5G-ACIA White Paper

Performance Testing of 5G Systems for Industrial Automation

5G Alliance for Connected Industries and Automation

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1 Key terms

Baseline parameters
A baseline parameter is one that influences the performance of a system under test, but is not the subject of testing. Examples include the number of devices and the type of propagation environment. For the test results of a specific test case to be consistent, all relevant baseline parameters must be of constant value. A particular baseline parameter may however be deliberately varied across multiple test cases to assess the impact of that variation on the measured performance parameters. Baseline parameters are described in more detail in section 3.

Performance
Performance is whether and how well a defined task is executed or a defined service provided. Put simply, the performance of a system under test can be expressed in terms of parameters such as transmission time, data throughput and service availability. These are described in more detail in section 3.

Performance parameters
A performance parameter is any parameter of a system under test that requires investigation to support informed, accurate decision-making on, for example, the ability of a particular 5G system to correctly execute a defined task or provide a defined service. Examples include message loss ratio and transmission time. Performance parameters are described in more detail in section 3.

Performance testing
Performance testing comprises the measurement and/or calculation of one or more predefined performance parameters. Such testing is carried out to obtain meaningful results for informed, accurate decision-making on, for example, the ability of a particular 5G system to execute a defined task or provide a defined service.

Reference interface
Reference interfaces are where performance test measurements are made. They must be selected from those interfaces that are available, i. e. exposed. A measurement requires at least one reference interface. More details are given in section 4.3.

2 Introduction

5G wireless communication is key to the advancement of industrial automation (Industry 4.0), opening up entirely new possibilities. However, frequently, especially in factories, the corresponding application is extremely sensitive to poor communication performance, e. g. non-deterministic timing behaviour, potentially causing significant production equipment downtime.

The successful roll-out of 5G in these scenarios will therefore require the advance stress testing of wireless communication performance under realistic conditions (see also *A Unified Approach for the Assessment of Industrial Wireless Solutions* [1]).

This 5G-ACIA white paper seeks to show how this (stress) performance testing can be achieved.

The goal of the presented methods is to verify compliance with the values required for the application to operate reliably in the specified use case – and, additionally, to determine the communication system's entire performance range (its maximum and minimum values). The user organization can then be confident the application will work in practice, and is aware of its capabilities.

This paper initially identifies the parameters of relevance to industrial automation that are to be tested (performance parameters). It also gives the parameters that are not to be tested but must be described and/or controlled (baseline parameters).

It then considers how to test the defined performance parameters. This entails describing the key elements of any system under test, and how this must interface with the testing system.

This is followed by the presentation of a universal testing system concept, i. e. a configuration valid for all performance testing in industrial automation. For greater clarity, this is then applied to three differing systems under test, i. e. a wireless device, a wireless communication system (i. e. all components required for wireless communication), and a logical link. These variants are generic in nature, and in practice would need to be tailored to the specific use case.

The white paper concludes with the depiction of a process for developing a physical testing infrastructure, i. e. testbeds, for identified areas of interest, and for their endorsement by 5G-ACIA.

This white paper is aimed at developers and manufacturers of wireless devices and systems using 5G technologies for industrial use cases. In addition, it is suitable for operators, installation companies, and users of these devices and systems.

3 Performance testing parameters

There are two types of parameters to be considered in performance testing. Firstly, the performance parameters, also known as characteristic parameters, are those to be measured and/or calculated. They allow the assessment of a system's performance under certain conditions. These conditions have to be precisely described and controlled, i. e. by means of the second type of parameters, the baseline parameters, which influence performance but are not themselves the subject of testing.

3.1 Performance parameters

The performance parameters relevant to industrial automation are:

- **Transmission time:** The transmission time is the interval between the moment of delivery of the first user data bit, or byte, of a message to the source reference interface and the moment of delivery of the final user data byte of the same message to the target reference interface.
- **Message reception interval:** The interval between two consecutive messages received, i. e. the interval, measured at the target reference interface, between the delivery of the final user data byte of a message from a specific source and the delivery of the final user data byte of the following message from the same source.
- **Response time:** The interval between the moment of delivery of the first user data bit, or byte, of a request message to the source reference interface, and the moment the final bit, or byte, of the response message is delivered to the same source reference interface.
- **Data throughput:** The number of user data bytes, or user data bits, transferred at the target reference interface per unit of time.
- **Message loss ratio:** The ratio of the number of lost messages to the total number of messages sent.
- Service availability: When applied to a logical link or a service, availability is the ratio of uptime to observation time.
- **Network availability:** Applied to the wireless communication system, network availability is the ratio of concurrent uptime of all logical links to observation time.

- **Time between failures:** The time between failures of a logical link.

There may be up to five types of values based on ITU-T, G.1000 *Communications quality service: A framework and definitions* [2] and VDI/VDE Guideline 2192 *Quality of Service – Description and examples* [3], for each performance parameter:

- **The required value:** This value is a threshold[1] that must be complied with if the application is to operate correctly.
- **The guaranteed or assured value:** This value can be achieved with the specified wireless communication system.
- **The achieved value:** This value reflects what is actually achieved by the wireless communication system.
- **The perceived value:** This value reflects what the application 'believes' to have experienced.
- **The current value:** This value is determined, measured or calculated at a specified point in time or during a specified period.

Achieved or perceived values are not usually the focus of industrial automation. Instead, required, assured and current values would typically be used.

3.2 Baseline parameters

There are two types of baseline parameters: Firstly, those related to the application itself, and secondly, those related to the environment in which the application operates during testing.

Both parameter types are defined by 5G-ACIA on the basis of various standards [4, 5, 6, 7] and other publications [8, 9]. The baseline parameters of relevance to performance testing of industrial applications are as follows:

- **Spatial extent of the industrial facility:** The spatial extent of the real-world facility in which industrial automation applications operate, determined by length, width and height.
- **Spatial extent of the application:** The maximum spatial extent of an application is determined by the positions and movements of its constituent automation devices. There may be multiple applications, with differing spatial extents, within a given industrial facility.
- **Type of propagation environment:** This describes the environment in which the application operates during testing, e. g. high-bay warehouse, factory floor or large-scale chemical plant with both indoor and outdoor areas.
- **Ambient conditions:** Ambient conditions such as temperature, humidity or air pressure may influence propagation.
- **Number of wireless devices:** The number of wireless devices has an impact on communication load and medium utilization. It is often assumed that the number of devices is the same as the number of logical links. However, this is not typically the case in real-world industrial automation use cases.
- **Number of logical links:** This describes how many communication relationships exist within the automation system. It is one of the parameters used to determine the total communication load within the communication system.
- **Type of communication service:** Confirmed or unconfirmed. A confirmed communication service for a specific reference interface comprises, for example, two logical links operating in opposite directions between two devices.
- **Positions of wireless devices and distances between them:** The position of and physical distances between any two communication devices that are logically linked. These positions and the distance can vary dynamically in the case of mobile devices.

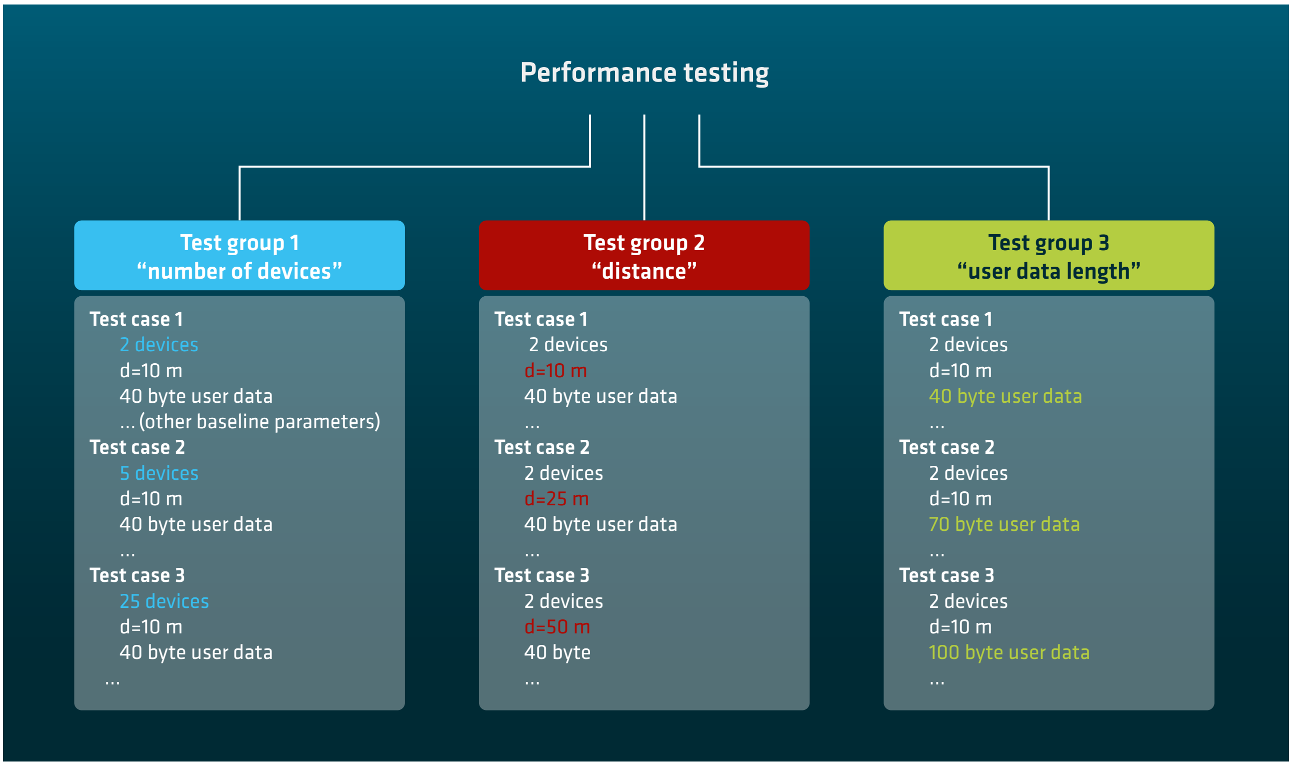
1 Depending on the parameter, this value is a minimum (for example network availability) or a maximum (for example message reception interval). Accordingly, the other value types are greater or smaller than the required value or at least equal to it.

- **Device mobility:** In practice, this comprises multiple parameters, depending on the use case, e.g. the speed of each device and the range of its movement.
- **Active device factor:** The number of concurrently active devices expressed as a percentage of the total number of devices where active means the devices are exchanging data using the communication system.
- **User data length:** The number of bytes that the automation application transfers via the reference interface for transmission.
- **Transfer interval:** The time between two consecutive transfers of user data at the source reference interface. This parameter can be described by a single value (periodic traffic) or a statistical distribution function (aperiodic traffic). In the case of bursts, there are two relevant time intervals, i.e. the time between two bursts and the time between two individual messages within a given burst.
- **Data traffic volume per unit of area:** This is calculated using multiple parameters such as number of devices, number of logical links and user data length.
- **Survival time:** The time an application consuming a communication service can continue to operate correctly without receiving an anticipated message.
- **Observation time:** Time during which tests were conducted on the system under test. It is the key time reference for performance parameters (e.g. message loss ratio) and/or for statistical values for performance parameters (e.g. mean time between failures).

3.3 Test groups and test cases

Performance testing typically comprises one or more test groups as depicted in Figure 1. Each test group investigates the performance parameter(s) of interest and consists of one or multiple test cases. For each test case, each baseline pa-

Fig. 1: Performance testing with example test groups consisting of test cases with varying baseline parameters



Source: 5G-ACIA

rameter (e.g. number of devices, distance between wireless devices, user data length) has a single specified value. However, the value of one or more baseline parameters is altered within a test group, i.e. from one test case to the next, in order to assess the impact of the altered baseline parameter(s) on the performance parameter(s).

Although the baseline parameters do not vary within a test case, the performance parameters measured or achieved may exhibit a range of values. For example, the number of devices might be increased incrementally to establish the system's maximum performance in a high-density environment. Also, the impact of the number of devices on e.g. the achieved/measured transmission time might be analyzed.

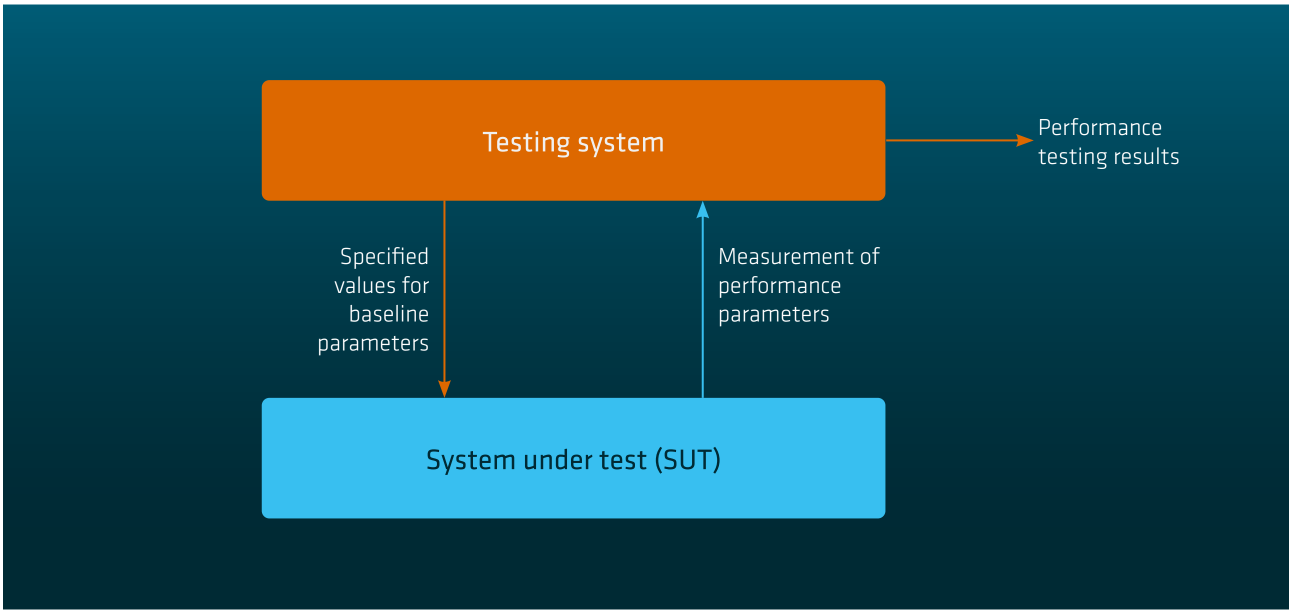
4 How to test performance parameters

Once performance parameters and baseline parameters for the system under test (SUT) have been defined, it is necessary to establish the testing system to measure and/or calculate corresponding performance values. The testing system needs to accurately measure the performance parameters and to accurately reproduce or maintain the baseline parameters. A system under test may comprise one or more independent wireless systems.

4.1 System under test and testing system in a performance test

During a performance test, the testing system controls the SUT and its baseline parameters, ensuring that these comply with test specifications. In particular, this includes the provision of messages, i.e. user data of a certain length and in accordance with the specified transfer interval. For further

Fig. 2: Performance testing concept with testing system and SUT



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information on data traffic typical for industrial applications, refer to the 5G-ACIA white paper *A 5G Traffic Model for Industrial Use Cases* [10]. It is only possible to precisely measure performance parameters when the testing system is able to ensure the specified values for baseline parameters. This interdependency is depicted in Figure 2.

Performance testing can be carried out in three differing testing environments:

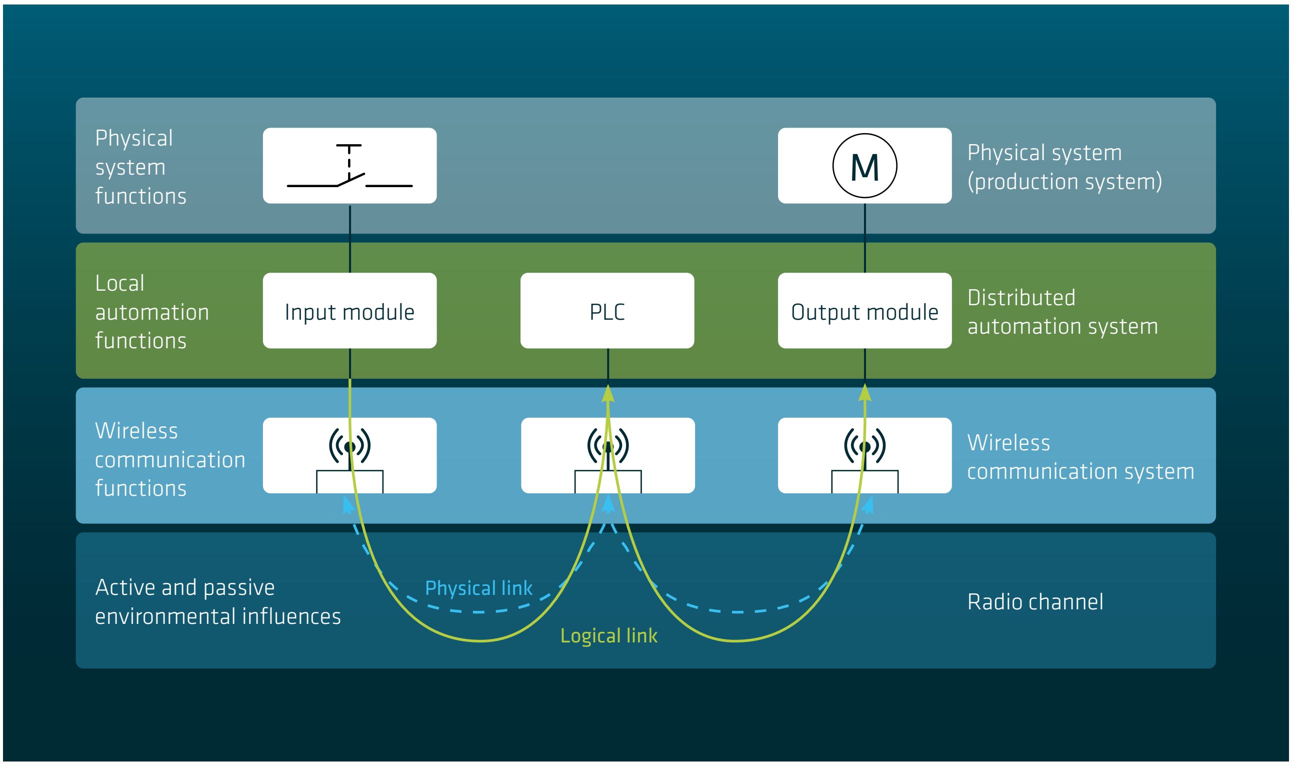
- Target real-world environment, i. e. on-site at the actual factory, before/while system is in operation, i. e. during/after the radio-planning phase, or for trouble-shooting.
- Reference environment, i. e. physically emulated environment, for example a factory-like building.
- Laboratory environment, i. e. virtually emulated environment, for example by means of a channel emulator, anechoic/absorber chamber.

Note that channel measurements and the development of channel models are not within the scope of this paper. However, the intention is for industrial channel models to be used for performance testing in laboratory environments.

4.2 Typical system under test in industrial automation

Figure 3 gives a simplified example of a typical industrial application. The signal from a switch is detected by an input module, and transmitted to a programmable logic controller (PLC). The output signal generated by the PLC is transmitted to an output module that controls a motor. This figure makes the structure of the overall system clear. The physical system performs the automation task by means of its physical system functions (e. g. adjusting the motor speed).

Fig. 3: Example of wireless industrial automation



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The physical system is controlled by the distributed automation system, which uses local automation functions to control the physical system, e. g. to set the motor speed.

Similarly, the distributed automation system relies on a wireless communication system to exchange information between spatially distinct entities of the automation system.

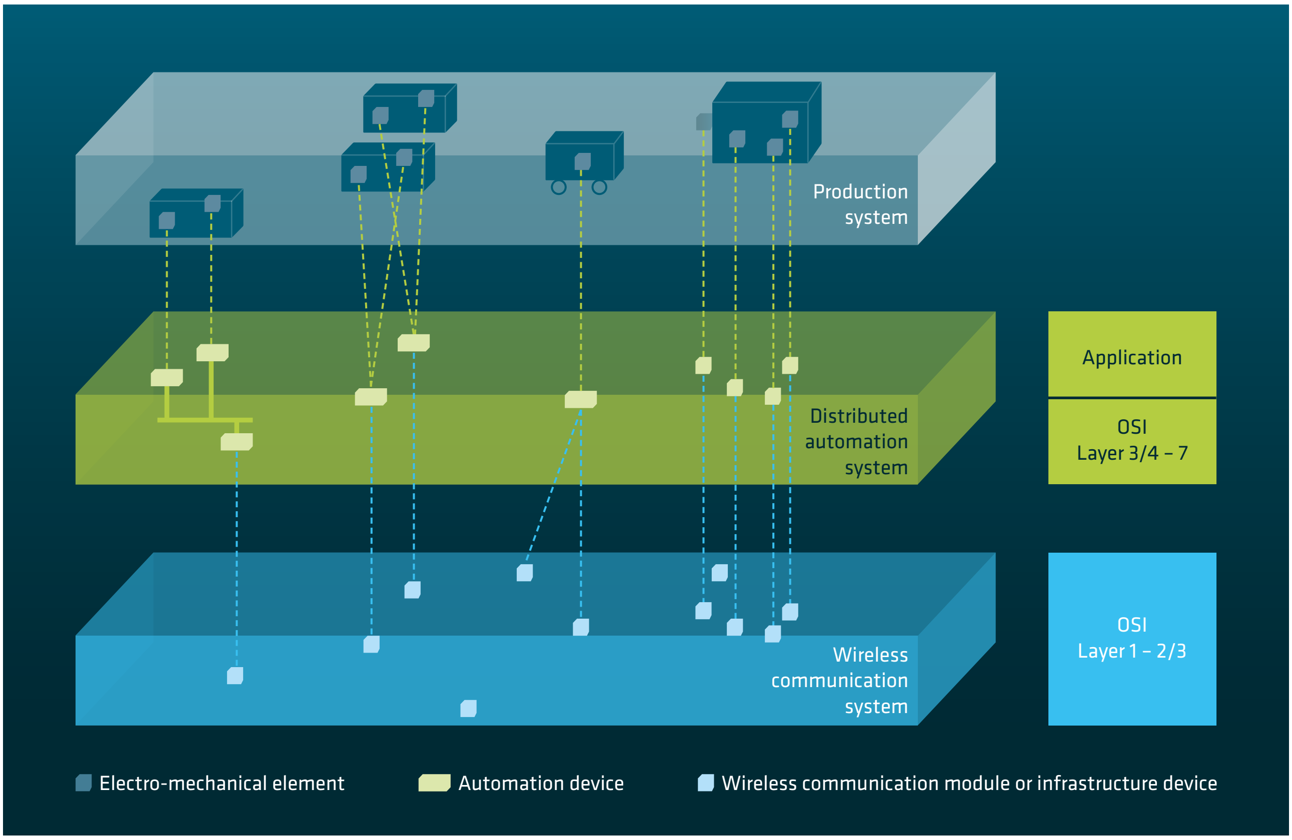
The wireless communication system uses the radio channel, which is subject to active and passive environmental influences, e. g. other wireless communication systems if active, or multipath propagation if passive.

In addition to the communication links shown in this simple example application, further links are possible, for example for device configuration, device diagnosis or for alerts and/or alarms. In practice, there are multiple physical devices and multiple automation functions for each automation device. There might also be several automation devices for each wireless communication module. Infrastructure components might be present, and the wireless modules are able to communicate with multiple devices.

A given wireless industrial automation system will always comprise the three systems depicted in Figure 3: physical production system, distributed automation system and wireless communication system.

However, in reality, these systems are distributed and the relationship between them will be more complex, i. e. as shown in Figure 4. For example, a production system asset, such as an automated guided vehicle (AGV), shown here as large dark blue boxes, can possess multiple electro-mechanical elements, i. e. a switch or a motor, shown here as small light blue

Fig. 4: Wireless industrial automation as a system of systems [11]



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boxes. It is also possible for multiple electro-mechanical elements to be controlled or monitored by a single automation device, shown here as a small greenish-yellow box.

The positions of and the connections between automation devices are aligned with the production system's topology. Multiple automation devices can be connected with each other via a legacy industrial Ethernet network, shown here as thick solid green lines. Therefore, an automation device does not necessarily include a wireless communication module, shown here as a small blue box.

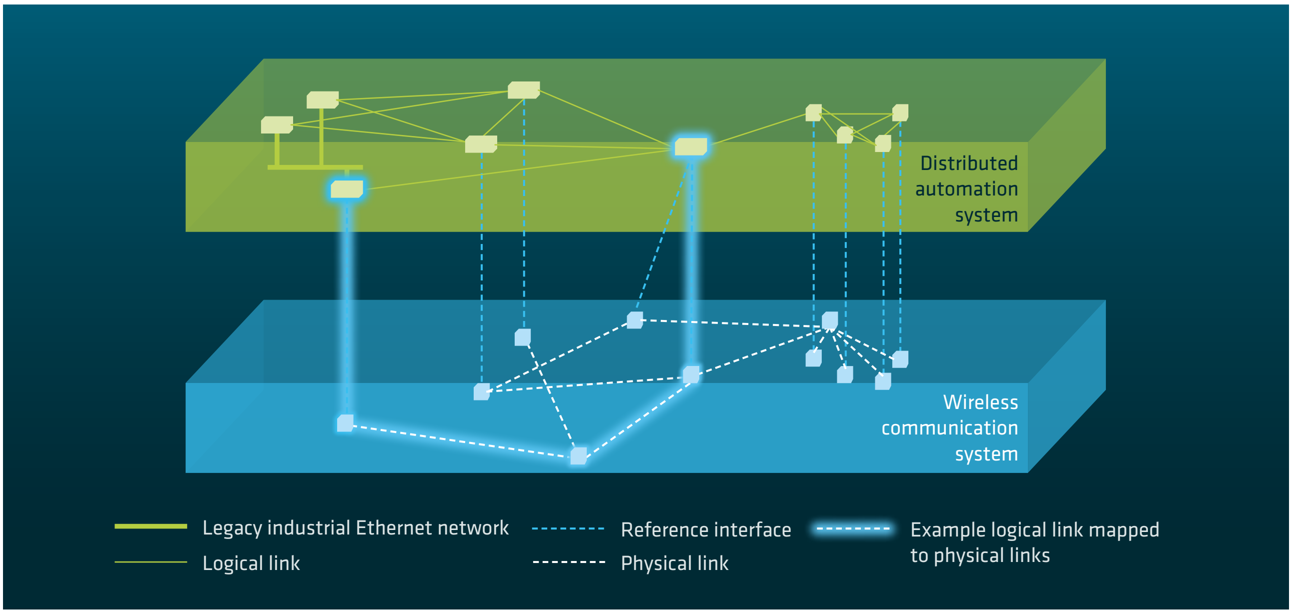
Depending on the wireless technology employed, infrastructure devices such as base stations or access points might be necessary. However, an automation device can include multiple wireless communication modules, e.g. for redundancy purposes. There are therefore usually complex mapping relationships between the three systems.

The required values for performance parameters, and the values for baseline parameters influencing the wireless communication system(s), are defined in accordance with the real-world production system and/or the automation system controlling that production system.

4.3 Interfacing system under test and testing system

Within the system of three systems, it is now necessary to introduce our testing system. This is performed at the interface between the automation and wireless communication systems. This is known as the reference interface. The logical links between automation devices may differ from the physical links between wireless communication modules. A logical link may be formed of multiple physical links. Initially, 5G systems will not provide direct communication links between wireless automation devices, called side-links. Nonetheless, the concept of performance testing should take into account the possibility of side-links. The result of any measurement applies to the performance of one or multiple logical links. Wherever an automation device is connected to a wireless communication module, a corresponding reference interface

Fig. 5: Mapping of logical to physical links; highlighted: Example logical link consisting of two physical links between two automation devices



Source: 5G-ACIA

exists. Any test performed will require one or more reference interfaces.

A reference interface used for testing will have one or more logical endpoints. These endpoints are employed for measurements of the performance parameters.

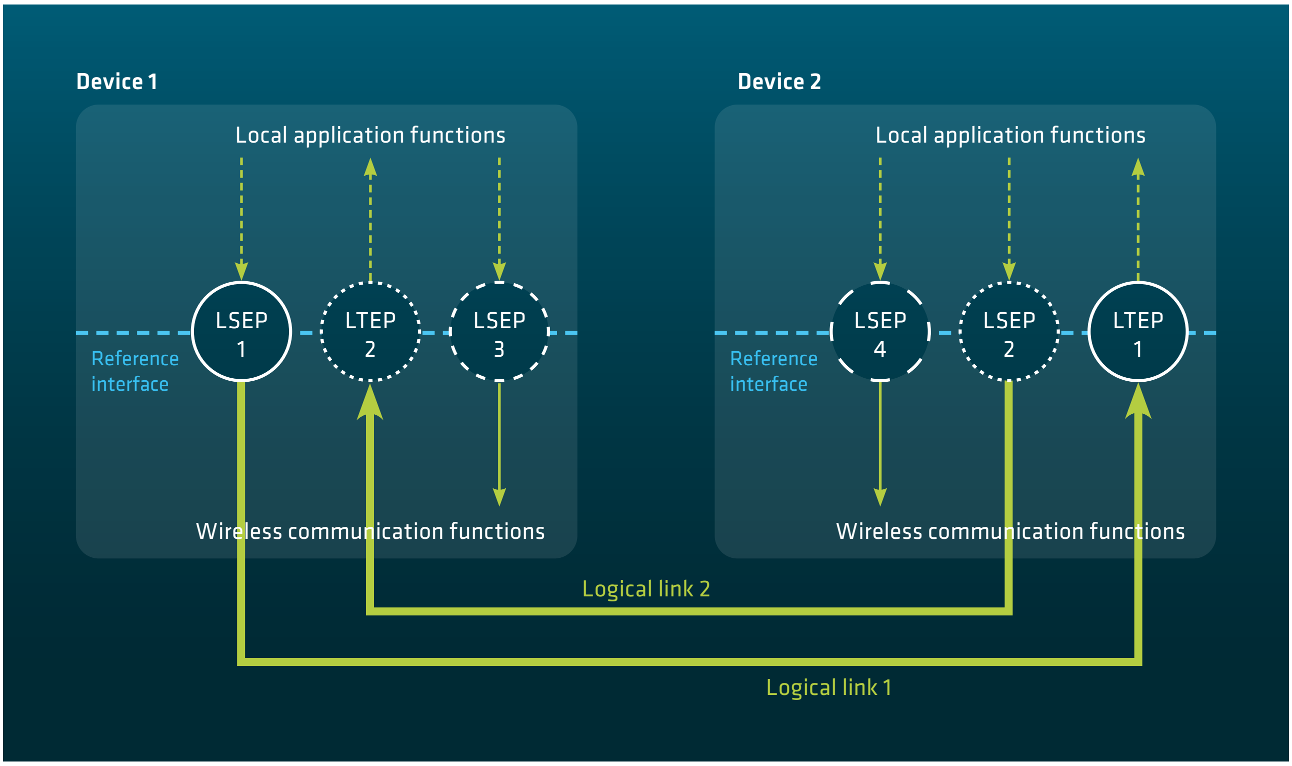
Figure 6 shows a reference interface between local application functions and the wireless communication functions. In this example, there are six endpoints. Device 1 has two logical source endpoints (LSEPs) and one logical target endpoint (LTEP). Device 2 also has two LSEPs and one LTEP. There are two logical links between device 1 and device 2 connecting LSEP 1 and LTEP 1, and LSEP 2 and LTEP 2, respectively.

The two devices with their local application functions exchange messages via their wireless communication functions. To test performance, e.g. message loss ratio or transmission time, messages are sent from the application function as part of the testing system to the communication function via the reference interfaces.

The performance of a logical link is described by the performance parameters (characteristic parameters), such as transmission time, message reception interval, service availability or time between failures. A performance parameter measurement between an LSEP and an LTEP is event-triggered by message send time and message receive time at the endpoints. The testing system is connected to the reference interface hardware, i.e. the testing system takes the place of the automation application.

It is possible for there to be higher communication layers above the reference interface. Therefore, the performance perceived by the automation system may differ from the performance measured. Any wireless communication system

Fig. 6: Reference interface and logical links between the application and the communication function



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accessed by the SUT forms part of the testing system. The testing system is configured according to the test case specification.

If the wireless communication function is implemented in a separate device, the hardware reference interface may, for example, be an Ethernet connector RJ45 or M12, RS485, RS232 or a USB connector type A, B or C. In this case, the software reference interface is a fieldbus or industrial Ethernet protocol according to IEC 51158 and IEC 61784, TCP/IP protocol.

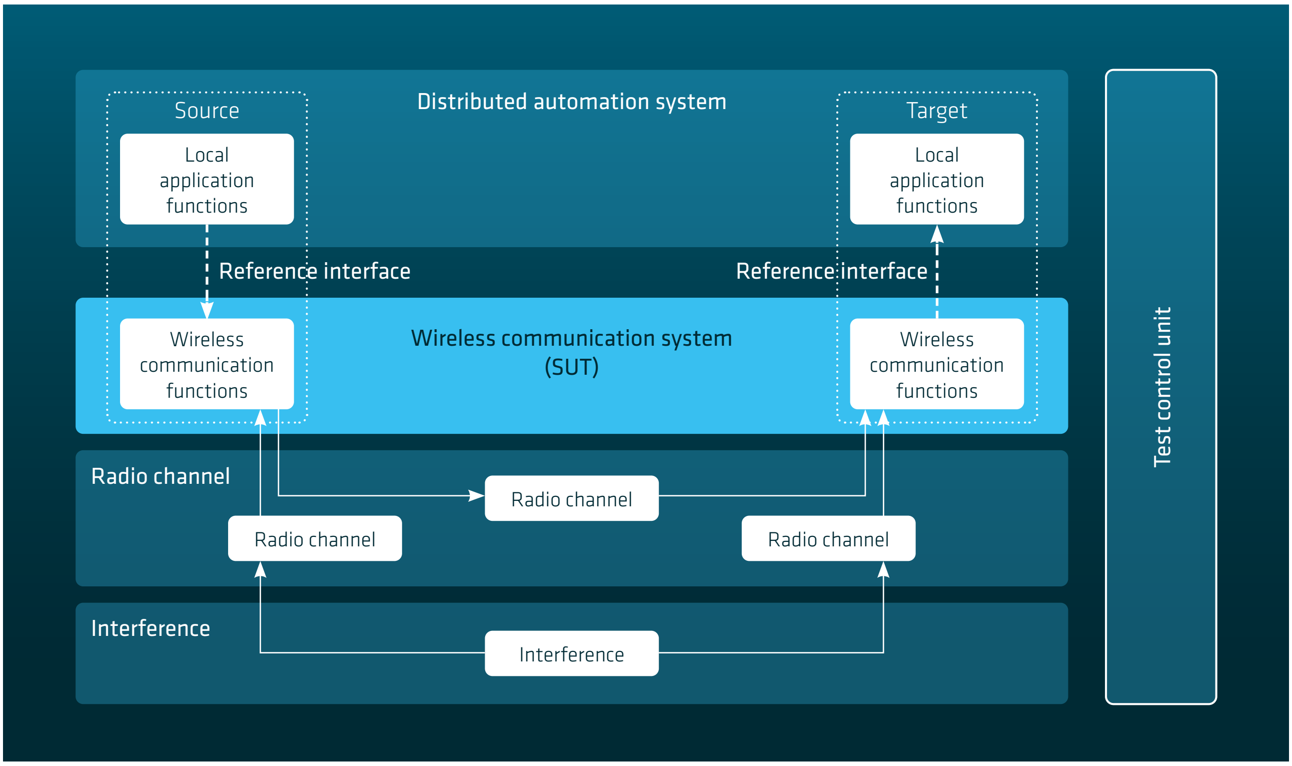
Basic approaches to the integration of industrial Ethernet networks with a 5G network are described in [12]. If the wireless communication function is implemented in a wireless communication module integrated within an automation device, the reference hardware interface is a PCIe/PCI connector M.2, UART, SPI or a proprietary USB trace port. In this case, the software reference interface is a proprietary or standard API.

4.4 Universal testing system concept

This section describes a universal testing system, comprising the components needed to ensure that all baseline parammeters are consistent across all tests within a given test case and controlled across all test cases within a given test group. This allows the performance parameter(s) to be measured at the reference interface(s) with the necessary reproducibility and comparability. This universal concept is valid for all performance testing, but needs to be adapted to the specific SUT. By way of example, this paper describes how it can be applied to three generic SUT variants in section 4.5.

The universal concept is depicted in Figure 7. It shows the SUT in light blue and the testing system with all its components in dark blue. The testing system must provide the specified values for all relevant baseline parameters.

Fig. 7: Universal concept for performance testing



Source: 5G-ACIA

In the universal concept,

- the values for application-related baseline parameters are provided by the distributed automation system,
- the values for passive environmental baseline parameters are reproduced by the testing system's radio channel,
- the values for active environmental baseline parameters are reproduced by the testing system's interference source.

Each of the three components can either be a real-world physical entity or be emulated by the testing system.

All three components are controlled by a dedicated unit within the testing system as shown on the right-hand side of the figure. A test control unit allows interactive on-site or remote control of the testing system, e. g. for configuration and parameterization, operation and reporting.

The local application functions and the wireless communication functions interact via the reference interface(s). The wireless communication functions transfer information via the radio channel.

The testing system has to be capable of scaling testing for wireless communication systems from a single device up to multiple wireless devices with multiple links. It must also be possible to test several independent wireless systems operating concurrently, i. e. with no links between them.

As described in section 4.1 , performance testing can be conducted in three environments: the target real-world environment, reference environment or laboratory environment. The testing system must be adapted accordingly.

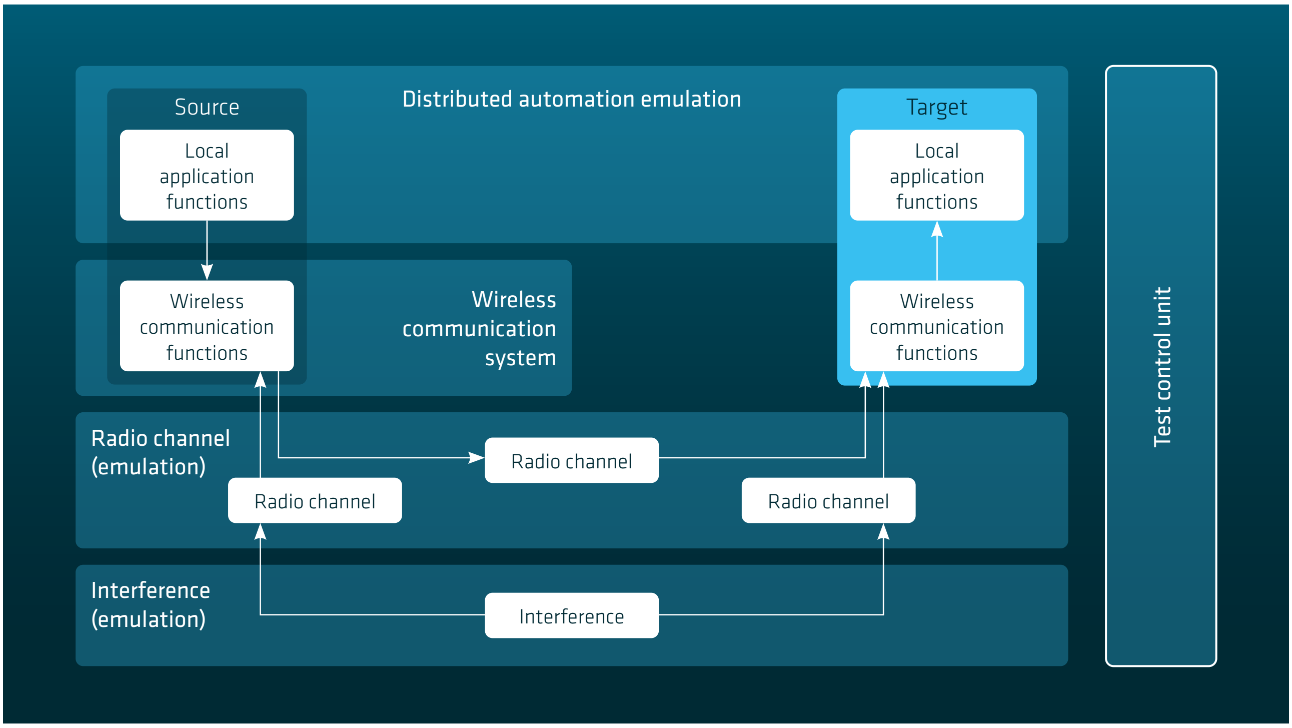
- When testing in a target real-world environment (e. g. an actual factory), the distributed automation system is used as is, or is supplemented by the testing system for data traffic generation, or it can be replaced entirely by the testing system. The choice depends on the performance testing objectives and the constraints of the real-world environment. This environment also provides the radio channel and any interference, i. e. they are not emulated by the testing system. As a result, test cases are not fully configurable, but have to take account of these constraints and preconditions.
- When testing in a reference environment (i. e. a physical reproduction of a target real-world environment), a physical reproduction of the distributed automation system by means of test equipment is required. Special structures are typically installed to intentionally influence the radio channel by creating shadowing and/or reflections. The characteristics of the real-world wireless channel are recreated by means of factory-typical impairments, such as distances, physical obstacles, etc. Furthermore, wireless transmissions can be optionally influenced by an interference signal similar to that of the target use case.
- When testing in a laboratory environment (i. e. virtual emulation of the target real-world environment), the distributed automation system, the radio channel and interference are essentially emulated in accordance with the test case. This is achieved by using, for example, special test and measurement equipment, channel emulators and/or signal generators.

4.5 Application of the universal concept to three system-under-test variants

There are many possible SUT variants, however this paper focuses on three, i. e. a communication device or module, a communication system, and a logical link. This section describes how the universal testing system concept is applied to each variant.

The testing system as tailored for a wireless device or communication module as the SUT is shown in Figure 8. This tailored testing system can be used in a reference environment (physical reproduction) or a laboratory environment (virtual emulation). It is not suitable for a target real-world environment as it is not possible to fully control the wireless communication system in this situation.

Fig. 8: SUT: Wireless device or communication module

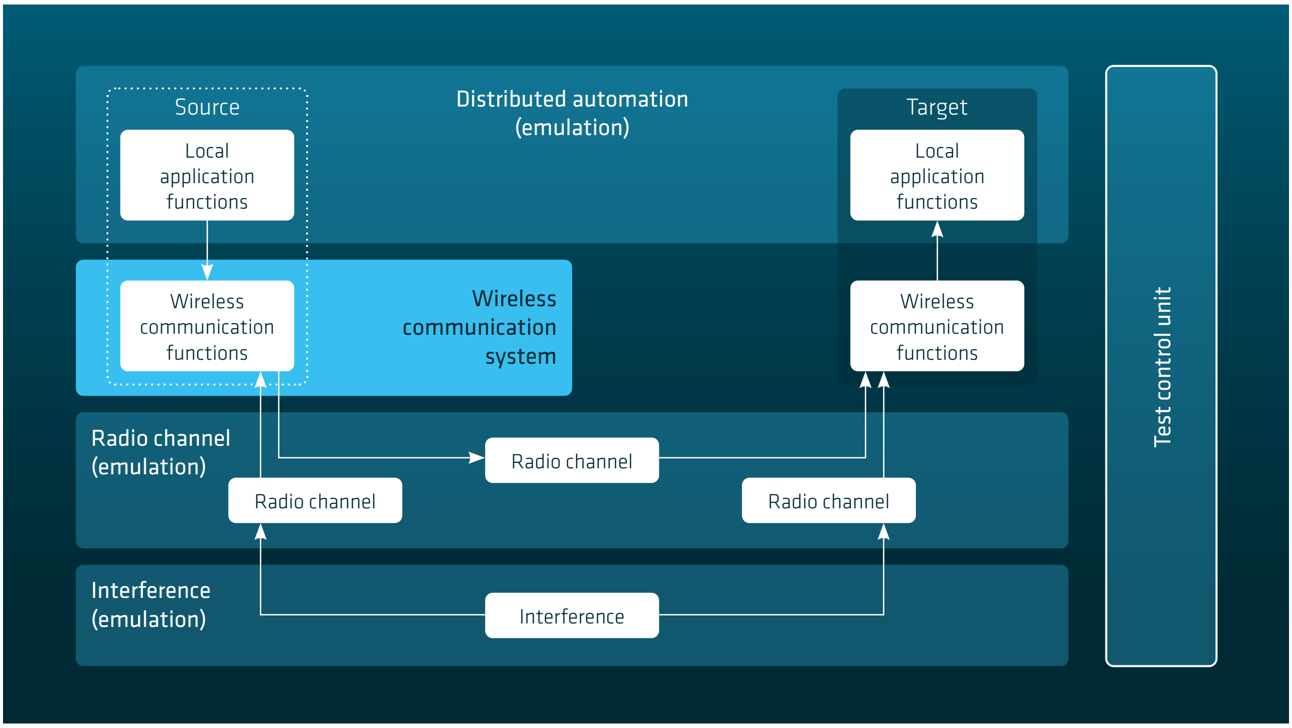


Source: 5G-ACIA

A testing system as tailored for a wireless communication system as the SUT, e.g. a 5G network including radio access network (RAN), core network (CN) and many wireless devices, is shown in Figure 9. Configuration of RAN, CN and wireless devices is defined in the test case specification. This tailored testing system can be used in a target real-world environment, a reference environment (physical reproduction), or a laboratory environment (virtual emulation).

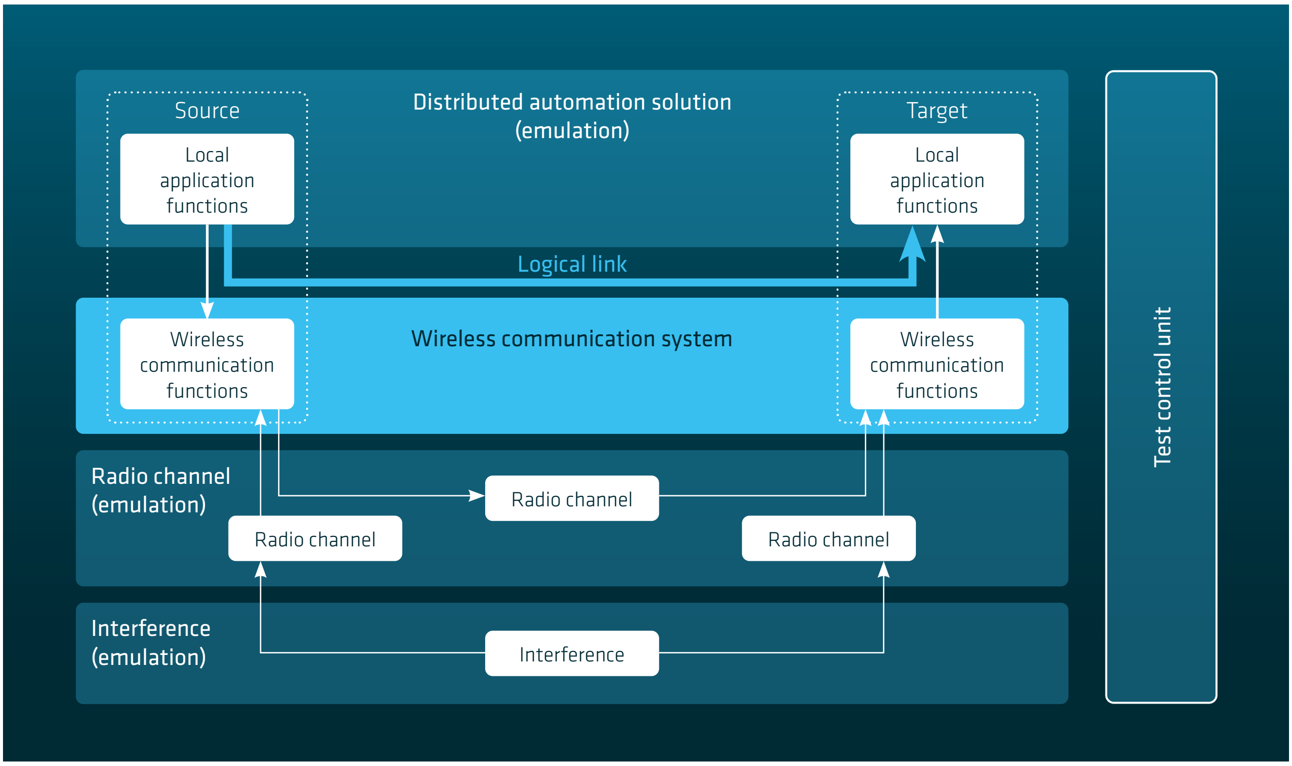
A testing system as tailored for logical links as the SUT is shown in Figure 10. The focus is a single logical link or a set of logical links implemented by means of one or multiple physical links, i.e. a corresponding wireless communication system. It is advisable to carry out multiple test cases with various baseline parameter values, i.e. configuration scenarios, obstacle and interference situations. This tailored testing system is best suited to target real-world environments where the communication system is already fully installed and operational. However, it can also be employed in a reference environment (physical reproduction) or a laboratory environment (virtual emulation).

Fig. 9: SUT: Wireless communication system



Source: 5G-ACIA

Fig. 10: SUT: Logical link



Source: 5G-ACIA

5 5G-ACIA endorsement of testbeds

5G-ACIA is aware of the need for reliable and comparable test results. With this in mind, it has created a process to endorse the use of a given testbed for a specific project with a defined scope and duration. The endorsed testbed is described in a profile which is published on the 5G-ACIA website.

Each testbed must be

- in one or more area of interest to 5G-ACIA,
- for one or more testing type,
- with one or more defined purpose.

The three areas of interest are factory automation, process automation, and intralogistics. Within the chosen area of interest, the testbed must be for a defined use case.

In accordance with [13], testbeds with 5G-ACIA endorsement may be employed to conduct a variety of testing types, of which performance testing is just one. Other permissible testing types are validation, conformance and interoperability. Testbeds with 5G-ACIA endorsement are not currently intended to be used for product certification.

Permissible purposes are demonstration, education and training, technology evaluation and product development support.

To qualify for endorsement, the testbed must fulfill the following requirements:

- The testbed must be led by a 5G-ACIA member organization who names an official contact.
- At least 75 % of all testbed participants must be 5G-ACIA members.
- The application for endorsement must clearly describe the scope and duration of the testbed, the area of interest including the use case, the type(s) of testing, and the testbed's purpose(s).
- If the testbed is for performance testing, such testing must be based on the principles set out in this white paper. Corresponding test cases need to be described in detail. This entails the specification of the performance parameters to be measured and the values of the baseline parameters.
- The testbed participants are solely responsible for financing, developing and operating the testbed.

Each endorsement application undergoes a review process and requires official approval by the 5G-ACIA plenary. Once a testbed is officially approved, the testbed participants are entitled to promote the testbed as "endorsed by 5G-ACIA" and use the corresponding logo.

To allow rapid, reliable assessment and comparison of performance testing results, 5G-ACIA-endorsed testbeds will employ a shared, harmonized performance test report format. Results will be presented by means of both statistics and graphics. Moreover, it is permissible to supplement the elements mandated by 5G-ACIA to include testbed-specific graphics and/or result assessments.

6 References

[1] L. Rauchhaupt, M. Krätzig, U. Meier and P. Neufeld, *A unified approach for the assessment of industrial wireless solutions*, IEEE 16th International Conference on Emerging Technologies and Factory Automation (ETFA), 2011.

[2] ITU-T, *G.1000 Communications quality of service: A framework and definitions,* 2001.

[3] VDI/VDE, *VDI/VDE 2192: Quality of Service – Description and Examples*, 2020.

[4] 3GPP TS 22.104, *Service requirements for cyber-physical control applications in vertical domains*, V16.5.0, 2020

[5] VDI/VDE, *VDI/VDE 2185-4 Radio-based communication in industrial automation – Metrological performance rating of wireless solutions for industrial automation applications,* Part 4, 2019.

[6] 3GPP TS 22.261, *Service requirements for the 5G system*, V16.13.0, 2020

[7] IEC 62657-4, *Industrial communication networks – Wireless communication networks – Part 4: Coexistence management with central coordination of wireless applications*, IEC, 2019.

[8] S. Willmann, *Aspects of Dependability,* Magdeburg, 2017.

[9] 5G-ACIA, *Use Cases and Requirements*, 2019.

[10] 5G-ACIA, *A 5G Traffic Model for Industrial Use Cases*, 2019.

[11] L. Underberg and L. Rauchhaupt, *Performance testing of novel wireless communication networks for industrial automation on the example of 5G*, Conference on Communication in Automation (KommA), 2019.

[12] 5G-ACIA, *Integration of Industrial Ethernet Networks with 5G Networks*, 2019.

[13] 5G-ACIA, *Selected Testing and Validation Considerations for Industrial Communication with 5G Technologies*, 2019.

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