PD IEC TR 61850-90-13:2021

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# Communication networks and systems for power utility automation

Part 90-13: Deterministic networking technologies

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# National foreword

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# IEC TR 61850-90-13

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# TECHNICAL REPORT

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## Communication networks and systems for power utility automation – Part 90-13: Deterministic networking technologies

INTERNATIONAL
ELECTROTECHNICAL
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## Part 90-13: Deterministic networking technologies

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IEC TR 61850-90-13, which is a technical report, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

The text of this Technical Report is based on the following documents:

| Draft TR | Report on voting |
|---|---|
| 57/2236/DTR | 57/2301/RVDTR |

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

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This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 61850 series, published under the general title *Communication networks and systems for power utility automation*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
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# INTRODUCTION

Deterministic networking technologies enable applications that require bounded communication delays regardless of network load or reconfiguration. They allow traffic of different time-criticality to share the same physical medium. Deterministic network technologies are based on the pre-allocation of resources using for example scheduling, traffic shaping and the pre-emption of low priority messages to guarantee the timely delivery of high-priority traffic.

Power automation and control is an industry domain where deterministic networking is needed to support existing use cases and applications (requiring real-time communication), and to enable new developments. This networking is currently being provided by SDH networks or dedicated (for protection communications) Ethernet networks; however significant drives (economic and political) are now emerging to use "converged" Ethernet networks.

In this document the term WAN is used for the inter-substation communication networks, with the driving force usually being the desire of a utility to use the same network infrastructure for IT as well as for operational tasks such as inter-substation protection communications.

The term LAN is used for the intra-substation communication networks. Converged networks are those supporting mixed traffic (e.g. process data, configuration management, voice and video surveillance data) in the same network being used for critical power automation applications. In the same way that using public transportation to get from A to B in a timely (deterministic) manner requires the ability to be guaranteed a seat at a particular time, using a communication network for the deterministic delivery of data also requires the guarantee of access at a particular time. This document identifies, describes, and discusses the known technologies to address this determinism issue.

Summary:

Clause 5 describes the problem (with non-deterministic networks);

Clause 6 provides use cases;

Clause 7 lists deterministic networking technologies;

Clause 8 discusses interoperability issues;

Clause 9 suggests changes to the IEC 61850 standards needed to support determinism;

Annex A lists some related works and liaisons.

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# COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

## Part 90-13: Deterministic Networking Technologies

## 1 Scope

This part of IEC 61850, which is a Technical Report, provides information, use cases, and guidance on whether and how to use deterministic networking technologies. Furthermore, this document comprises technology descriptions, provides guidance how to achieve compatibility and interoperability with existing technologies, and lays out migration paths. It will separate the problem statement from the possible solutions.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60834-1:1999, *Teleprotection equipment of power systems – Performance and testing – Part 1: Command systems*

IEC 60870-5-104:2006, *Telecontrol equipment and systems – Part 5-104: Transmission protocols – Network access for IEC 60870-5-101 using standard transport profiles*

IEC/IEEE 61588:2009*, Precision clock synchronization protocol for networked measurement and control systems*

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEC 61850-5:2013, *Communication networks and systems for power utility automation – Part 5: Communication requirements for functions and device models*

IEC 61850-6:2009*, Communication networks and systems for power utility automation – Part 6: Configuration description language for communication in electrical substations related to IEDs*

IEC 61850-8-1:2011, *Communication networks and systems for power utility automation – Part 8-1: Specific communication service mapping (SCSM) – Mappings to MMS (ISO 9506-1 and ISO 9506-2) and to ISO/IEC 8802-3*

IEC 61850-9-2, *Communication networks and systems for power utility automation – Part 9-2: Specific communication service mapping (SCSM) – Sampled values over ISO/IEC 8802-3*

IEC/IEEE 60802, *Time-sensitive networking profile for industrial automation*

IEC/IEEE 61850-9-3-2016, *IEC/IEEE International Standard – Communication networks and systems for power utility automation – Part 9-3: Precision time protocol profile for power utility automation*

IEC TR 61850-90-1:2010, *Communication networks and systems for power utility automation – Part 90-1: Use of IEC 61850 for the communication between substations*

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IEC TR 61850-90-2:2016, *Communication networks and systems for power utility automation – Part 90-2: Using IEC 61850 for communication between substations and control centres*

IEC TR 61850-90-4:2020, *Communication networks and systems for power utility automation – Part 90-4: Network engineering guidelines*

IEC TR 61850-90-5:2012, *Communication networks and systems for power utility automation – Part 90-5: Use of* IEC 6*1850 to transmit synchrophasor information according to* IEEE *C37.118*

IEC TR 61850-90-12:2020, *Communication networks and systems for power utility automation – Part 90-12: Wide area network engineering guidelines*

IEC 62351-7:2017, *Power systems management and associated information exchange – Data and communications security – Part 7: Network and System Management (NSM) data object models*

IEC 62439-3:2016, *Industrial communication networks – High availability automation networks – Part 3: Parallel Redundancy Protocol (PRP) and High-availability Seamless Redundancy (HSR)*

IEEE 802.1AS, *IEEE Standard for Local and Metropolitan Area Networks – Timing and Synchronization for Time-Sensitive Applications*, available at http://www.ieee.org

IEEE 802.1Q, *IEEE Standard for Local and metropolitan area networks – Bridges and Bridged Networks;* available at <http://www.ieee.org>

IEEE 802.1Qcc-2018, *IEEE Standard for Local and Metropolitan Area Networks – Bridges and Bridged Networks – Amendment 31: Stream Reservation Protocol (SRP) Enhancements and Performance Improvements*

IEEE 802.3-2018, *IEEE Standard for Ethernet*

IEEE C37.94-2017, *IEEE Standard for N times 64 kbps Optical Fiber Interfaces between Teleprotection and Multiplexer Equipment*

IEEE C37.118.1-2011, *IEEE Standard for Synchrophasor Measurements for Power Systems*

## 3 Terms and definitions, abbreviated terms and acronyms

### 3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

**3.1.1**
**Centralized Network Configuration**
**CNC**
logical component that configures network resources on behalf of TSN applications (users)

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**3.1.2**
**Centralized User Configuration**
**CUC**
logical component that discovers and configures application (user) resources in end stations; the CUC exchanges information with the CNC in order to configure TSN features on behalf of its end stations

**3.1.3**
**convergence**
heterogeneous applications running on devices connected to the same physical network (LAN, WAN, or combination of both) which are able to exchange data, within the defined QoS parameters derived from application requirements

**3.1.4**
**deterministic jitter**
property of a system to change its output in response to a change of its input after a guaranteed minimum delay and before a guaranteed maximum delay, under error-free conditions

**3.1.5**
**deterministic latency**
property of a system to change its output in response to a change of its input within a guaranteed maximum delay, under error-free conditions

**3.1.6**
**deterministic networking**
predictable network behaviour which can be characterized by bounded latency, nearly zero jitter and extremely low data loss rates

**3.1.7**
**DetNet**
IETF Deterministic Networking (DetNet) Working Group

**3.1.8**
**end station**
device attached to a local area network (LAN) or wide area network (WAN), which acts as a source of, and/or destination for, traffic carried on the LAN or WAN

Note 1 to entry: The term end-station is used in relation to time-sensitive networking.

**3.1.9**
**EtherCAT**
Ethernet fieldbus system according to the type 12 specifications of IEC 61158 (all parts)

**3.1.10**
**hard real time**
property of a system with a deterministic latency

**3.1.11**
**jitter**
time variation of an expected occurrence with respect to a defined period

**3.1.12**
**Listener**
end station that is the destination, the receiver of a Stream

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**3.1.13**
**Pdelay**
measure of the time from when a message is transmitted from one device to when the same part of the same message is received by the other device and vice versa as defined in IEC/IEEE 61588 and IEEE 802.1AS-2020

**3.1.14**
**pre-emption**
suspension of the transmission of a pre-emptible frame to allow one or more express frames to be transmitted before transmission of the pre-emptible frame is resumed

**3.1.15**
**process data**
data object containing application objects designated to be transferred cyclically or acyclically for the purpose of processing

**3.1.16**
**project**
system part with ownership of a set of IEDs, typically those located in one substation, and handled by one system configuration tool

**3.1.17**
**soft real-time**
property of a system whose latency is a probabilistic function with a low probability to exceed defined upper and lower bounds under error-free conditions

**3.1.18**
**Stream**
unidirectional flow of time-sensitive application data between from one source (Talker) to one or more destinations (Listeners)

**3.1.19**
**Talker**
end station that is the source or producer of a Stream

**3.1.20**
**traffic shaping**
queue management technique in packet-based networks to administrate data rates and bandwidth

**3.1.21**
**TSN**
series of Ethernet standards which is developed by the Time-Sensitive Networking task group in the scope of IEEE 802.1

## 3.2 Abbreviated terms and acronyms

The following abbreviated terms and acronyms apply to this document.

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| | |
|---|---|
| ARP | Address Resolution Protocol |
| CIP | Critical Infrastructure Protection |
| CNC | Centralized Network Configuration |
| CUC | Centralized User Configuration |
| DC | Distributed Clocks |
| DDoS | Distributed Denial of Service |
| DoS | Denial of Service |
| DER | Distributed Energy Resources |
| DL- | Data-link layer (as a prefix) |
| DLL | DL-layer |
| DLPDU | DL-protocol-data-unit |
| ENI | EtherCAT Network Information |
| ESI | EtherCAT Slave Information |
| ESP | Electronic Security Perimeter |
| FQTSS | Forwarding and Queueing for Time-Sensitive Streams |
| GNSS | Global Navigation Satellite System |
| GOOSE | Generic Object Oriented Substation Event |
| HMI | Human Machine Interface |
| HSR | High-availability Seamless Redundancy |
| ID | Identification |
| IED | Intelligent Electronic Device – any programmable or configurable device in the system |
| IERS | International Earth Rotation and Reference Systems Service |
| IETF | Internet Engineering Task Force |
| IP | Internet Protocol |
| IPv4 | Internet Protocol version 4 |
| IPv6 | Internet Protocol version 6 |
| IS-IS | Intermediate System to Intermediate System |
| IT | Information Technology |
| LAN | Local area network |
| LD | Logical Device (IEC 61850) |
| MAC | Media Access Control |
| MPLS | Multiprotocol Label Switching |
| MSRP | Multiple Stream Registration Protocol (MSRP) |
| NERC | North American Electric Reliability Corporation |
| NFV | Network Function Virtualization |
| OSI | Open System Interconnect |
| PDF | Portable Document Format |
| PMU | Phasor Measurement Unit |
| PRP | Parallel Redundancy Protocol |
| PTP | Precision Time Protocol |
| QoS | Quality of Service |
| RAS | Remedial Action Scheme |

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| | |
|---|---|
| RSTP | Rapid Spanning Tree Protocol |
| SA | Substation Automation |
| SCD | System Configuration Description in the sense of 61850-6. Output of a system tool of a project to configure the IEDs belonging to the project (imported by IED tools). |
| SCL | Substation Configuration description Language according to IEC 61850 |
| SDH | Synchronous Digital Hierarchy |
| SDN | Software Defined Networking |
| SNMP | Simple Network Management Protocol |
| SONET | Synchronous Optical NETwork |
| SRP | Stream Reservation Protocol |
| SP | Synchrophasor |
| SPS | Special Protection Schemes |
| SS | Substation System |
| SV | Sampled Values |
| SW | Software |
| TAI | International Atomic Time |
| TDM | Time-division Multiplexing |
| TCP | Transmission Control Protocol |
| TP | Tele-Protection |
| TSN | Time Sensitive Networking |
| UDP | User Datagram Protocol |
| UNI | User Network Interface |
| VLAN | Virtual LAN |
| WAN | Wide area network |
| XML | eXtensible Markup Language |
| YANG | Yet Another Next Generation, a modeling language for network management |

NOTE Abbreviated terms used for the identification of the common data classes and as names of the attributes are specified in the specific clauses of this document and are not repeated here.

# 4 Characteristics of determinism

## 4.1 Deterministic latency

A system with a deterministic latency is characterized by a guaranteed maximum delay between a change at its input and the reaction at its output, under error-free conditions.

Mathematically, the input to output delay of a system with a deterministic latency presents a probability distribution function (pdf) that has an upper bound smaller than a given deadline, in contrast to a non-deterministic system whose delay has a low, but non-zero probability, to exceed the deadline under error-free conditions, see Figure 1.

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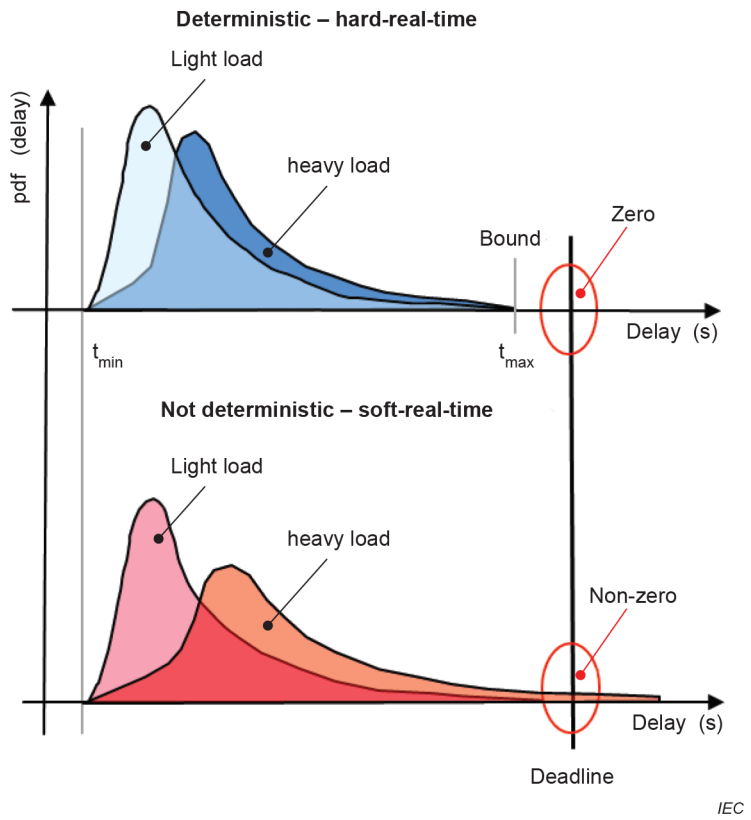


**Figure 1 – Delay probability for hard- and soft-real-time system**

Determinism is provided under all normal operating conditions, in particular, irrespective of the network traffic, but not in case of any hardware failure. Redundancy can provide deterministic behaviour in spite of a limited number of hardware failures.

A deterministic delay allows in particular to detect a hardware failure in case the deadline is not met.

The basis of determinism is the exclusive, pre-allocation of resources (bandwidth, processing power, buffers) for a given transmitted data item. Different networking methods exist for it, in particular cyclic polling or time-triggered protocols.

In a network, each critical data item to be transmitted is assigned a given bandwidth, a delivery bound and a maximum production rate. The receiver of the data is informed of the age of the received data, and can take action if the deadline is expired. The network elements also need this information to assign the resources.

Determinism therefore requires that the resources can be allocated. For instance, if the transmission of a critical data takes 1 microsecond (100 bits at 100 Mbit/s) on the medium and its deadline is 1 ms, at most 1 000 such messages can be transmitted, in reality less since the propagation time is not included and other traffic (management, etc.) may share the medium.

Data can be grouped in critical sets with the same delivery bound and production rate.

### 4.2 Deterministic jitter

A jitter is defined as the deviation $\sigma$ with respect to a fixed, mean value. A low-jitter system exhibits a pdf that is a small, tall pulse around a defined mean delay, with a minimum delay greater than zero and a maximum delay, see Figure 2.

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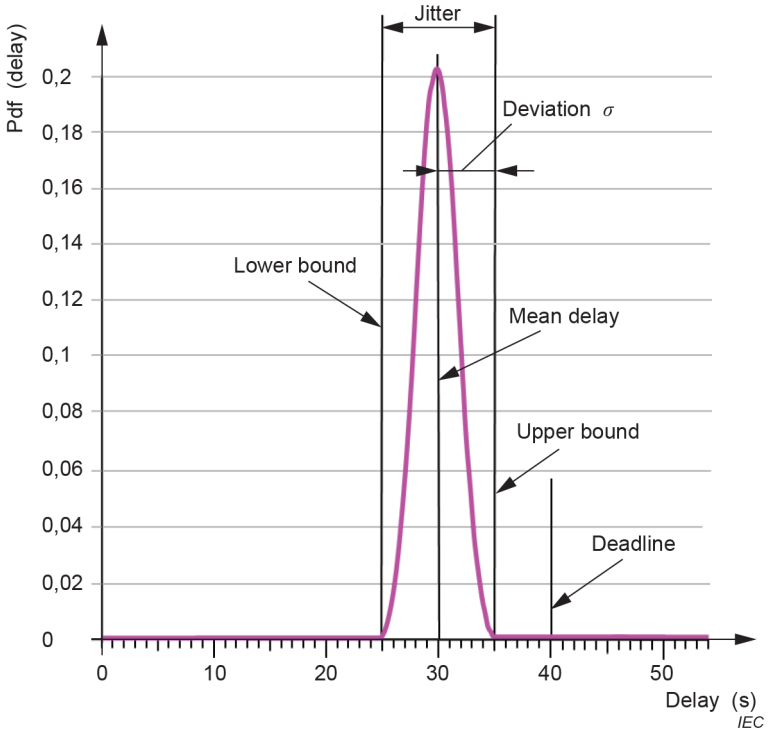


**Figure 2 – Low jitter – jitter deterministic delay**

To achieve such a behaviour, the mean value must be respected. This may imply delaying purposely the output (e.g. in air traffic control or manufacturing).

Low-jitter operation requires determinism, but it does not request a jitter-free transmission, if a global time is available.

Low-jitter is the essence of streaming video or telephone over a packet-switched network.

## 5 Problem Statement

### 5.1 Overview

Deterministic networking technologies evolve and provide means to support and improve existing use cases as well as opportunities to foster new applications. These use cases are typically clustered into two application domains: Substation-LAN and WAN-based.

IEC 61850-5 and IEC TR 61850-90-12 identify communication requirements between intelligent electronic devices within plants and substations in the power system, between such stations (e.g. between substations for line protection) and between the plant or substation and higher-level remote operating places (e.g. network control centre) and maintenance places. Clause 11 of IEC 61850-5:2013 defines the performance requirements related to the different messages used in IEC 61850-based substation networks. Additional requirements for communication between substation and substation and control centres are specified in IEC TR 61850-90-12:2020, Clause 5. These messages are classified using their type and performance requirements. They also define requirements for data and communication quality (Data Integrity, Reliability, Availability). Finally, they cover the communication system requirements for performance, communication redundancy, failure recovery and recovery delay.

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The performance requirements of IEC 61850-5 and the recommendations in IEC TR 61850-90-12 assume transfer delay under normal conditions without disturbed communication (IEC 61850-5:2013, 11.1.2.1). These documents do not require bounded latency and bounded jitter explicitly. Although, some applications could benefit from bounded latency and bounded jitter under condition such as network congestion.

Installed substation networks meet the requirements of IEC 61850-5 and operate well with current technology. This TR addresses technology change and future needs such as migration to packet switching technology, digitization of substation and RAS, combined with Distributed Generation, DER, upcoming new trends in the energy markets and society, significant emergence of software for the integrated/centralized protection and substation automation functions and OT/IT/Telecom/Security convergence. See Clause 6 for more detailed discussion of the typical use cases.

## 5.2 Problems with existing technologies

For inter-substation WANs, the protection functions used by power utilities to protect their critical assets are mostly using TDM communication networks with deterministic channel latencies of a few milliseconds. In order to avoid maintaining these TDM networks that are being phased out or for other reasons, many utilities are moving to packet-based networks. When this migration is combined with the integration of inter-substation protection and RAS functions with the corporate needs on a common communication platform, new problems arise. For such migrations, since the protection fault-clearing times affect a transmission power line's power-handling rating, the replacement Ethernet channel latency shall not be higher than that of the original TDM channel.

Actual packet switching technologies face higher challenges than TDM technologies to meet the latency requirements of the applications (e.g. the <5 ms specified in IEC TR 61850-90-12 for current differential protection). The difficulty to predict the latencies encountered as traffic traverses a network is the major problem (queuing latencies) especially for networks carrying other (IT) traffic.

A more challenging problem for some utilities is a requirement that the bidirectional latencies of channels used for current-differential be symmetric, typically with an asymmetry below 0,4ms (or even lower according to CIGRE recommendations [1][1]). This requirement is needed only for relays without an external timing source (e.g. GNSS, PTP) [2].

For Substation-LANs,

– Integration and convergence of networks in the substation over a single infrastructure, for all types of traffic, is a trend for some utilities. It may lead to increased network loading, impacting the need to prioritize protection function traffic.
– Protection function traffic, especially sampled values and some mission-critical GOOSE messages, shall be continuously prioritized over the substation telecom network, even with traffic fluctuations.

Present grid automation communication based on packet-switched networks exhibit a traffic-dependent, variable latency. Every increase in non-critical traffic can increase the latency of time-critical data. This makes it difficult to add new traffic to an existing network. Present networks have insufficient control over the traffic, therefore the network engineers overprovision the network. A proper network design and priority planning, as well as enhanced quality of service mechanism can limit the effects to a level which is not critical anymore for usual applications. Simulation tools offer only a limited support. Overprovisioning of network bandwidth is one of the techniques currently used to increase the probability of delivery of critical traffic by preventing network congestion. The overprovisioning of network bandwidth is not an efficient resource usage. Utilities are looking for new ways to optimize the bandwidth usage and minimize the overdesigning of their networks.

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

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IEC TR 61850-90-4 and IEC TR 61850-90-12 recommend the use of VLANs and QoS mechanisms for increasing the probability of meeting the communication requirements specified in IEC 61850-5. These mechanisms do not guarantee that these requirements will be met in case of network congestions that may impact the transmission of critical flows.

In large substations, the number of IEDs and the necessity of doing multicast filtering make the configuration of the network and specifically the VLANs very complex. Today system-engineering tools can support the design and configuration of substation networks.

## 5.3 Improvements in networking communication from using the capabilities of deterministic communication technologies

The upcoming trends and future evolutions are bringing new use cases and operational modes that will change the way the substation and its functions are seeing currently. On the other hand, the current activities on the IEC 61850 extensions that are going on in the Working Group 10 of IEC Technical Committee 57 will also generate some new impacts for the Utilities. Is the current network architecture and technology sufficient for them?

Communication networks based on Ethernet and IP are the deployed technologies to meet the performance requirements of IEC 61850-5 over substation LANs. MPLS or IP (IPv4, IPv6) is becoming a commonly deployed technology to meet requirements and implement architectures over the WAN. These technologies evolve over time and new network capabilities to improve performance are getting developed and standardized. Additionally, deterministic network technologies are available as standards for the LAN and WAN environments. These standards explicitly address real-time and deterministic behaviour for domains such as industrial and power automation, automotive, transportation, and audio/video. Along these lines, deterministic networking technologies may provide capabilities to meet the following requirements in power utility automation:

– Functional requirements like performance and quality of data exchange;
– Non-functional requirements such as manageability;
– Flexibility in network topology meeting redundancy requirements (e.g. meshed network with seamless redundancy);
– 1+n redundancy schemes are achievable;
– Enhancements of network security (e.g. network access control, filtering, visibility);
– System and architectural aspects such as converged networking to enable a multi-service architecture in a substation (Security Monitoring, IoT, SPS/TP/SCADA, Phone [Safety requirements imposed by the NERC], Tele-commissioning, Market info, Management of Telecom components, HMI, etc.) and over the WAN.

## 5.4 Drawbacks of deterministic networking

### 5.4.1 General

It is one key objective of this document to address the challenges of introducing new network technologies, even within a layered architecture such as IEC 61850. Use and application of deterministic networking technologies should consider integration and compatibility with existing network technologies and applications. This encompasses the engineering process as well as other configuration efforts. This Technical Report provides guidance regarding co-existence and interoperability with existing technologies and how to address technology changes. In addition, it assesses the impact on application operation and considers migration strategies. It is key to choose the appropriate deterministic networking technology in order to meet the requirements, to accomplish the improvements, and to achieve co-existing with current-use cases and deployments. The deployment of deterministic network technologies may impose the following issues and raise potential questions:

– Compatibility with existing solutions;
– Deterministic networking requires specific configuration across the network. How does this fit with existing configurations?

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– Publishers / subscribers of data may need to be deterministic networking-aware devices
– New challenges in case of fully converged networks in terms of security,
– New challenges regarding operation and maintenance, responsibility boundaries, operational processes.

### 5.4.2 Change in network design

Since thousands of grid automation networks today operate reliably, one of the major motivations for determinism is to allow "convergence", i.e. merging the time-critical and non-critical traffic on the same network. This convergence is not broadly accepted, especially in the substation, because of security and responsibility concerns. This document will bring clarity to which network convergence applies: process bus, station bus, inter-substation or wide area network to Control Centres or Phasor Data Concentrators. The deterministic technology employed may depend on the particular network. Determinism is an end-to-end property, from application to applications. Making only the network deterministic does not ensure overall determinism. The time-critical traffic can only be protected from random, non-critical traffic if all elements in the chain (IEDs, bridges, routers, etc.) behave deterministically and all delays and generation rates are predictable, which is not the case today. The network engineer will have to estimate the maximum production rate of the publishing applications and the performance of the network nodes (per hop behaviour). This requires a better understanding of the network traffic patterns than today.

### 5.4.3 Changes to the network infrastructure

All network elements must support deterministic operation and provide the resources. For instance, in the case of TSN, bridges would implement at least a subset of the TSN standard suite [3] and provide the corresponding SNMP, YANG or IEC 61850 management. Even if classical RSTP is displaced, traffic characterisation, traffic limitation and topology restrictions will have to be observed in the same way as today.

### 5.4.4 Change to the network tools

Manufacturer-independent tools will be needed to configure and troubleshoot the deterministic network since the network operation cannot anymore be handled manually. Such tools rely on characterization of the bridge performance and on characterization of the data production patterns of the IEDs. They must be integrated with the substation configuration tools (CID, SCD) and generate the corresponding resource reservation, either in a static or in a dynamic way.

### 5.4.5 Hardware changes to the IEDs

IEDs need to support deterministic operation, at least to support basic scheduling. The current technology in the IEC 61850 IEDs may need to be extended by new clock synchronisation, redundancy and hardware components.

### 5.4.6 Change to the IED applications

The introduction of deterministic network may require changes in the applications.

### 5.4.7 Change to the standard

The communication object models (IEC 61850-7-x) and SCD (IEC 61850-6) need extension to support the configuration of the network elements. A new SCSM IEC 61850-8-x specification is needed to support determinism. In the case of TSN, a profile of the TSN standard suite for grid automation is needed. A TSN profile for industry automation started in 2018 as IEC/IEEE 60802 and it would be advisable to align the IEC Technical Committee 57 profile with the outcome of that joint development.

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