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vertical domains  
(3GPP TS 22.104 version 16.5.0 Release 16)**

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# Foreword

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# Introduction

The present document addresses a challenging class of vertical applications, namely cyber-physical control applications, which require very high levels of communication service availability, and some of them also require very low end-to-end latencies.

Real-time Ethernet is one of the established wireline communication technologies for cyber-physical control applications, and this specification identifies requirements that 5G systems must meet to support real-time Ethernet.

The present document provides new Stage 1 requirements based on the input from relevant stakeholders of the respective vertical domains.

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# 1 Scope

The present document provides Stage 1 normative service requirements for 5G systems, in particular service requirements for cyber-physical control applications in vertical domains. In the context of the present document, cyber-physical systems are to be understood as systems that include engineered, interacting networks of physical and computational components; control applications are to be understood as applications that control physical processes.

Communication services supporting cyber-physical control applications need to be ultra-reliable and, in some cases, the end-to-end latency must be very low. Communication for cyber-physical control applications supports operation in various vertical domains, for instance industrial automation and energy automation.

The aspects addressed in the present document include:

- end-to-end service performance requirements and network performance requirements related to these end-to-end service performance requirements;
- support for LAN-type services specific to industrial/high performance use cases. Related Ethernet functionalities include, for example, those in IEEE 802.1Qbv.

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# 2 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

- References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific.
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- For a non-specific reference, the latest version applies. In the case of a reference to a 3GPP document (including a GSM document), a non-specific reference implicitly refers to the latest version of that document *in the same Release as the present document*.

- [1] 3GPP TR 21.905: "Vocabulary for 3GPP Specifications".
- [2] 3GPP TS 22.261: "Service requirements for the 5G system".
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NOTE: IEEE Std 802.1Qbv-2015 "Enhancements for Scheduled Traffic" has been included into IEEE Std 802.1Q-2018.
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- [22] "IEEE Standard for Local and metropolitan area networks--Timing and Synchronization for Time-Sensitive Applications," IEEE Std 802.1AS-Rev/D7.3, pp. 1-502, August 2018.
- [23] 3GPP TS 22.289: "Mobile Communication System for Railways".

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## 3 Definitions, symbols and abbreviations

### 3.1 Definitions

For the purposes of the present document, the terms and definitions given in 3GPP TR 21.905 [1] and the following apply. A term defined in the present document takes precedence over the definition of the same term, if any, in 3GPP TR 21.905 [1].

**characteristic parameter:** numerical value that can be used for characterising the dynamic behaviour of communication functionality from an application point of view.

**clock synchronicity:** the maximum allowed time offset within a synchronisation domain between the sync master and any sync device .

NOTE 1: Clock synchronicity (or synchronicity) is used as KPI of clock synchronisation services.

NOTE 1A: Clock synchronicity is also referred to as clock (or time) synchronization precision.

**clock synchronisation service:** the service to align otherwise independent user-specific UE clocks.

**communication service availability:** percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.

NOTE 2: The end point in "end-to-end" is assumed to be the communication service interface.

NOTE 3: The communication service is considered unavailable if it does not meet the pertinent QoS requirements. If availability is one of these requirements, the following rule applies: the system is considered unavailable if an expected message is not received within a specified time, which, at minimum, is the sum of maximum allowed end-to-end latency and survival time.

NOTE 4: This definition was taken from TS 22.261 [2].

**communication service reliability:** ability of the communication service to perform as required for a given time interval, under given conditions.

NOTE 5: Given conditions would include aspects that affect reliability, such as: mode of operation, stress levels, and environmental conditions.

NOTE 6: Reliability may be quantified using appropriate measures such as mean time between failures, or the probability of no failure within a specified period of time.

NOTE 7: This definition is based on IEC 61907 [7].

**end-to-end latency:** the time that takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.

NOTE 8: This definition was taken from TS 22.261 [2].

**error:** discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition.

NOTE 9: taken from IEC 61784-3 [3].

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

NOTE 10: Low latency typically means below 10 ms delivery time.

NOTE 11: This definition is taken from IEC 62657-1 [18].

**global clock:** a user-specific synchronization clock set to a reference timescale such as the International Atomic Time.

**influence quantity:** quantity not essential for the performance of an item but affecting its performance.

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

NOTE 12: This definition is taken from IEC 62657-1 [18].

**service area:** geographic region where a 3GPP communication service is accessible.

NOTE 13: The service area can be indoors.

NOTE 14: For some deployments, e.g., in process industry, the vertical dimension of the service area can be considerable.

NOTE 15: This definition was taken from TS 22.261 [2].

**survival time:** the time that an application consuming a communication service may continue without an anticipated message.

**sync device:** device that synchronizes itself to the master clock of the synchronization domain.

**sync master:** device serving as the master clock of the synchronization domain.

**transfer interval:** time difference between two consecutive transfers of application data from an application via the service interface to 3GPP system.

NOTE 16: This definition is based on subclause 3.1.85 in IEC 62657-2 [17].

**user experienced data rate:** the minimum data rate required to achieve a sufficient quality experience, with the exception of scenario for broadcast like services where the given value is the maximum that is needed.

NOTE 17: This definition was taken from TS 22.261 [2].

**vertical domain:** an industry or group of enterprises in which similar products or services are developed, produced, and provided.

**working clock:** a user-specific synchronization clock for a localized set of UEs collaborating on a specific task or work function.

## 3.2 Symbols

For the purposes of the present document, the following symbols apply:

<symbol>            <Explanation>

## 3.3 Abbreviations

For the purposes of the present document, the abbreviations given in 3GPP TR 21.905 [1] and the following apply. An abbreviation defined in the present document takes precedence over the definition of the same abbreviation, if any, in 3GPP TR 21.905 [1].

CSIF	Communication Service Interface
EPON	Ethernet Passive Optical Network
FIFO	First In, First Out
GOOSE	Generic Object-Oriented Substation Event
HCL	Higher Communication Layer
HMI	Human Machine Interface
IMU	Inertial Measurement Unit
LCL	Lower Communication Layer
PMU	Phasor Measurement Unit

---

## 4 Overview

### 4.1 Introduction

For the purpose of this document, a vertical domain is a particular industry or group of enterprises in which similar products or services are developed, produced, and provided. Automation refers to the control of processes, devices, or systems in vertical domains by automatic means. The main control functions of automated control systems include taking measurements, comparing results, computing any detected or anticipated errors, and correcting the process to avoid future errors. These functions are performed by sensors, transmitters, controllers, and actuators.

In the context of this document, cyber-physical systems are referred to as systems that include engineered, interacting networks of physical and computational components. Cyber-physical control applications are to be understood as applications that control physical processes. Cyber-physical control applications in automation follow certain activity patterns, which are open-loop control, closed-loop control, sequence control, and batch control (see Clause 4.2).

Communication services supporting cyber-physical control applications need to be ultra-reliable, dependable with a high communication service availability, and often require low or (in some cases) very low end-to-end latency.

Communication in automation in vertical domains follows certain communication patterns. The most well-known is periodic deterministic communication, others are aperiodic deterministic communication and non-deterministic communication (see Clause 4.3).

Communication for cyber-physical control applications supports operation in various vertical domains, for instance industrial automation and energy automation. This document addresses service requirements for cyber-physical control applications and supporting communication services from the vertical domains of factories of the future (smart

manufacturing), electric power distribution, and central power generation. Service requirements for cyber-physical control applications and supporting communication services for rail-bound mass transit are addressed in TS 22.289 [23].

## 4.2 Activity patterns in automation

**Open-loop control:** The salient aspect of open-loop control is the lack of feedback from the output to the control; when providing commands to an actuator, it is assumed that the output of the influenced process is predetermined and within an acceptable range. This kind of control loop works if the influences of the environment on process and actuator are negligible. Also, this kind of control is applied in case unwanted output can be tolerated [8].

**Closed-loop control:** Closed-loop control enables the manipulation of processes even if the environment influences the process or the performance of the actuator changes over time. This type of control is realised by sensing the process output and by feeding these measurements back into a controller [8].

**Sequence control:** Sequence control may either step through a fixed sequence or employ logic that performs different actions based on various system states and system input [8]. Sequence control can be seen as an extension of both open-loop and closed-loop control, but instead of achieving only one output instance, an entire sequence of output instances can be produced [9].

**Batch control:** Batch processes lead to the production of finite quantities of material (batches) by subjecting input materials to a defined order of processing actions by use of one or more pieces of equipment [10].

## 4.3 Communication attributes

Communication in automation can be characterised by two main attributes: periodicity and determinism.

Periodicity means that a transmission interval is repeated. For example, a transmission occurs every 15 ms. Reasons for a periodical transmission can be the periodic update of a position or the repeated monitoring of a characteristic parameter. Most periodic intervals in communication for automation are rather short. The transmission is started once and continuous unless a stop command is provided.

An aperiodic transmission is, for example, a transmission which is triggered instantaneously by an event, i.e., events are the trigger of the transmission. Events are defined by the control system or by the user. Example events are:

- Process events: events that come from the process when thresholds are exceeded or fallen below, e.g., temperature, pressure, level, etc.
- Diagnostic events: events that indicate malfunctions of an automation device or module, e.g., power supply defective; short circuit; too high temperature; etc.
- Maintenance events: events based on information that indicates necessary maintenance work to prevent the failure of an automation device.

Most events, and especially alarms, are confirmed. In this context, alarms are messages that inform a controller or operator that an event has occurred, e.g., an equipment malfunction, process deviation, or other abnormal condition requiring a response. The receipt of the alarm is acknowledged usually within a short time period by the application that received the alarm. If no acknowledgment is received from the target application after a preset time, the so-called monitoring time, the alarm is sent again after a preset time or some failure response action is started.

Determinism refers to whether the delay between transmission of a message and receipt of the message at the destination address is stable (within bounds). Usually, communication is called deterministic if it is bounded by a given threshold for the latency/transmission time. In case of a periodic transmission, the variation of the interval is bounded.

## 4.4 Control systems and related communication patterns

There are preferences in the mapping between the type of control and the communication pattern. Open-loop control is characterised by one or many messages sent to an actuator. These can be sent in a periodic or an aperiodic pattern. However, the communication means used need to be deterministic since typically an activity response from the receiver and/or the receiving application is expected.

Closed-loop control produces both periodic and aperiodic communication patterns. Closed-loop control is often used for the control of continuous processes with tight time-control limits, e.g., the control of a printing press. In this case, one typically relies on periodic communication patterns. Note that in both the aperiodic and periodic case, the communication needs to be deterministic.

Logging of device states, measurements, etc. for maintenance purposes and such typically entails aperiodic communication patterns. In case the transmitted logging information can be time-stamped by the respective function, determinism is often not mandatory.

In practice, vertical communication networks serve a large number of applications exhibiting a wide range of communication requirements. In order to facilitate efficient modelling of the communication network during engineering and for reducing the complexity of network optimisation, traffic classes or communication patterns have been identified [6]. There are three typical traffic classes or communication patterns in industrial environments [6], i.e.,

- deterministic periodic communication: periodic communication with stringent requirements on timeliness of the transmission.
- deterministic aperiodic communication: communication without a preset sending time. Typical activity patterns for which this kind of communication is suitable are event-driven actions.
- non-deterministic communication: subsumes all other types of traffic, including periodic non-real time and aperiodic non-real time traffic. Periodicity is irrelevant in case the communication is not time-critical.

Some communication services exhibit traffic patterns that cannot be assigned to one of the above communication patterns exclusively (mixed traffic).

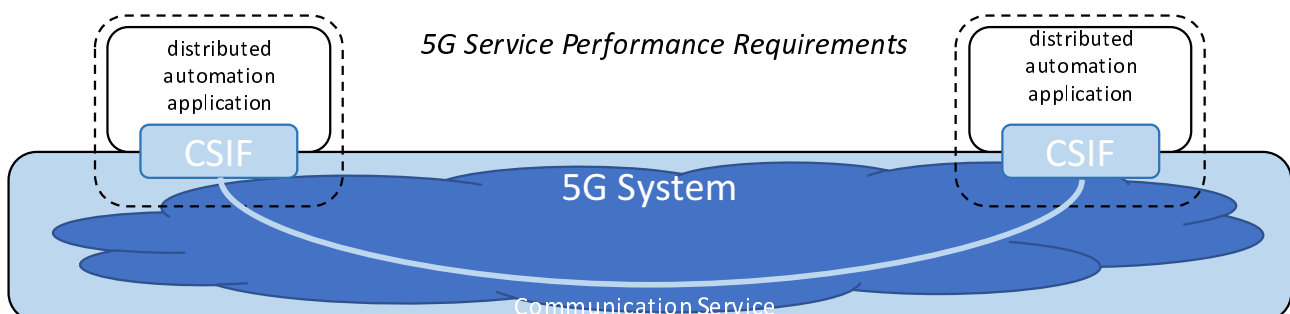
## 4.5 Implications for 5G systems

In order to be suitable for automation in vertical domains, 5G systems need to be dependable and flexible to meet specific KPIs to serve specific applications and use cases. They need to come with the system properties of reliability, availability, maintainability, safety, and integrity. What particular requirements each property needs to meet depends on the particularities of the domain and the use case. The requirements in this document provide various sets of performance criteria that need to be met to satisfactorily support different use cases of cyber-physical control applications used by various vertical markets.

# 5 Performance requirements

## 5.1 Overview

There are two fundamental perspectives concerning dependable communication in 5G systems: the end-to-end perspective of the communication services and the network perspective (see Figure 5.1-1).



CSIF – Communication Service Interface between distributed automation application/function and 5G system

**Figure 5.1-1: Network perspective of 5G system**

The Communication Service in Figure 5.1-1 may be implemented as a logical communication link between a UE on one side and a network server on the other side, or between a UE on one side and a UE on the other side.

In some cases, a local approach (e.g. network edge) is preferred for the communication service on the network side in order to reduce the latency, to increase communication service availability, or to keep sensitive data in a non-public network on the factory site.

The tables in Clauses 5.2 through 5.5 below provide sets of requirements, where periodicity and determinism are critical to meeting cyber-physical control application needs in various vertical scenarios. While many use cases have similar KPI values, the important distinction is that in order to meet the needs of different verticals and different uses, the 5G system will need to be sufficiently flexible to allow deployment configurations that can meet the different sets of KPIs specific to each use.

Communication service availability is considered an important service performance requirement for cyber-physical applications, especially for applications with deterministic traffic. The communication service availability depends on the latency and reliability (in the context of network layer packet transmissions, as defined in TS 22.261 [2]) of the logical communication link, as well as the survival time of the cyber-physical application (see Annex C.3 for further details on these relations).

The communication service reliability requirements also depend on the operation characteristics of the corresponding cyber-physical applications. Typically, the communication services critical for the automation application also come with stringent communication service reliability requirements. Note that the communication service reliability requirement has no direct relationship with the communication service availability requirement.

The "# of UEs" in the tables in clauses 5.2 to 5.5 is intended to give an indication of the UE density that would need to be served within a given service area (e.g. to understand the kind of capacity demand it puts on the 5G system).

Clock synchronisation is needed in many "vertical" use cases. The requirements and tables in Clause 5.6 provide specific criteria for managing time sensitive communications in an industrial environment.

High accuracy positioning is becoming essential for Factories of the Future. The reason for this is that tracking of mobile devices as well as mobile assets is becoming increasingly important in improving processes and increasing flexibility in industrial environments, Clause 5.7 provides positioning requirements for horizontal accuracy, availability, heading, latency and UE speed in an industrial use case scenario.

An example of the relationship between reliability (in the context of network layer packet transmissions, as defined in TS 22.261 [2]), survival time, and communication service availability of a logical communication link is illustrated in the following Table 5.1-1.

**Table 5.1-1: Example of relationship between reliability (as defined in TS 22.261) and communication service availability when the survival time is equal to the transfer interval.**

Communication service availability	Reliability (as defined in TS 22.261)
99,9999 %	99,9 %
99,999999 %	99,99 %
99,99999999 %	99,999 %
99,9999999999 %	99,9999 %
99,999999999999 %	99,99999 %

## 5.2 Periodic deterministic communication

Periodic deterministic communication is periodic with stringent requirements on timeliness and availability of the communication service. A transmission occurs every transfer interval. A description of periodic deterministic communication can be found in Clauses 4.3 and 4.4. Additional information on the underlying use cases of the sets of requirements in Table 5.2-1 can be found in Annex A. Further information on characteristic parameters and influence quantities used in Table 5.2-1 can be found in Annex C.

The 5G system shall be able to provide periodic deterministic communication with the service performance requirements for individual logical communication links that realise the communication services reported in Table 5.2-1.