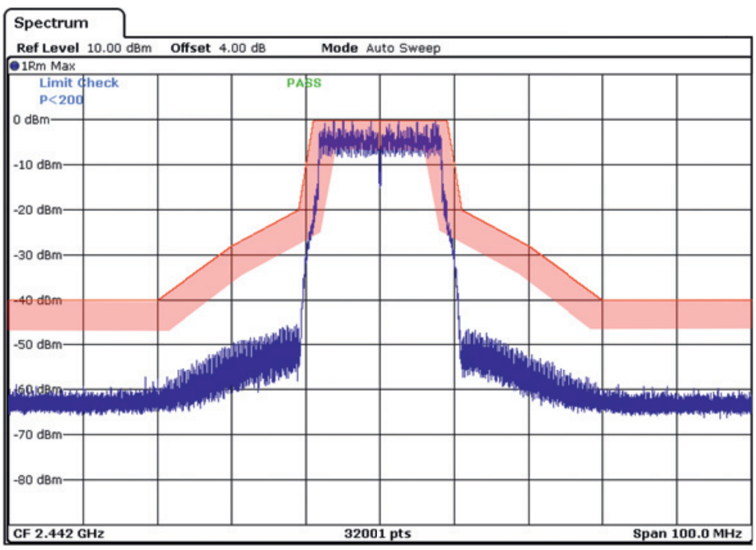

Figure 13: Spectrum and spectral mask for WLAN to IEEE 802. 11g

The WLAN packets containing user data have a fixed length of 185 bytes. Each WLAN packet with user data content is acknowledged by the receiver in an acknowledgement packet. The bidirectional transmission of 64 byte long UDP packets in a WLAN message is shown in Figure 14. Between the WLAN packet with data content and the acknowledgement (ACK) , there is no radio transmission for a period of 10 µs (SIFS: Short Interframe Space). Following the acknowledgement (ACK), no radio transmission may take place for a period of at least 50 µs (DIFS: Distributed Interframe Space).

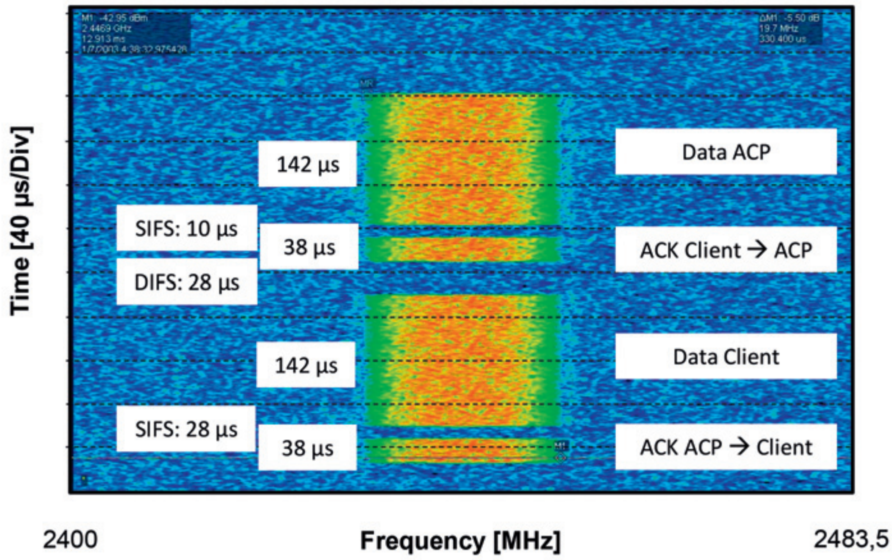

Figure 14: Spectrogram of WLAN messages

The data transmission for a transfer interval of 16 ms is shown in table 11.

Time [ms]	Channel	Frequency [MHz]	Transmission direction	Packet length		Packet type
				[byte]	[µs]	
0.000	7	2442	Access Point → Client 1	185	142	User data
0.152	7	2442	Client 1 → Access Point	29	50	ACK
0.230	7	2442	Client 1 → Access Point	185	142	User data
0.382	7	2442	Access Point → Client 1	29	50	ACK
5.000	7	2442	Access Point → Client 2	185	142	User data
5.152	7	2442	Client 2 → Access Point	29	50	ACK
5.230	7	2442	Client 2 → Access Point	185	142	User data
5.382	7	2442	Access Point → Client 2	29	50	ACK
10.000	7	2442	Access Point → Client 3	185	142	User data
10.152	7	2442	Client 3 → Access Point	29	50	ACK
10.230	7	2442	Client 3 → Access Point	185	142	User data
10.382	7	2442	Access Point → Client 3	29	50	ACK
15.000	7	2442	Access Point → Client 4	185	142	User data
15.152	7	2442	Client 4 → Access Point	29	50	ACK
15.230	7	2442	Client 4 → Access Point	185	142	User data

Continuation on following page

Time [ms]	Channel	Frequency [MHz]	Transmission direction	Packet length		Packet type
				[bit]	[µs]	
15.382	7	2442	Access Point → Client 4	29	50	ACK
…	…	…	…	…	…	…
45.000	7	2442	Access Point → Client 10	185	142	User data
45.152	7	2442	Client 10 → Access Point	29	50	ACK
45.230	7	2442	Client 10 → Access Point	185	142	User data
45.382	7	2442	Access Point → Client 10	29	50	ACK
…	…	…	…	…	…	…
128.000	7	2442	Access Point → Client 1	185	142	User data
128.152	7	2442	Client 1 → Access Point	29	50	ACK
128.230	7	2442	Client 1 → Access Point	185	142	User data
128.382	7	2442	Access Point → Client 1	29	50	ACK
…	…	…	…	…	…	…
173.000	7	2442	Access Point → Client 10	185	142	User data
173.152	7	2442	Client 10 → Access Point	29	50	ACK
173.230	7	2442	Client 10 → Access Point	185	142	User data
173.382	7	2442	Access Point → Client 10	29	50	ACK

Table 11: PROFINET IO communication by WLAN

11.3.4 Periodic exchange of process data by WISA

The WISA system consists of a base station and several wireless nodes. The cells of neighbouring WISA systems may overlap (see Figure 15).

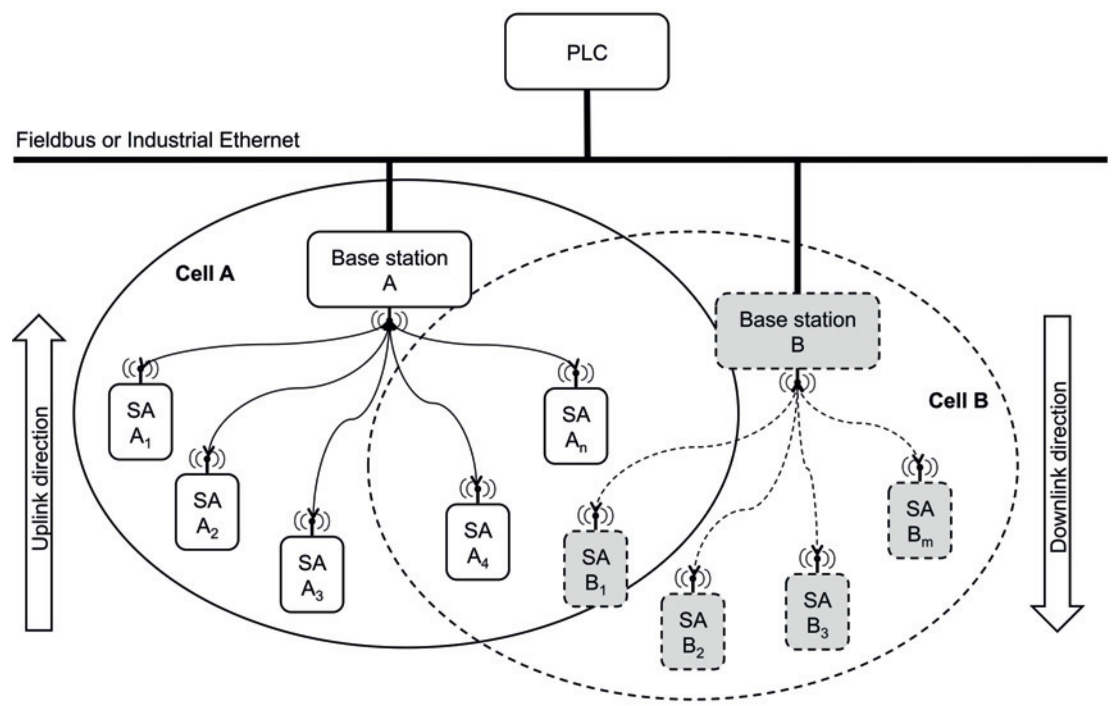

Figure 15: System structure of WISA

Like Bluetooth, the WISA system uses the physical layer of the IEEE 802.15.1 [7] standard. The spectral mask with limit values as per [7] is presented in Figure 10.

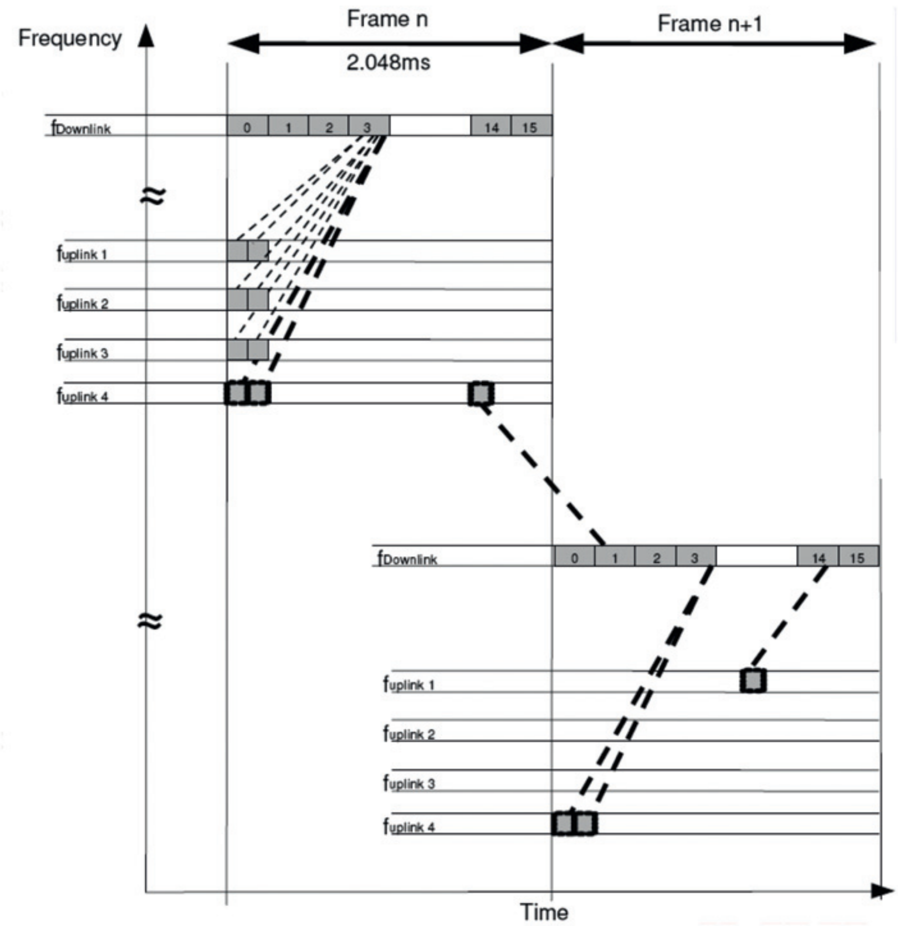

Figure 16: WISA TDMA/FDD/FH pattern

For channel access control, WISA uses a combination of Time Division Multiple Access with Frequency Division Duplex and Frequency Hopping (TDMA/FDD/FH), as shown in Figure 16. The downlink transmission from the WISA base station to the sensors and actuators (S/A) is always active for the purpose of packet and slot synchronization of the sensors and actuators (S/A). The S/A are thus enabled to find the time slots in which they can transmit an uplink message. The uplink transmission from the S/A to the base station is only active for the duration of transmission of the process data and synchronization data.

For data transmission, WISA uses one downlink channel from the base station to the S/A and four uplink channels from the S/A to the base station. The downlink channel and the four uplink channels synchronously change the hopping frequency. For the TDMA process, data transmission takes place in time frames (Tframe) with a length of 2048 µs. For downlink transmission, that time frame is divided into 16 downlink slots of 128 µs length each. The uplink frames are aligned to the downlink frames. A maximum of 32 uplink slots of 32 µs length per time frame and uplink channel can be transmitted. Guard slots are inserted at the start and end of the time frame, and are reserved for the switchover time on change of frequency.

In contrast to Bluetooth, WISA uses a deterministic frequency hopping method. The available frequency band is divided into seven sub-bands (n_B = 7) with a bandwidth of B_S = 11 MHz. Each sub-band has eleven hopping frequencies (n_I = 11) with a bandwidth of B_H = 1 MHz. For the starting frequency f_0 = 2403 MHz, therefore, the hopping frequency for a WISA system can be calculated in accordance with equation (1).

$$f = f_0 + W \cdot B_S + X \cdot B_H$$
$$f = 2403 \text{ MHz} + W \cdot 11 \text{ MHz} + X \cdot 1 \text{ MHz} \quad (7)$$

The change in the variables W and K on each frequency hop is calculated in accordance with equation (2).

$$W_0(j) = j, \; j = 0 \,..\, 6$$
$$W_K(j) = (W_0(j) \cdot (K+1)) \bmod 7, \text{ for } K = 0 \text{ to } 5$$
$$X_0(i) = i, \; i = 0 \,..\, 10$$
$$X_I(i) = (X_0(i) \cdot (I+1)) \bmod 11, \text{ for } I = 0 \text{ to } 9. \quad (8)$$

The WISA cell is identified by the cell ID, which can be described by the following expression:

$$Cell_{ID} = 10 \cdot K + I \quad (9)$$

The index pair (K, I), which is determined by the selected cell ID, determines the sequences $W_K(j)$ and $X_I(i)$. Selection of the numbers for i and j in $W_K(i)$ and $X_I(j)$ is effected by the following equation:

$$j = FN \bmod 7$$
$$i = FN \bmod 11. \quad (10)$$

As a result, there are 60 different frequency hopping sequences with a period of 77 transmissions. Each individual frequency is occupied once each period. Finally, the frequency for each downlink and uplink transmission can be calculated deterministically. For the downlink direction, calculation of the frequency hop is effected using the following equation:

$$f_{DL}(FN) = f_0 + W_K(j) \cdot B_S + X_I(i) \cdot B_H \quad (11)$$

For the uplink direction, calculation of the frequency hop is performed in accordance with equations (6) to (9) below for the four separate uplink frequencies.

$$f_{UL1}(FN) = f_0 + ((W_K(j)+3) \bmod 7)\cdot B_S + X_I(i)\cdot B_H \quad (12)$$

$$f_{UL2}(FN) = f_0 + ((W_K(j)+3) \bmod 7)\cdot B_S + (X_I(i)+3)) \bmod 11)\cdot B_H \quad (13)$$

$$f_{UL3}(FN) = f_0 + ((W_K(j)+3) \bmod 7)\cdot B_S + (X_I(i)+6)) \bmod 11)\cdot B_H \quad (14)$$

$$f_{UL4}(FN) = f_0 + ((W_K(j)+3) \bmod 7)\cdot B_S + (X_I(i)+9)) \bmod 11)\cdot B_H \quad (15)$$

As the uplink transmission is very short and only takes place when required, while however the downlink is permanently active with a notable channel occupation (2048 µs), only the downlink is taken into account in specifying the interference profile.

11.3.5 Video transmission by WLAN

As for the interference profile for PROFINET IO communication by WLAN, the interference profile for video transmission by WLAN is specified to the IEEE802.11g standard. In contrast to the fixed packet lengths in the interference profile for PROFINET IO communication by WLAN, however, the packet length in the interference profile for video transmission by WLAN varies. Variable channel occupation of 10 %, 20 % and 30 % channel occupation time is specified. For that purpose, a sequence of data packets with random packet lengths is generated. Each data packet is followed by an acknowledgement. Waiting times are then interposed in a random sequence, with the result that different constellations are created.

11.3.6 Bluetooth inquire

Bluetooth inquire defines part of the establishment of a connection in Bluetooth by the Bluetooth master. The Bluetooth inquire process is performed after switching on, after breaks in connection or in response to defective Bluetooth communication connections. In Bluetooth inquire, 16 frequencies are occupied, and are divided into four subbands. The inquire messages are transmitted repeatedly on the same frequencies after a cycle of 10 ms, known as the train. The channel occupation for each inquire message is T_{on} = 166 µs.

The inquire messages are transmitted in the channels in a cycle of 625 µs. The transmission channels are located 2 MHz apart within each sub-band. Sub-bands 1 to 4 occupy the following frequency ranges:

- Sub-band 1:
  Occupied frequency range from 2403 MHz to 2410 MHz,
- Sub-band 2:
  Occupied frequency range from 2432 MHz to 2438 MHz,
- Sub-band 3:
  Occupied frequency range from 2448 MHz to 2454 MHz,
- Sub-band 4:
  Occupied frequency range from 2464 MHz to 2470 MHz.

Time [µs]	Centre frequency [MHz]	Transmission direction	Packet length	
			[bit]	[µs]
0	2448	Master Broadcast	166	166
625	2464	Master Broadcast	166	166
1250	2432	Master Broadcast	166	166
1875	2403	Master Broadcast	166	166
2500	2450	Master Broadcast	166	166
3125	2466	Master Broadcast	166	166
3750	2434	Master Broadcast	166	166
4375	2405	Master Broadcast	166	166
5000	2452	Master Broadcast	166	166
5625	2468	Master Broadcast	166	166
6250	2436	Master Broadcast	166	166
6875	2407	Master Broadcast	166	166
7500	2454	Master Broadcast	166	166
8125	2470	Master Broadcast	166	166
8750	2438	Master Broadcast	166	166
9375	2409	Master Broadcast	166	166

Table 12: Channel occupation for a train in the Bluetooth inquire procedure

Each train is repeated at least 256 times. This repetition is performed four times. If no connection is established, the inquiry procedure is repeated once each minute.

11.3.7 WLAN probe request

A WLAN client without a connection to a WLAN access point attempts to connect to a WLAN access point. In the active search for WLAN access points, the WLAN client transmits probe requests. The probe request message is transmitted for every known Service Set Identifier (SSID) on every possible WLAN channel. The data transmission rate for the WLAN probe request messages is 6 Mbit/s with BPSK modulation and a bandwidth of 20 MHz.

For the WLAN probe request interference profile, 10 known SSIDs are specified for one WLAN client. WLAN channels 1 to 13 are used. The probe request message occupies the medium for a duration of 274 µs, followed by a DIFS of 28 µs in length.

Designation	Symbol	Channel occupation in [µs]
Probe request message	T_{on}	274
DIFS	T_{off}	28
Number of probe request messages	N	10

Table 13: Channel occupation for WLAN probe request

12 Requirement profile

The requirement profile is a set of required values for application-related, environment-related, device and system-related influencing parameters and characteristic parameters which applies to a class of applications. In more concrete terms, a requirement profile is a combination of an application profile (section 10) and an environmental profile (section 10.7).

Furthermore, the requirement profile includes requirements for product characteristics and additional functions (section 11.3.1).

13 Ability profile

The ability profile is a set of warranted values for application-related, environment-related, device and system-related influencing parameters and characteristic parameters which applies to a wireless solution. This means that the wireless solution is capable, with the value set stated for the device and system-related influencing parameters (see [4]), to implement a concrete application of a requirement profile. The ability profile also includes the descriptions of product characteristics and additional functions (section 11.3.1) where these exist.

14 Classification of the ZDKI projects in application areas

On the basis of the approach described above, the ZDKI collaborative projects address requirement profiles as set out in table 14.

	DEAL	HiFlecs	KOI	ParSec	PROWILAN	OWICELLS	TreuFunk	SBDist
Machine or manufacturing cell		X	X	X		X		X
Manufacturing workshop including crane and store		X			X		X	
Robot arm	X		X		X	X		
High bay store and storage and retrieval vehicles		X						
Film wrapper	X	X						
HiFlecs profile A		X						
HiFlecs profile B		X						
HiFlecs profile C		X						

Table 14: Application profiles of the ZDKI collaborative projects

15 Bibliography

[1] EPCTM Radio-Frequency Identity Protocols – Class-1 Generation-2 UHF RFID Protocol for Communications at 860 MHz – 960 MHz – Version 1.1.0

[2] IEC: Industrial communication networks – Wireless communication networks – Part 1: Wireless communication requirements and spectrum considerations, IEC TS 62657-1:2014

[3] IEC: Industrial communication networks – Wireless communication networks – Part 2: Coexistence management, IEC 62657-2

[4] VDI/VDE, Radio based communication in industrial automation, VDI/VDE Guideline 2185, Part 1

[5] VDI/VDE, Radio based communication in industrial automation, VDI/VDE Guideline 2185, Part 2

[6] IEEE 802.15.1 IEEE Standard for Telecommunications and Information Exchange Between Systems – LAN/MAN Specific Requirements – Part 15: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Wireless Personal Area Networks (WPANs)

[7] IEEE 802.11 IEEE Standard for Information technology – Telecommunications and information exchange between systems Local and metropolitan area networks – Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications

[8] BZKI "Aspects of Dependability Assessment in ZDKI", 2017

16 Appendix

16.1 Template for application profile

The template presented in table 15 can be used for the description of an application profile. If a parameter is not relevant, a dash "-" is to be entered as the value. Simultaneous compliance with all the values stated in the application profile is mandatory.

Parameter	Value	Unit
Transmission time (t_{TMode}, t_{TP95}, t_{Tmax})		s
Update time (t_{UMean}, t_{USD})		s
Response time (t_{RMode}, t_{RP95})		s
Data throughput (R_{Mean}, R_{SD})		bit/s
Minimum availability		
Maximum packet loss rate		
Maximum spatial dimension of the application (length, width, height)		m
Maximum number of logical automation devices		pcs.
Maximum distance between logical automation devices		m
Relative movement between logical automation devices (maximum speed, maximum distance)		m/s m
Logical topology (value from list)		-
Maximum user data length		bit
Minimum transfer interval		s
Reference interface (value from list)		-
Information security (value from list)		-
Functional safety (value from list)		-

Table 15: Template for application profile

16.2 Template for passive environmental influences

The template presented in table 16 can be used for the description of passive environmental influences. If a parameter is not relevant, a dash "-" is to be entered as the value. Simultaneous compliance with all the values stated for passive environmental influences is mandatory.

Parameter	Value	Unit
Characterization of the operational area (value from list)		-
Dimensions of the operational area (length, width height)		m
Line of sight (value from list)		-
Number and maximum speed of moving objects in the operational area		pcs., m/s
Natural ambient conditions (minimum and maximum temperature, air pressure, maximum relative humidity)		°C, °C bar %
Maximum distance between logical automation devices		m
Relative movement between logical automation devices (maximum speed, maximum distance)		m/s m
Frequency band (lower and upper frequency limits)		Hz
Antenna system (value from list)		-

Table 16: Template for passive environmental profile

16.3 Template for active environmental influences

The template presented in table 17 can be used for the description of active environmental influences. If a parameter is not relevant, a dash "-" is to be entered as the value. Simultaneous compliance with all the values stated for active environmental influences is mandatory. An environmental profile can contain several sets of active environmental influences.

Parameter	Value	Unit
Wireless communication technology, wireless communication standard, wireless application (value from list)		-
Frequency band of the wireless application (lower and upper frequency limits)		Hz
Frequency channel of the wireless application (channel number or centre frequency and bandwidth or lower and upper frequency limits)		- Hz Hz
Use of frequency spectrum time by the wireless application ($T_{ON}max$, $T_{OFF}min$ or DC)		s s %
Transmission power of the wireless application (EIRP)		dBm
Spectral mask of the wireless application		-

Table 17: Template for active environmental profile

16.4 Template for product characteristics

The template presented in table 18 can be used for the description of product characteristics. If a parameter is not relevant, a dash "-" is to be entered as the value. Simultaneous compliance with all the values stated for product characteristics is mandatory.

Product characteristic	Value	Unit
Maximum power		mW
Autarkic energy supply		-
Maximum frame size (length, width, height)		mm
Degree of protection (IP)		-
Usability in potentially explosive atmospheres		-
Maximum product price		€
Maximum operating costs		€/a
Climate classification		-
Temperature range		°C
Shock resistance		g/ms
Vibration resistance		g/Hz/min
Weight		g

Table 18: Template for required product characteristics

16.5 Template for additionally required functions

The template presented in table 19 can be used for the weighting of additionally required functions. By completing the cells, the importance of the function can be assessed as between desirable "1" and absolutely required "5". An entry of "0" in a cell means that the function is not required. The additionally implemented functions can be listed in the ability profile.

Weighting	0	1	2	3	4	5
Plug & Play functions						
Functions for graphical display of the communication status to the user						
Functions for coexistence management						
Functions for synchronization of the distributed applications						
Localization functions						

Table 19: Template for additionally required functions

Notes

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