5GACIA

Selected Testing and Validation Considerations for Industrial Communication with 5G Technologies

5G Alliance for Connected Industries and Automation

5G ACIA

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Contents

1 Introduction

The fifth generation of cellular networks (5G) will support massive machine-type communication (mMTC), ultra-reliable and low-latency communication (URLLC) and enhanced mobile broadband (eMBB). This is drawing interest from various industries (vertical domains). It will pave the way for numerous new use cases and applications in discrete and process manufacturing, and will lay the foundations for smart factories.

The 5G Alliance for Connected Industries and Automation (5G-ACIA) was established in 2018 to serve as a global forum for addressing, discussing, and evaluating technical, regulatory, and business aspects of 5G of relevance to industry (see [1]). Of key concern to 5G-ACIA is the quality of industrial communication based on 5G, and therefore testing and validation of 5G technologies.

The deployment of 5G technologies for industrial automation will bring new challenges for all parties. It will not only support the superfast transmission of data from one subscriber to another. Above all, it will enable the connection of devices with diverse communication needs. In Industry 4.0 scenarios, these needs can even change during ongoing operation. In the future, the automation industry will work closely with developers, manufacturers and operators of 5G communication systems in the development and production of automation systems. In other words, responsibilities may be divided between the automation and communications industries. The use of a 5G communication solution therefore requires the specification of a clear interface and the definition of performance and reliability requirements for this interface. The division into automation functions and communication functions impacts both hardware and software, and also the corresponding services, including testing and validation.

For testing and validation, the deployment of 5G technologies for industrial automation will therefore result in the following:
• New types of devices/systems requiring testing (new test objects), for example combining wireless modules and automation devices (wireless devices),
• New types of tests to demonstrate compliance with the communication requirements of the application, as e.g. described in 3GPP TS 22.104 [45] and 3GPP TS 22.261 [46]:
• New roles and responsibilities, e.g. for demonstrating interoperability between wireless devices.

This document aims to clarify the role and the focus of 5G-ACIA with regard to testing and validation of 5G industrial applications. The following points will be addressed:
• The current status of communication system testing with regard to industrial use cases,
• The approach to date, and current roles and responsibilities with regard to test specifications and test performance,
• Further activities required to achieve comprehensive testing of 5G-based communication solutions for connected industries and automation,
• With the above in mind, this document also aims to help establish a shared vocabulary for and understanding of testing and validation.
• This paper is structured as follows:
• Section 2 defines key terms,
• Section 3 outlines the current situation,
• Section 4 describes the organizations that will potentially be involved in the specification of tests and validation,
• Section 5 describes test objects, and how they should be tested,
• Section 6 considers the corresponding test types and goals.

The paper concludes in section 7 by formulating recommendations for the test types applicable to the various test objects.

The paper also identifies future work activities required on the part of 5G-ACIA with regard to tests not yet addressed and specified. However, 5G ACIA does not itself directly address testing and validation for the core network or base stations, or validation of concepts, methods or algorithms.

2 Terms and definitions

This is a list of the most important terms used in this white paper with definitions.
- Where not otherwise indicated, definitions are from 5G-ACIA
- Some are based on existing definitions but slightly amended by 5G-ACIA. This is indicated accordingly, and the source of the underlying definition is given
- Direct citations are in italics and parentheses, and the source is given
- Where a term is defined in detail later in this white paper, reference is simply made to the corresponding section

Application – Hardware and software system (automation system) thatcontrols machines (e.g. a packaging machine) or industrial equipment (e.g. an overhead monorail system)

Base station – Infrastructure device within the radio access network (RAN) for establishing one or more radio cells for bidirectional wireless transmissions between wireless devices and the core network

Certification – Actions taken by an independent entity to ascertain and document that an organization, product, process or service meets the defined requirements of standards or technical specifications

Certification scheme – Set of requirements and rules defined for the certification process by the certification owner

Characteristic parameter – Physical or mathematical metric that can be used to characterize the time or error behavior of a wireless solution. A characteristic parameter is a primary, or core, parameter
Note: From the point of view of an automation application, the values of a characteristic parameter provide information on the properties of a wireless solution. Both individual values and aggregated values (statistics) may be used in the context of testing/validation
Based on VDI/VDE Guideline 2185 4:2018

Communication function – Hardware and/or software instance of a communication stack "Testing the extent to which an implementation under test (IUT) is a conforming implementation" (Source: ISO/IEC 9646-1:1994)
Note: Conformance testing in the sense of EU harmonization legislation is not included here

Equipment under test – Device, combination of devices, or item of equipment that is tested with regard to compliance with defined requirements

Field trial – Testing of the performance of a communication solution under the conditions (specific application or use case) under which it will be deployed

Implementation conformance statement – "A statement made by the supplier of an implementation or system claimed to conform to a given specification, stating which capabilities have been implemented. The ICS can take several forms: protocol ICS, profile ICS, profile specific ICS, and information object ICS"
(Source: ISO/IEC 9646-1:1994)

Implementation under test – This is hardware or software that implements one or more layers of the OSI reference model specified by ISO and which is to be studied by testing
(Based on ISO/IEC 9646-1:1994)
Note: This includes radio transmission

Influencing parameter – Parameter or physical metric whose value exerts an influence on the value of one or more characteristic parameters. An influencing parameter is a secondary or indirect parameter Note: A distinction is made between influencing parameters, firstly, related to the application, the device or system, and, secondly, related to the environment in which the application, device or system operates (Based on VDI/VDE Guideline 2185 4:2018)

Infrastructure device – Device that is essential for implementing a wireless communication system on the basis of a technology or standard, but without an interface to an automation application
Example: Router or base station without an interface to the wired industrial network or without automation application functions (Based on IEC 62657 2:2013, 3.1.33)

Interoperability testing – Verification of information exchange between products according to a specific standard or reference specification by means of a defined test
The purpose of an interoperability test is to ascertain that a communication system supports the end-to-end functionality defined in a specification (Based on ETSI EG 202 810)

Local application function – Hardware and/or software of a device that is an element of a locally distributed application

Logical endpoint – Point within a communication relationship where user data are exchanged between a local application function and a communication function
Note: One or more logical endpoints form a reference interface of a wireless communication module

Logical link – "Application oriented communication relationship which enables the transmission of user data between one logical end point of the reference interface in a source device and one logical end point of the reference interface in a target device"
(Source: IEC 62657 4, 3.1.2)

Mobile network operator – Entity which operates a public or non-public mobile network

Operational technology – "Operational technology (OT) is hardware and software that detects or causes a change through the direct monitoring and/or control of physical devices, processes and events in the enterprise"
(Source: https://www.gartner.com/it-glossary/operational-technology-ot)

Plugfest – Event held to test and improve interoperability between communication devices and equipment in line with a specific standard or reference specification. The event is conducted by the developers and/or manufacturers of those devices and equipment to obtain information and insights that enable them to improve their products. Ideally, a plugfest should be conducted in accordance with a defined test specification. Plugfests are not a replacement for conformance tests or other tests with official industry-wide recognition. ETSI organizes these types of events under the name PlugtestsTM

Qualified equipment – Device or combination of devices that has been shown and certified by rigorous and well-defined testing to interoperate with other equipment
Note: Once an item of equipment under test (EUT) has been successfully tested against an item of qualified equipment (QE) it is considered to be a QE itself; Once a QE is modified it loses its status as QE and reverts to being an EUT (Based on ETSI EG 202 237 V1.2.1 (2010-08))

Radio access network – Telecommunications network where access to the network (connection between wireless device and network) is implemented over an air interface
(Based on ETSI EN 303 472, V.1.1.1 (2018-10))

Radio bearer – Radio communication channel on a defined frequency for the transfer of data between the wireless devices and the radio network

Reference interface – "Exposed interface between an automation application and the wireless communication function
Note 1: There is no consistently defined interface for measurement and automation. The interface of the device might be a serial or a parallel hardware interface, a fieldbus interface, a software interface, or serial, parallel, discrete, and analogue interface"
(Source: IEC 62657 2:2013, 3.1.66)

System – "Set of interrelated elements considered in a defined context as a whole and separated from their environment
Note 1: Such elements may be material objects and concepts as well as their results (e.g. forms of organization, mathematical methods, programming languages)
Note 2: The system is considered to be separated from the environment and from the other external systems by an imaginary surface, which cuts the links between them and the system
Note 3: The language GRAFCET can be used to describe the logical behavior of any kind of system" (Source: IEC 60050-351:1998, 351-11-0)

System under test – "The real open system in which the implementation under test (IUT) resides" (Source: ISO/IEC 9646-1:1994)

Test – Generic term for activities such as evaluation, validation, investigation, verification

Test bed – Platform comprising, firstly, hardware and/or software that implements or reproduces the behavior of a communication system, and, secondly, equipment (hardware and/or software) for testing the behavior of that system

Test interface – Test object interface that exchanges messages subjected to a specified test for the purposes of determining the characteristics of message transmission
Note: When testing compliance with application requirements, this interface is known as a reference interface

Test object – "Item submitted to a test, including any accessories, unless otherwise specified" (Source: IEC 60050-151:2001, 151-16-28)

Use case – Description of the behavior of a system (e. g. industrial equipment) from the user's point of view

Validation – Test that ascertains whether a defined goal has been achieved

Verification – Test that ascertains whether specified parameter values have been achieved

Wireless communication module – Instance of a communication function that does not include application functions

Wireless communication solution – "Specific implementation or instance of a wireless communication system
Note 1 to entry: A wireless communication solution may be composed of products of one or more producers" (Source: IEC 62657 2:2013, 3.1.49)

Wireless communication system – "Set of interrelated elements providing a wireless communication
Note: A wireless communication system is a high level representation of a system, while a wireless communication solution is a practical instance of a system."
(Source: IEC 62657 2:2013, 3.1.50)

Wireless device – An item of equipment that uses radio waves for wireless communication with another item of equipment (Based on IEC 62657 2:2013, 3.1.96)

3   Requirements to be tested

3.1   General

In addition to the specific requirements of individual use cases, there are also general requirements for a 5G communication solution. The wireless devices must comply with the relevant regulations and be implemented in accordance with technical specifications or standards. In addition, wireless devices from multiple vendors must (inter)operate reliably when combined in one system. This includes the ability to replace a wireless device from one vendor with a product from a different vendor. Compliance with these general requirements has to be demonstrated by testing.

Standards organizations such as 3GPP define and specify cellular technologies, including a multitude of test cases as the basis for demonstrating compliance with the specifications. The testing industry develops appropriate test platforms and tools, and implements the agreed conformance test cases. This allows testing of the devices and/or system under tests in a laboratory environment.

3.2   Use case requirement and application profiles

Industrial use cases often differ greatly with regard to wireless communication requirements. This is reflected in the many specification approaches [2], [3], [7], [45]. In fact, no two use cases are the same. To assess the suitability of wireless solutions for specific use cases, it makes sense to group requirements into requirement profiles. In order to test these requirements empirically, they must be described using quantitative parameters. A requirement profile therefore consists of a set of parameter values that describe the minimum requirements of a given application. A requirement profile considers both the application itself and its environment.

3.3   Concept of a locally distributed application

The current paradigm shift in industrial production requires, inter alia, clear segregation of the locally distributed application and the communication network. For 5G testing, this makes the communication behavior experienced by the application of interest. The interface between the application and the communication network is called the reference interface. The communication behavior experienced by the application can be expressed by the values of characteristic parameters. These values are related to the reference interface, which comprises multiple logical endpoints. By the same token there are multiple reference interfaces and logical links between them. Ultimately any test will be applied to the behavior of a logical link (end-to-end connection, see also Figure 3). For example, a given application may require confirmation of information transfer at the reference interface. If this confirmation is not provided by 5G technologies, there is a discrepancy between communication requirements and provision. In this case, there are two possible ways to overcome the problem:

- The missing communication functions are provided by 5G technologies, then the entire communication stack can be tested.
- A reference interface has to be agreed within the communication stack. The tests are performed at this interface. The remainder of the communication stack must be implemented and tested separately, possibly by a different party.

This example shows that close cooperation between vendors (ICT companies) and users (OT companies) is essential in the discussion and preparation of 5G technology tests for connected industries and automation.

4 Current status of standardized tests for communication

4.1 General

Principles of testing, test methods, test procedures and test documentations are usually standardized. However, not every type of test described in section 6 is aligned with a specific standard. Furthermore, there is not always a standard available for each and every test object listed in section 5. This section 4 provides an overview of standards that have been developed or are currently being developed in relevant organizations. Reference is made to the type of test, the test objective and the test object.

4.2 3GPP

The 3rd Generation Partnership Project (3GPP) is a collaborative project that brings together standardization organizations from around the world to create globally acceptable specifications for mobile networks.

A major objective of 3GPP standardization is to enable interoperability in a multi-vendor, multi-network, multi-service environment. 3GPP test specifications include conformance test and interoperability test specifications.

The conformance testing system is a specialized tool built for the purpose of testing and on which specific test cases run. The system under test (SUT) is controlled by the conformance testing system with open standardized communication links (open interfaces) for testing. The 3GPP working group Radio Access Network 5 (RAN5) develops standardized conformance test specifications with test cases for user equipment (UE). Based on these test cases, certification bodies such as the Global Certification Forum (GCF) and the Personal Communications Service (PCS) Type Certification Review Board (PTCRB) select the number of test cases required for UE certification.

The test specifications for UE are based on the requirements defined by 3GPP working group RAN4 for the radio test cases, and 3GPP working groups RAN1 and RAN2 for the signaling and protocol test cases. RAN4 develops test specifications for base stations, but no global certification regime exists.

3GPP working group RAN5 develops UE conformance test specifications such as protocol test and inter radio access technology (RAT) test specifications for GSM, GPRS, EDGE, 3G UMTS and CDMA, HSDPA, HSUPA, HSPA+, 4G / LTE, LTE-Advanced, LTE-Advanced Pro and 5G. This working group provides the formal description of protocol test cases using Testing and Test Control Notation (TTCN) in coordination with Mobile Competence Centre Task Force (MCC TF 160) in accordance with the needs of the testing community. Wireless communication conformance testing comprises RF conformance testing and signaling conformance testing for UE and base stations.

Currently, test specifications exist for LTE Rel-12, Rel-13, Rel-14 and Rel-15, however many work items of the working group RAN5 for Rel-15 have not been completed yet. The 5G system work item addresses various radio and core network interface options. Both a non-standalone (NSA) option with New Radio (NR) and LTE and standalone (SA) options are included in the RAN5 work plan.

In addition to formal conformance tests, there is a need to specify mobile network operator acceptance tests, including end-user-centric tests.

Based on 3GPP working group RAN4 conformance test specifications, the ETSI Task Force for the Production of Harmonized Standards (TFES, see section below) is developing European Norms (EN) for base stations, repeaters and user equipment. It is seeking to ascertain whether specified requirements match the essential parameters described under article 3.2 of RED 2014/53/EU [47].

4.3   ETSI

ETSI is one of the three European standards organizations for the electrical industry (the other two being CEN and CENELEC). The majority of standardization work is carried out in technical committees whose members are experts drawn from ETSI member companies or organizations. Each technical committee is responsible for drafting standards for its technology cluster, e.g. maritime radio equipment, energy efficiency technologies, radio products and EMC, mobile communications, etc.

In this context, the Task Force for the Production of Harmonized Standards (TFES) was formed from EMC and Radio Spectrum Matters (TC ERM) and Mobile Standard Groups (TC MSG). TFES is responsible for developing European Norms (EN) intended to become harmonized standards.

Following approval by the technical committee, the EN is subjected to a public enquiry via each national standardization organization (NSO) with 41 NSOs at present. This involves consultation and formulation of national positions. Each national committee casts its vote on the technical committee. If any technical comment is received during this public enquiry, the technical committee considers it, and if appropriate, revises the EN accordingly and puts it to a second vote. Once the proposed EN has been approved by voting, the EN is published. During this enquiry and voting cycle, the European Commission also reviews the proposed EN. If this review and vote are successful, the European Commission cites the EN in the EU's Official Journal. At this point, the EN is a recognized, harmonized standard and can then be used by manufacturers for self-declaration of conformity. The EN development process is illustrated in Figure 1.

It should be noted that ETSI, via its Centre for Testing and Interoperability (CTI), offers a range of services for testing interoperability. CTI organizes PlugfestTM events to gain practical insights while developing a standard.

Fig. 1:   EN development process

Source: 5G-ACIA
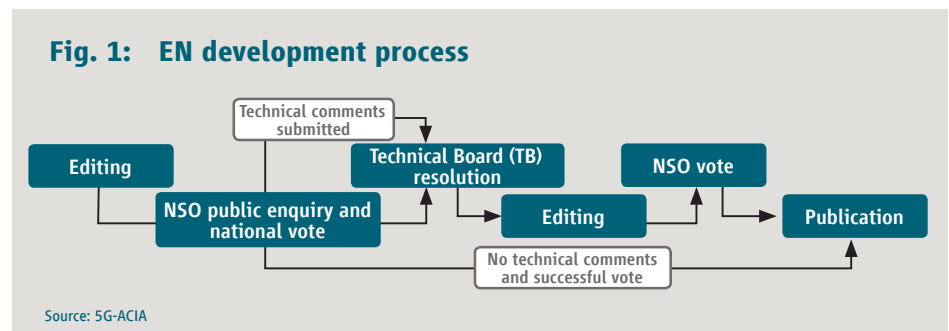
4.4   IEC

The International Electrotechnical Commission (IEC) is the world's leading organization for the drafting and publication of international standards for all electrical, electronic and related technologies. Where appropriate, the IEC cooperates with the ISO (International Organization for Standardization) or the ITU (International Telecommunication Union) to

ensure that international standards are harmonized and complementary. Joint committees ensure that standards combine and consolidate all relevant knowledge of experts working in related areas. [4]

The IEC System for Conformity Assessment Schemes for Electrotechnical Equipment and Components (IECEE), is a multilateral certification system based on IEC international standards. Its members apply the principle of mutual recognition for (reciprocal acceptance of) test results to ensure certification and/or approval at national levels around the world. The product category "Industrial automation" is one of 23 categories of electrical and electronic equipment and testing services the IECEE covers.

For industrial communication standards in the past, test specifications were developed by the user organizations as described in section 4.7 below.

4.5   IEEE

"IEEE is a leading developer of industry standards in a broad range of technologies that drive the functionality, capabilities, and interoperability of products and services, transforming how people live, work, and communicate." [5]. One of the topics addressed by the Institute of Electrical and Electronics Engineers (IEEE) is communication. *"The IEEE 802 LAN/MAN Standards Committee develops and maintains networking standards and recommended practices for local, metropolitan, and other area networks …The most widely used standards are for Ethernet, …wireless LAN, wireless PAN, wireless MAN, …and wireless RAN."* [6] Current 3GPP standards do not support Ethernet, but this is under preparation. Once Ethernet service is introduced into non-public (private) LTE/5G networks for factory automation, interoperability with current industrial Ethernet protocols will need to be assured. In the future this will also include time-sensitive networking (TSN).

4.6   IETF

The Internet Engineering Task Force (IETF) is responsible for the standardization of the Internet Protocol (IP). Services offered by non-public 5G/LTE networks in accordance with today's 3GPP standards are based on IP. For this reason, IP functionality is a key aspect of 5G testing and verification for industrial scenarios. IP tests must consider a number of scenarios, such as routing, unicast, broadcast and multicast transmissions, and quality of service (QoS). For example, current public LTE networks do not allow direct communication between wireless devices. In factory automation, devices need to communicate with each other. Moreover, machines will often share a single cellular connection, but there is a need to communicate with individual devices within each machine. With today's public cellular networks this is not possible, as only one IP address is allocated to each device.

4.7   User organizations for industrial communication systems

Testing on the part of user organizations for industrial communication systems primarily addresses interoperability and the seamless integration of devices into multi-vendor automation systems. Test procedures are based on the relevant specifications issued by the organizations and are usually standardized by IEC/TC65. Successful completion of all mandatory tests is a precondition for certification of conformity from the user organization. The tests are "black-box" tests, except for the inspection of the corresponding device descriptions/drivers. Typically, the devices are tested under normal operating conditions and under stress conditions to ensure that they fulfill user expectations with respect to communication quality and reliability. The electrical properties and timing behavior on the

communication channel are measured. The expected behavior due to parameterization and the provision of suitable diagnostic information on the device itself and in the network in the event of an error are also tested.

Generally, user organizations supply test kits that allow tests to be easily performed at the same time as development work. The final test is performed by certified test laboratories.

5   Test objects

5.1   General

Test objects for 5G communication in industrial scenarios vary considerably in type. This section provides an overview of the most relevant. For the conformance test methodology according to the ISO Open Systems Interconnection (OSI) reference model, the test object is referred to as the system under test (SUT). According to the definitions given in section 2, an SUT is a system that hosts at least one OSI layer implementation. In accordance with its definition, an SUT can be a wireless system, a wireless device, part of a wireless device, or even a set of wireless systems. If the SUT is a wireless device, the term DUT is commonly used. In this sense, all test objects or items described below can also be referred to as an SUT.

On the basis of the following descriptions, section 7 discusses which test objects are relevant for consideration by 5G-ACIA.

5.2   Concepts, methods, algorithms

Concepts, methods and algorithms for data transmission or communication functions are developed during the first phase of a product or system development lifecycle. Examples include concepts for plug and work, medium access methods and security algorithms. To establish their suitability for the product or system requirement specifications, models are developed or prototypes implemented. The developer can perform tests by simulations using model instances or by analyzing prototype implementations.

The concepts, methods and algorithms are validated with respect to defined functional requirements.

Reference interfaces can vary greatly in type, according to the test object. Therefore, these interfaces must be clearly specified by the developer. Standardized characteristic parameters and units of measurement must be used.

5.3   Wireless communication solution

A wireless communication solution is a specific implementation or instance of a wireless communication system. It consists of devices (with wireless connectivity e.g. a robot or mobile phone), infrastructure devices (e.g. a base station), and communication links between them (see Figure 2). A wireless communication solution provides the infrastructure for implementing a set of logical (communication) links between distributed application functions.

A wireless communication solution can be the object of several types of tests. Examples include tests at product/system level (conformance, interoperability, etc.), tests of installation and commissioning, periodic audits, diagnosis and failure analysis. The tests are

performed to establish compliance with the specified requirements. The requirements may be modified during the lifecycle, for example, due to extensions or modifications to a factory or production system.

Depending on the hardware and software implemented, and the degree of functional integration into the hardware, the reference interfaces may vary greatly (see section 5.7).

Fig. 2: Wireless communication solution

Source: 5G-ACIA
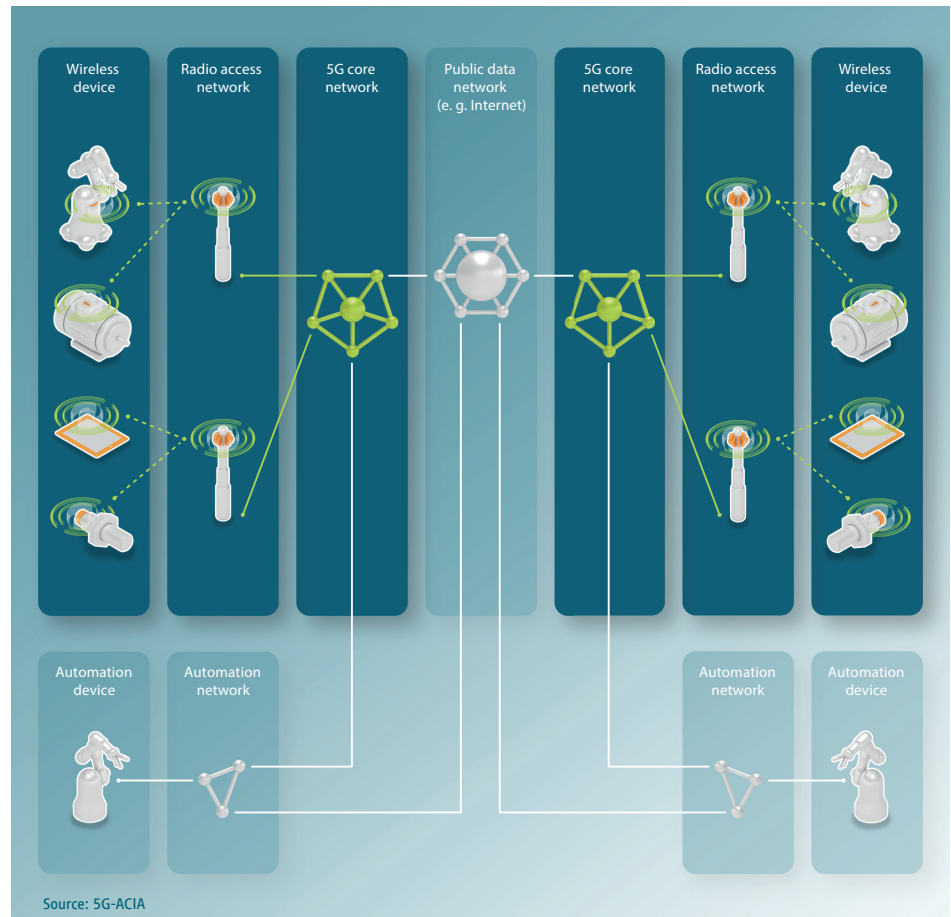
5.4   Logical link

A communication relationship between two logical endpoints in various reference interfaces is known as a logical link. Figure 3 shows a logical link between the tablet (left) and the motor (right), where the reference interfaces are located inside the devices.

User data, for example measurements made by a sensor or a set point for a drive control, are provided to the logical source endpoint for transmission. The identical data are expected at the target logical endpoint within an anticipated time interval or time frame, or in line with an anticipated data throughput.

To ensure test reproducibility and test result comparability, requirements and conditions impacting logical link transmissions should be standardized. Standardization should be independent of the underlying communication technology. The test standard should make it possible to formally describe requirements and conditions. Alternatively, requirement profiles for connected industries and automation can be developed.

Performance testing is the primary form of testing for logical links. For this reason, the required conditions and characteristics of the logical link must be defined in a quantifiable manner in the test specifications. Relevant parameters should be defined in a standard.

Depending on the hardware and software implemented, and the degree to which functions are integrated into the hardware, the reference interfaces of a logical link can vary greatly (see section 5.7).

Fig. 3: Logical link

Source: 5G-ACIA
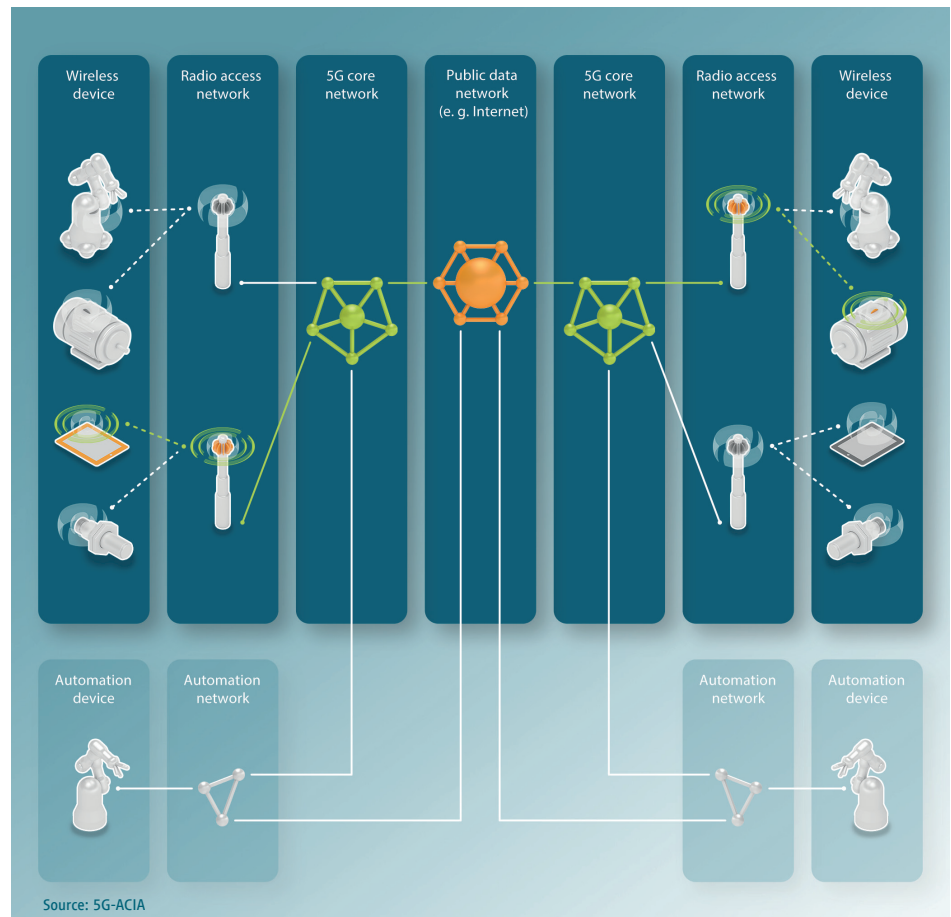
5.5   Core network

The core network, as depicted in Figure 4, connects the radio access network (RAN) to other private or public data networks, e. g. the Internet or the automation network. The RAN provides access to and coordinates management of resources across the base stations. Furthermore, the RAN allows a device to connect to the core network. It is responsible for device mobility management, including data routing and policy management.

The primary functions of the core network are, according to 3GPP TS 23.501 [48], to establish, manage, authenticate and secure data connections between wireless devices and a data network (DN) (e.g. the Internet or a cloud service). The following function modules are available for this purpose:
- Access and mobility management function (AMF): to establish a connection;
- AMF and session management function (SMF): to manage a connection;
- Unified data management (UDM) and authentication server function (AUSF);
- AMF, AUSF, SMF, and user plane function (UPF): to secure a connection.

With 5G, the core network also provides network slicing service functionality (NSSF), enabling operators to provide tailored network services for various industry use cases in line with their SLA by means of a single, end-to-end 5G infrastructure. The 5G core network will also support Wi-Fi access by means of a new platform called the non-3GPP interworking function (N3IWF).

The core network can be subjected to several types of tests.

Examples include tests for the various service types such as eMBB, URLLC and mMTC. Depending on the specific use case, tests may be performed on combinations of service types.

Where Wi-Fi interfaces have been implemented, additional tests may be required.

Fig. 4: Core networks

Source: 5G-ACIA
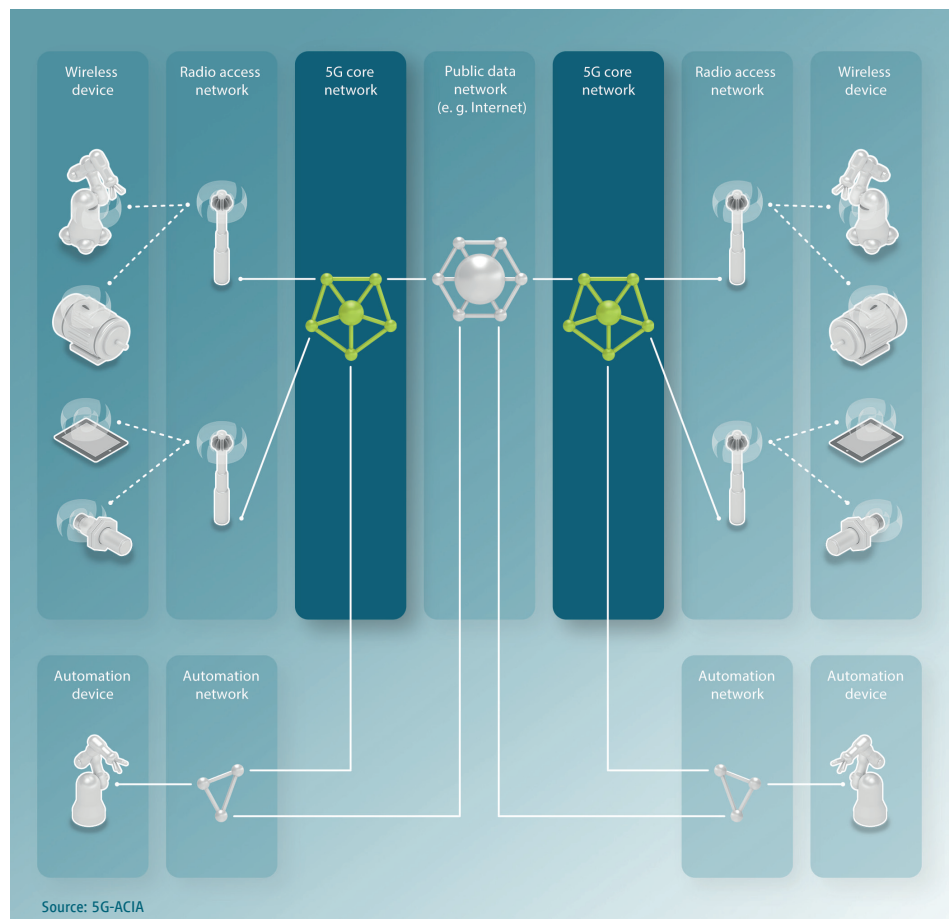
5.6 Base station

Infrastructure devices within a RAN (as shown in Figure 5) responsible for radio transmission or reception in a defined area to or from the UE are called eNB or ng-eNB for LTE technology or gNB for 5G NR technology (see [12]). Base stations comprise the full protocol stack for data processing and control of the physical and logical data link layers. A base station is connected to multiple transmit-receive points (TRPs), i. e. antennas. The TRPs can be co-located in one place or distributed.

Fig. 5: Base stations connected via the core network

Source: 5G-ACIA
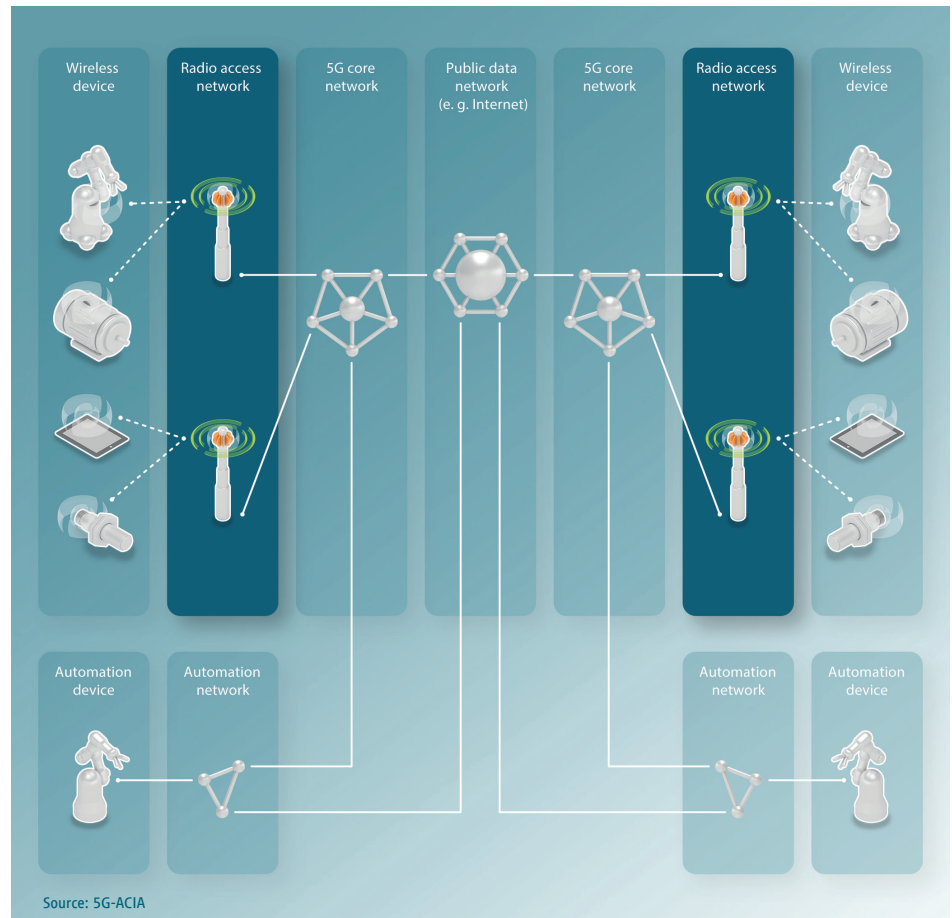
The gNBs and ng-eNBs provide the following radio resource management (RRM) functions, among others:
- Radio bearer, admission and connection, mobility control, dynamically allocating the resources to UEs for both uplink and downlink (scheduling),
- IP header compression, data encryption and data integrity protection,
- Routing of user plane data to UPF(s) and control plane data to AMF,
- Connection setup and termination,
- Scheduling and transmission of paging messages and system broadcast information,
- Measurement and measurement reporting configuration for device mobility and
- scheduling,
- Session management,
- Support for network slicing,
- QoS flow management and QoS mapping to data radio bearers,
- Radio access network sharing,
- Dual connectivity and interworking between NR and LTE networks.

The functional divide between the gNBs or ng-eNBs and the 5G core network is shown in Figure 6.

Fig. 6: Functional divide between base stations and 5G core network

gNB or ng-eNB
- Inter cell RRM
- Radio bearer control
- Radio admission control
- Connection mobility control
- Measurement, configuration & provision
- Dynamic resource allocation (scheduler)

5G core network

AMF
- NAS security
- Idle state mobility handling

SMF
- UE IP address allocation
- PDU session control

UPF
- Mobility anchoring
- PDU handling

Internet

Source: 5G-ACIA
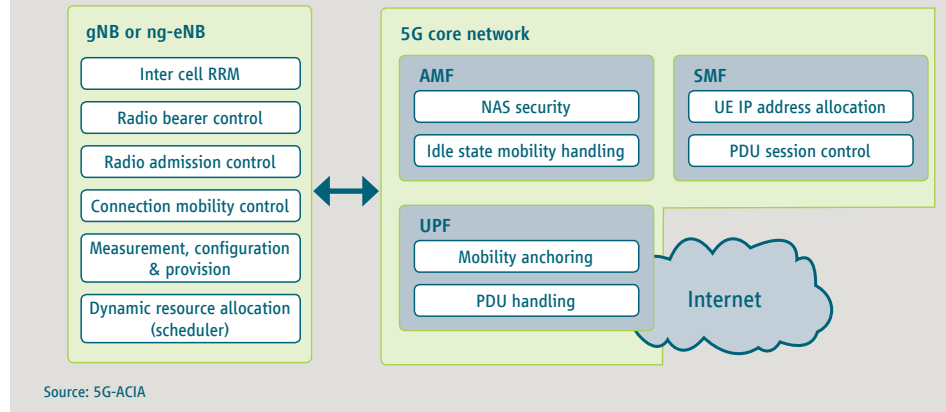
5.7 Wireless device

A wireless device implements wireless communication functions and local application functions. A wireless device incorporates a wireless communication module. A wireless communication module can, for example, be incorporated into a drive controller that implements the application functions. Another option is an integrated wireless device where wireless communication functions and application functions share the same microcontroller platform. Examples include a simple wireless sensor (as shown in Figure 7).

Fig. 7: Wireless devices

Wireless device | Radio access network | 5G core network | Public data network (e. g. Internet) | 5G core network | Radio access network | Wireless device

Automation device | Automation network | Automation network | Automation device

Source: 5G-ACIA

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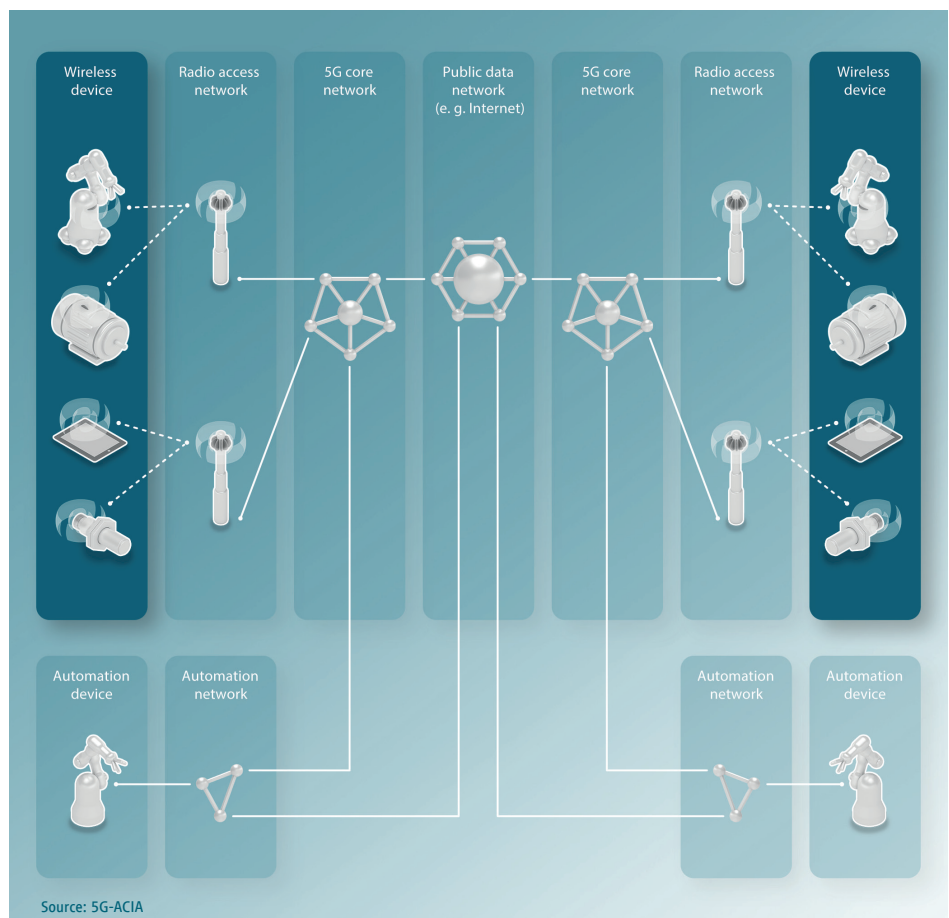
The device must be tested with respect to user requirements, as described in [7] or [8]. For example, communication performance should be tested, taking into account battery life of the wireless device or high device density. The test must establish that the wireless device fulfils reliability and availability requirements, positioning accuracy and security needs.

Depending on the hardware and software implemented, and the degree to which functions are integrated into the hardware, the reference interfaces of a logical link can vary greatly. An I/O device that incorporates 5G communication can only provide digital inputs and outputs for test purposes. In all cases, the hardware and software interface (IP, fieldbus, etc.) to be used for testing must be clearly specified. Standardized characteristic parameters and units of measurement must be used.

5.8　Wireless communication module

A wireless communication module is a component that implements wireless communication functions only. Wireless communication modules are incorporated into automation devices, as shown in Figure 8, in order to provide wireless connectivity. Under certain circumstances, the complete communication stack according to the OSI reference model may not be implemented as required by the application. Application functions are normally not implemented in a wireless communication module. Instead, the wireless communication module provides an interface that can be used by applications. The unmodulated data is transferred between the local industrial application and the 5G communication function via the interface. It can be implemented on the basis of interface standards, such as USB or PCI Express, and by means of standardized protocols, such as the AT command set or Ethernet. Implementation of both interface and protocol standards may be subjected to conformance testing, but this is not of high priority in the context of the manufacturing industry. More relevant is the range of functions provided at the interface. This includes user data traffic characteristics (for example user data lengths) and procedures for network registration, identification, security, etc. These functions could be considered within the scope of interoperability testing.

In the context of 5G-ACIA validation and testing, the wireless communication module is of interest, as it represents the interface between the 5G technology vendor and the vendor of the industrial device. This interface is the internal interface of the wireless device. In contrast, the modems on the 5G infrastructure side (i.e. at base stations) are not considered. 5G wireless communication modules must meet the 5G performance targets as specified by ITU. As the wireless communication module is one end of the 5G communication link, it needs to be tested to ensure the network requirements of the implemented service are fulfilled. Additionally, the modules should undergo performance testing since it may impact the end-to-end QoS from the application point of view.

Fig. 8: Wireless communication modules

Source: 5G-ACIA
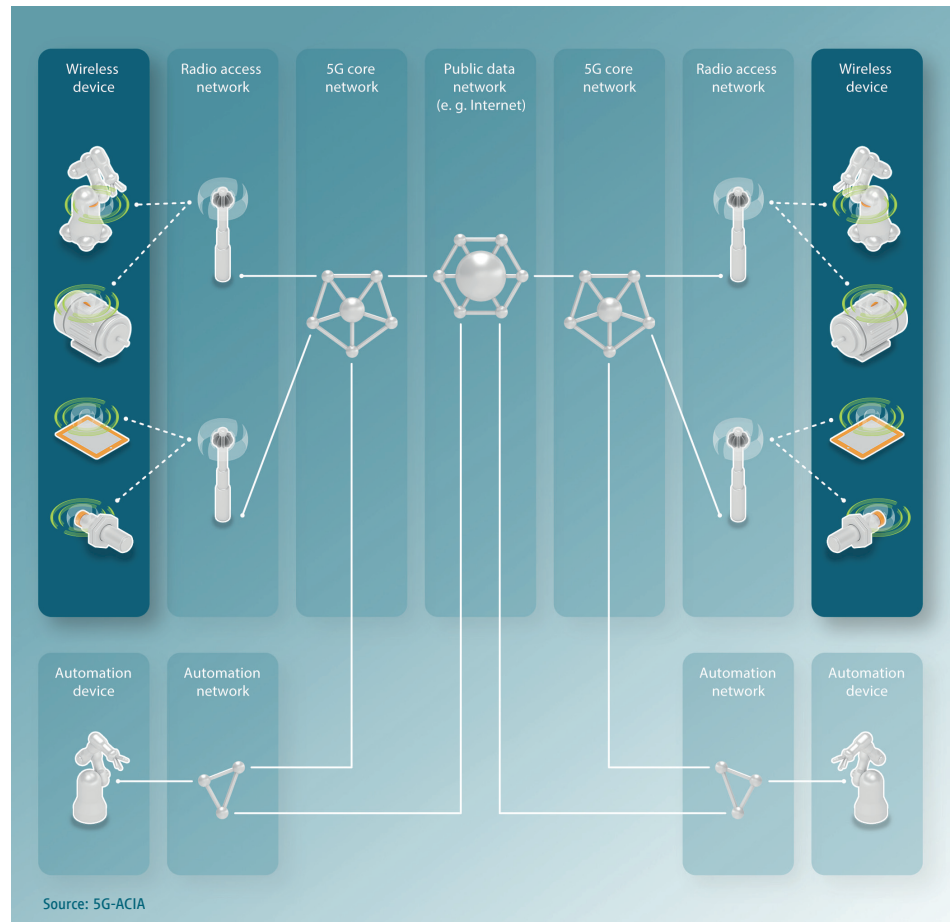
6 Test types and test objectives

6.1 General

The term "test" denotes a methodical experiment or examination to determine the suitability, characteristics or performance of a test object. Depending on the industry, area of expertise or personal preferences, a number of synonyms are used for the term "test" (see also the definition in section 2).

The test method depends on the lifecycle phase of the test object, and on the test objective. Figure 9 provides an overview of test types.

- Validation (of a product, concept, model or algorithm) and demonstration are important stages in the development of market-ready products,
- If products are based on a communication standard, for example, the product must be tested for conformance to that standard and for interoperability with other products designed and made to the same standard,
- When manufacturing a communication product, it is advisable to carry out in-process tests at various stages of production,
- When a communication product is installed and configured within an application system, commissioning and acceptance testing ensure its readiness for use and document the initial state,
- Periodic audits are performed to identify deviations from the initial or expected state. This can be supplemented or even replaced by diagnostic functions within the communication system itself,
- In the event an error occurs, dedicated tests can be used to discover the underlying cause.

Fig. 9: Test types across the lifecycle of a device or system

Product type	**Development**		Validation (concept, model, algorithm) — Demonstration
	Qualification/ certification		Conformance testing (standard) — Interoperability testing
	Certification / type approval		Certification testing
	Market introduction		Performance testing — Product validation
Product instance	**Manufacturing**		Product validation
	Operation	Commissioning and acceptance testing — Periodic audit — Diagnosis and failure analysis	

Source: 5G-ACIA

Tests can be performed using a simulation platform or a software and/or hardware testbed. Test types surrounded by dotted lines are described below for the sake of completeness and differentiation. It is recommended that 5G-ACIA undertake further activities for the test types with red borders.

6.2   Validation of concepts, models or algorithms

Newly developed methods, algorithms or models should be validated against the specified requirements. Validation means ascertaining that a concept, model or algorithm achieves a defined goal or to what extent they are practicable and feasible. This can be achieved by simulation or by measurements of example implementations in a software and/or hardware testbed.

In the context of mobile communication, the term proof of concept (POC) is sometimes employed for tests at this stage of development. A POC is the precursor to a demonstration. It does not result in deliverables. A POC clearly states what has to be tested, to what degree and under what conditions. The results of a POC are measurable and can serve as input for decision-making. In other words, it is not enough to say something "works", POC results must say how or how well it "works". A POC is a procedure to test a technical solution, idea or assumption in a customer's environment. The objective is to provide a high level of understanding of how the solution will function in a specific use case, and to give the mobile network provider an opportunity to closely align the solution's capabilities with real-world customer requirements.

Therefore, a POC is usually tailored to the use case and may or may not show to the full extent whether a given solution is going to work effectively. An example of a POC in the 5G context would be to determine whether radio access technologies for wireless communication interoperate.

Product or system validation is performed prior to taking a product or system to market. Product or system validation determines whether a product or system meets user requirements and functions as intended. This validation is performed across the entire product or system and usually by means of a simulated environment (relevant for the features included in the defined user requirements) and/or in real-world environments where the product or system will operate.

6.3 Demonstration

Many technologies undergo a demonstration stage because that is typically the best way to determine the feasibility and cost of implementation. Demonstration is an intermediate stage between validation of concept, model or algorithm and a performance testing. With the help of a demonstrator or prototype, either a fully implemented technical solution, or at least a substantial part of it, is simulated and tested to verify technical viability.

The objective is to generate a sufficiently large volume of test data within an acceptable time period for a specified number of use cases. A demonstrator varies in how closely it models the proposed solution, e.g. ranging from a visual mock-up to a working hardware and/or software implementation. This depends on the desired test data and use cases.
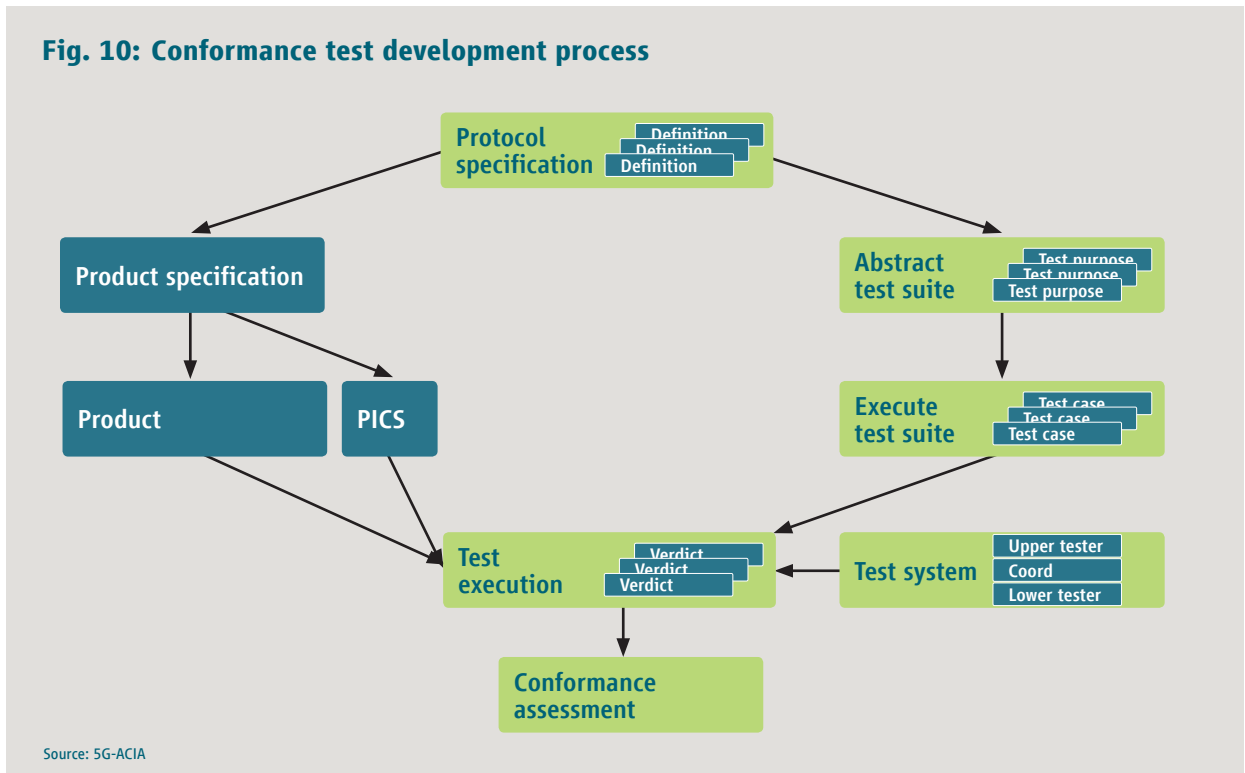
6.4 Conformance testing

Conformance testing entails establishing the extent to which a system under test (SUT) satisfies the requirements defined in the implementation conformance statement (ICS). It demonstrates that a product correctly implements the corresponding standard, and is able to exchange instructions and information with other implementations by means of a known protocol or set of protocols.

In the context of communication networks, a communication implementation, "the implementation under test (IUT)," is tested with respect to its specification. In this case, the specification includes RF (in the context of wireless communication networks) and protocol behavior, transfer syntax and signaling characteristics. The basics of conformance testing were defined by ITU-R in the technical recommendation X.290 [9] in 1988, which was subsequently refined by ISO/IEC in standard ISO/IEC 9646-1:1994 [49].

The process of developing a conformance test is depicted in simplified form in Figure 10. It begins with identifying the general conformance requirements of the RF (when applicable) and protocol specifications. The conformance requirements are divided into groups and subgroups by the specification of individual test objectives. This results in an abstract test suite. In a next step, the abstract test suite is converted into an executable form, comprising executable test cases. For each test case a verdict must be defined. A testing system needs to be created to apply the test cases to the system under test. The test can then be executed and conformance assessed.

Fig. 10: Conformance test development process

Source: 5G-ACIA

The use of formalized methods during the RF/protocol and test suite specification process enables automated, tool-based development testing. Moreover, the early availability of a conformance test allows a test-driven development process for product vendors.

Conformance testing aims to ensure that the results of tests performed in differing locations at differing times by differing people are comparable and consistent. This is of key importance when vendors, users and testers from multiple organizations become involved. Conformance testing of IUT is adaptable and may range from:
- Basic connection tests to identify significant cases of non-conformance, and serving as a "filter" before undertaking costlier tests, to
- Communication capability and behavior tests, up to
- Conformance resolution tests that give definite answers and diagnostic information in relation to specific conformance issues.

Test specifications and corresponding test suites can be developed for subsets of communication services only, or for specific communication layers only. In addition, the implementation conformance statements (ICS), which describe the features supported and not supported by the IUT, enable the creation of a test plan with test cases selected from the total list of test cases and applicable to the IUT.

Conformance testing will always be limited to a certain degree, for technical and economic reasons. Therefore, positive conformance testing results do not guarantee the implementation will correctly function as a whole. However, a positive result increases the probability that the communication implementation will communicate successfully with other communication implementations, and strengthens confidence in the communication implementation. Consequently, conformance is a prerequisite for interoperability.

6.5 Interoperability testing

The aim of an interoperability test is to ascertain that products developed by multiple manufacturers communicate correctly with one another in accordance with the same communication standard or reference specification.

"Interoperability testing is the most intuitive way of confirming that two or more systems work together. A number of standardization organizations use interoperability testing events as a means to raise the status of a specification to the level of a standard. At ETSI, interoperability testing events, so called Plugfests™, are organized and executed to provide feedback to technical bodies on the maturity of a given technology and its underlying standards." [10]

Ideally, interoperability tests should be based on a dedicated interoperability test standard.

6.6 Certification testing

By certifying a product, a person or entity attests that that product has passed performance and/or quality tests and meets the requirements given in regulations or specifications. Certification indicates to end-users that the product offers an acceptable level of quality regarding performance and interoperability, allowing them to distinguish products with proven quality from those with unknown quality. This process is based on a certification scheme.

The person or entity (i.e. industry association, user organization, government, etc.) that owns the certification scheme is responsible for establishing the rules that govern the certification process, and the requirements to be applied to the product by selecting the regulations, standards or specifications and the thresholds to be applied for the compliance verdicts.

In the context of communication, product certification is required when there are safety, security or connectivity implications. The aim of certification is to ensure that products do not have issues that could negatively impact the health or safety of persons or the QoS for other communication network users. For example, certification processes are applied to food, pharmaceuticals, healthcare products, hazardous goods, and products emitting radio waves, such as computers and cellular phones.

Typically, the certification process comprises, firstly, a phase to collect performance and/or interoperability behavior data and is followed, secondly, by a phase of reviewing the information prior to certification. The first phase can usually be performed by the certification applicant themselves or by an independent third party. The use of an independent third-party organization is mandated when the certification scheme requires neutrality and independence for the assessment of performance and/or interoperability.

In the second phase, the certifying body appointed by the owner of the certification scheme reviews the application, including the test results. If the certifier concludes that the product meets all required criteria as defined in the certification scheme, then the product is deemed worthy of certification. However, the final decision on granting or denying certification rests solely with the certification scheme owner, who is not permitted to be directly involved in product evaluation.

Usually, certified products are identified by a certification mark, such as a label (provided by the certification scheme owner) and are included on a publicly accessible list. The use of a certification mark is at the discretion of the certification scheme owner. The aim is to ensure certified products are easily identifiable and distinguishable from non-certified products.

Industry associations or user organizations may adopt an existing certification scheme (or schemes) and/or develop their own certification scheme. As an example, in the case of 5G technologies, GCF or PTCRB certification schemes for terminal products could be used as the basis for defining a 5G-ACIA certification scheme.

Type approval is a certification scheme owned by a government agency. It is a formal attestation that a product meets a minimum set of regulatory, technical and safety requirements. This can be based on the results of conformance testing plus the technical documentation provided by the product owner. Type approval may be mandatory for the sale and distribution of a product in a specific country or countries. Usually, type approval requires a declaration of conformity, where the product manufacturer or distributor takes responsibility for compliance with the regulations and applicable safety requirements.

6.7 Performance testing
6.7.1 Laboratory testing
The device and/or SUT are connected to an emulated network, which additionally may emulate real-world propagation effects. Due to the high number of potential test cases, laboratory testing needs to find a carefully considered trade-off between the number of meaningful test cases, i. e. the effort required to execute them, and the desired confidence level to comply with the given requirements. Laboratory testing is relevant to all ecosystem stakeholders as it provides indications of the real-world behavior of the wireless solution.

6.7.2 Field trials and field testing
A field trial or field test verifies the desired performance of the test object's system implementation in an environment which models the target application scenario to a large extent. i. e. field testing involves pre-commercial or commercial products deployed in the desired use case scenario. During the trial, wireless device and/or wireless system KPIs are captured and may be compared with predefined requirements. A field trial is performed on technical solutions that have already been validated. As a result, the field trial determines to what extent the required functionality is achieved under real-world conditions. Depending on the selected test setup, it is possible to a verify the function and/or configuration of a device or system. Field trials are relevant to all ecosystem stakeholders, as the real-world behavior of a specific wireless solution is analyzed.

Field tests are relevant for all ecosystem stakeholders, as the values of the characteristic parameters provide information on the real-world behaviour of the wireless solution.

6.8 Product validation
Product validation is a qualitative assessment to determine whether a wireless communication module, a base station or a wireless device meets user requirements. It is carried out before commencing volume manufacture.

6.9   Product verification

Product verification is a quantitative assessment to determine whether a wireless communication module, a base station or a wireless device meets design specifications. It is carried out when the product is manufactured.

6.10 Commissioning and acceptance testing

Commissioning and acceptance testing is the verification of a wireless solution before it enters ongoing operation. The installation of the communication system, its configuration and characteristic parameters should be documented, e.g. to serve as a reference for periodic audits or as a basis for extending or modifying the factory or production system.

6.11 Periodic audit

Periodic audits are performed to accomplish two purposes:

- To verify that products continue to comply with the requirements of conformance or certification testing. The goal is to ensure changes to the manufacturing process are not affecting the performance of the product and that it continues to be compliant. When performed by the manufacturer, it is considered an aspect of quality control. Where the certification scheme requires monitoring of production in addition to initial certification of the product design, it is performed by the certification scheme owner or their representative.
- To verify that a wireless communication system continues to work correctly after initial installation, without degradation of performance or functionality and that it still fulfils the applicable requirements. When performed by the owner of the wireless communication system, it is part of maintenance. Where the certification scheme requires certification of the entire system, it is performed by the scheme owner.

For both purposes, the periodic audits require measurement, examination and/or testing of one or more characteristics of the product or system, and comparison of the results with specified requirements to determine whether the requirements have been met for each characteristic.

In all cases, the measurement, examination or testing process has to be affordable and feasible in order to minimize required time and resources and to avoid interrupting the manufacturing process or operation of the system. The measurements, examinations or testing process usually comprises a subset of the tests for conformance testing. This subset is those tests that focus on the most relevant characteristics of applicable requirements, using tools that are suitable to testing in the manufacturing process or in the environment where the product is installed.

6.12 Diagnosis and failure analysis

In order to guarantee reliable use, communication systems must be constantly monitored. Where there are deviations from typical behavior, the reasons must be determined by suitable tests. If communication fails, communication must be analyzed and the cause identified and eliminated as quickly as possible.

7   Recommendations

Table 1 presents an overview of the relevant types of tests to be performed for the test objects described in this paper. The test objects are given on the left. The cells to the right indicate whether a test is recommended or required, and which tests are likely to be the subject of future work on the part of 5G-ACIA. The comment in each cell applies to the test object given in the left-hand column in its entirety. A dash indicates that the test is not relevant from 5G-ACIA's point of view. Certification tests are omitted in the table as they are highly diverse and their necessity depends on the specific product and/or target application.

Some of the tests listed in Table 1 are recommended or required. If the terms "recommended" or "required" are given for a test it is assumed that this test is already specified and will be performed independently of 5G-ACIA. Validation of 5G technology concepts, methods, algorithms or products, or of their combinations with industrial communication technologies, is recommended or required. The testing of core networks and base stations is beyond the scope of 5G-ACIA's remit.

Table 1: Relevant tests and test objects

TYPE OF TEST / TEST OBJECT		Validation	Demonstration	Conformance testing, interoperability testing	Performance testing	Commissioning and acceptance testing, periodic audit	Diagnosis and failure analysis
Concept, methods, algorithms		Required	Recommended	–	–	–	–
Wireless communication solution		–	Recommended	–	To be addressed by 5G-ACIA	Minimum requirements to be spec. by 5G-ACIA	Minimum requirements to be spec. by 5G-ACIA
Core network		–	–	–	Required	Required	Recommended
Logical link		–	–	–	To be addressed by 5G-ACIA	–	Minimum requirements to be spec. by 5G-ACIA
Product	Base station	Recommended	–	Required	–	–	Recommended
Product	Wireless device	Recommended	Recommended	5G-ACIA to contribute to specification	To be addressed by 5G-ACIA	–	Minimum requirements to be spec. by 5G-ACIA
Product	Wireless communication module	Recommended	–	Required	To be addressed by 5G-ACIA	–	Minimum requirements to be spec. by 5G-ACIA

Source: 5G-ACIA

Required: Testing based on existing specifications is required but beyond the scope of 5G-ACIA's remit.

Recommended: Testing is recommended but beyond the scope of 5G-ACIA's remit.

5G-ACIA intends to contribute to the specification of conformance and interoperability testing of wireless devices.

Performance testing of wireless solutions must consider a number of factors. 5G-ACIA should first define requirements for the test process. Then, uniform parameters and test verdicts must be developed based on the requirement specification defined by 5G-ACIA. Standardized test cases need to be derived for relevant use cases. Furthermore, 5G-ACIA will discuss how to design and build corresponding test interfaces. The relevance of physical tests or simulations may be discussed with respect to the various test objects. The architecture of a corresponding testing system may be made the subject of a work item.

5G-ACIA should provide recommendations for commissioning and acceptance testing, periodic audits, diagnosis and failure analysis of test objects as specified in Table 1. This includes suggestions for test parameters, functions and services, and for test cases. It is suggested that discussion of a "5G-ACIA approved" label, and related test and certification procedures, be postponed until legal issues have been clarified. If and when discussion goes ahead, it should consider the test object, test parameters and expected test results, the test procedure, the certification procedure, and a procedure to accredit test laboratories.

8 Abbreviations

AMF	Access and mobility management function
AUSF	Authentication server function
BS	Base station
CDMA	Code division multiple access
CTI	Centre for testing and interoperability
DN	Data network
DoC	Declaration of conformity
EDGE	Enhanced data rates for GSM evolution
eMBB	Enhanced mobile broadband
eNB	Evolved node B (base station) for UMTS and LTE
EN-DC	E-UTRA NR dual connectivity
EUT	Equipment under test
E-UTRA	Evolved Universal Mobile Telecommunications System
FDD	Frequency division duplex
GCF	Global Certification Forum
gNB	Next generation base station (node B) for 5G
GPRS	General Packet Radio System
GSM	Global system for mobile communication
HSDPA	High speed downlink packet access
HSPA+	Evolved HSDPA
HSUPA	High speed uplink packet access
ICS	Implementation conformance statement
ICT	Information and communications technology
IMS	IP multimedia subsystem
IUT	Implementation under test
KPI	Key performance indicator
LTE	Long Term Evolution
MCC TF	Mobile Competence Centre Task Force
mMTC	Massive machine type communication
N3IWF	Non-3GPP interworking function
NAS	Non-access stratum
ng-eNB	Next generation eNodeB
NodeB	Base station for UMTS and LTE
NR	New Radio
NSSF	Network slice selection function
OSI	Open system interconnection
OT	Operational technology
QE	Qualified equipment
QoS	Quality of service

PCS	Personal communications service
PDU	Protocol data unit
PICS	Protocol implementation conformance statement
PTCRB	PCS Type Certification Review Board
RAN	Radio access network
RAT	Radio access technology
RF	Radio frequency
RRM	Radio resource management
SLA	Service level agreement
SMF	Session management function
SUT	System under test
TDD	Time division duplex
TFES	Task Force for the Production of Harmonized Standards
TSN	Time sensitive networking
TTCN	Testing and test control notation
UDM	Unified data management
UE	User equipment
UMTS	Universal Mobile Telecommunications System
UPF	User plane function
URLLC	Ultra-reliable low-latency communication
UTRA	Universal terrestrial radio access

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