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Precision clock synchronization protocol for networked measurement and control systems

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

PRECISION CLOCK SYNCHRONIZATION PROTOCOL FOR NETWORKED MEASUREMENT AND CONTROL SYSTEMS

FOREWORD

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International Standard IEC/IEEE 61588 has been processed through subcommittee 65C: Digital communications, of IEC technical committee 65: Industrial-process measurement and control.

The text of this standard is based on the following documents:

IEEE Std	FDIS	Report on voting
1588 (2002)	65C/333/FDIS	65C/340/RVD

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

The committee has decided that the contents of this publication will remain unchanged until 2007.

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Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

Sponsor

TC9—Technical Committee on Sensor Technology
of the
IEEE Instrumentation and Measurement Society

Approved 12 September 2002

IEEE-SA Standards Board

Abstract: A protocol to synchronize independent clocks running on separate nodes of a distributed measurement and control system to a high degree of accuracy and precision is specified. The protocol is independent of the networking technology, and the system topology is self-configuring.
Keywords: clocks, distributed system, master clock, measurement and control systems, real-time clock, synchronized clocks

IEEE Introduction

The objective of this standard is to specify a protocol to synchronize independent clocks running on separate nodes of a distributed measurement and control system to a high degree of accuracy and precision. The clocks communicate with each other over a communication network. In its basic form, this protocol is intended to be administration free. The protocol generates a master slave relationship among the clocks in the system. Within a given subnet of a network, there will be a single master clock. All clocks ultimately derive their time from a clock known as the grandmaster clock. The communication path between any clock and its grandmaster clock is part of a minimum spanning tree.

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PRECISION CLOCK SYNCHRONIZATION PROTOCOL FOR NETWORKED MEASUREMENT AND CONTROL SYSTEMS

1. Overview

This standard is divided into nine clauses. They are as follows:

Clause	Purpose
1	Provides the scope and benefits of this standard
2	Lists references to other standards that are referenced by this standard
3	Provides definitions that are either not found in other standards or have been modified for use with this standard
4	Provides conventions for the notation used in this standard
5	Defines the datatypes used in this standard
6	Provides an overview of the protocol specified by the standard
7	Defines the precision time protocol (PTP)
8	Defines the format of messages passed between participating clocks
9	Defines requirements for conformance

Annexes are provided as follows:

Annex	Purpose
A	Using the PTP
B	Defines time scales and epochs in PTP
C	Defines subdomain_name to address mappings
D	Defines the Ethernet implementation of PTP
E	Bibliography

Annexes defining communication-medium-specific implementation details for additional network implementations are expected to be provided in future revisions of this standard.

1.1 Scope

This standard defines a protocol enabling precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects. The protocol will be applicable to systems communicating by local area networks supporting multicast messaging including, but not limited to, Ethernet. The protocol will enable heterogeneous systems that include clocks of various inherent precision, resolution, and stability to synchronize. The protocol will support systemwide synchronization accuracy in the submicrosecond range with minimal network and local clock computing resources. The default behavior of the protocol will allow simple systems to be installed and operated without requiring the administrative attention of users.

1.2 Purpose

Measurement and control applications are increasingly using distributed system technologies such as network communication, local computing, and distributed objects. Many of these applications will be enhanced by having an accurate systemwide sense of time achieved by having local clocks in each sensor, actuator, or other system device. Without a standardized protocol for synchronizing these clocks, it is unlikely that the benefits will be realized in the multivendor system component market. Existing protocols for clock synchronization are not optimum for these applications. For example, Network Time Protocol (NTP) targets large distributed computing systems with millisecond synchronization requirements. The protocol proposed in this standard specifically addresses the needs of measurement and control systems:

— Spatially localized
— Microsecond to submicrosecond accuracy
— Administration free
— Accessible for both high-end devices and low-cost, low-end devices

2. References

This standard shall be used in conjunction with the standards listed in this clause. When the following standards are superseded by an approved revision, the revision shall apply.

IEEE Std 802.3™-2002, Information technology—Telecommunications and information exchange between systems—Local and metropolitan area networks—Specific requirements—Part 3: Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications.[1]

ISO 8601:2000, Data elements and interchange formats—Information interchange—Representation of dates and times.[2]

ISO/IEC 8859-1:1998, Information technology—8-bit single-byte coded graphic character sets—Part 1: Latin alphabet No. 1

[1]IEEE Publications are available from the Institute of Electrical and Electronics Engineers. 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA and <http://standards.ieee.org/sds/index.html>.

[2]ISO publications are available from the International Organization for Standardization, <http://www.iso.ch/iso/en/prods-services/ISOstore/store.html>.

3. Definitions

This clause defines terms that have specific meanings in the context of the PTP.

3.1 boundary clock: A clock with more than a single PTP port, with each PTP port providing access to a separate PTP communication path.

3.2 clock: A node that is capable of providing a measurement of the passage of time since a defined epoch. In this standard, the term *clock* is interpreted to mean either an ordinary clock or a PTP port of a boundary clock unless otherwise stated or obvious from the context.

3.3 clock timestamp point: A point in the network protocol stack of a clock at which timestamps are generated for Sync and Delay_Req messages sent or received by the clock. This point is defined for both the inbound and outbound paths in the protocol stack.

3.4 direct communication: A communication of PTP information between two PTP clocks with no intervening boundary clock.

3.5 epoch: The reference time defining the origin of a time scale.

3.6 event: An abstraction of the mechanism by which signals or conditions are generated and represented.

3.7 external synchronization: The process of bringing two clocks into a synchronized state by means other than the use of the PTP. *See also:* **synchronized clocks.**

3.8 grandmaster clock: Within a PTP subdomain, a PTP clock that is the ultimate source of time for clock synchronization using the PTP protocol.

3.9 interface definition language (IDL): A programming-language-independent method of specifying operation syntax [B1].[3]

3.10 master clock: In the context of a single PTP communication path, a clock that when viewed from the path appears to be the source of time to which all other clocks synchronize.

3.11 message timestamp point: A distinguished feature of Sync and Delay_Req messages serving as a reference point in these messages. A timestamp is defined by the instant a message timestamp point passes the clock timestamp point in a protocol stack.

3.12 network: A communication mechanism for passing PTP messages among multiple clocks.

3.13 node: A device that can issue or receive PTP communications on a network.

3.14 ordinary clock: A PTP clock with a single PTP port.

3.15 ordinary communication: A communication of non-PTP information between two nodes.

3.16 port number: An index identifying a specific PTP port on a PTP clock.

3.17 preferred master clock set: A set of clocks that will be favored over those not so designated in the selection of the grandmaster clock within a subdomain.

[3]The numbers in brackets correspond to those of the bibliography in Annex E.

3.18 precision time protocol (PTP): The protocol defined by this standard. As an adjective, it indicates that the modified noun is specified in or interpreted in the context of this standard.

3.19 PTP clock: A clock that participates in the PTP protocol.

3.20 PTP communication: Information used in the operation of the PTP protocol, transmitted in a PTP message over a PTP communication path.

3.21 PTP communication path: A segment of a network enabling direct communication between two PTP clocks.

3.22 PTP domain: A collection of one or more PTP subdomains.

3.23 PTP message: One of the five designated messages types defined in this standard: Sync, Delay_Req, Follow-up, Delay_Resp, and Management.

3.24 PTP multicast communication: A PTP message sent from any PTP port and received and processed by all PTP ports on the same PTP communication path. PTP multicast communications are not automatically forwarded to other PTP communication paths by routers or other similar network components.

3.25 PTP node: A node that issues any message that will be received by a second node resulting in any change in state in the second node that influences any aspect of the PTP protocol.

3.26 PTP port: The logical access point to a PTP clock for PTP communications on a single PTP communication path.

3.27 PTP subdomain: A logical grouping of PTP clocks that synchronize to each other using the PTP protocol but that are not necessarily synchronized to PTP clocks in another PTP subdomain.

NOTE—It should be emphasized that this grouping is logical. Clocks sharing a PTP communication path may or may not be in the same PTP subdomain, and clocks in the same PTP subdomain may or may not share a PTP communication path.

3.28 state transition diagram: A graphical means of expressing the allowed states of an object and the allowed transitions from one state to another (see 4.3).

3.29 subnet: A subset of a network. If a network contains devices whose function is to pass messages and these devices do not pass PTP non-management messages, then the network can be partitioned into regions in such a way that:

— No two nodes in a region communicate via one of these devices, and
— All communication between regions is via one or more of these devices.

Each such region is a subnet. If a network does not contain any such devices, it is a subnet.

3.30 synchronized clocks: Two clocks are synchronized to a specified uncertainty if they have the same epoch, and measurements of any time interval by both clocks differ by no more than the specified uncertainty. The timestamps generated by two synchronized clocks for the same event will differ by no more than the specified uncertainty.

3.31 timeout: A mechanism for terminating requested activity, at least from the requester's perspective, that does not complete within the time specified.

3.32 universally unique identifier (UUID): An identifier that has a unique value within some defined universe. For purposes of this standard, the universe consists of all possible PTP artifacts having a UUID unless otherwise stated.

4. Conventions

The specifications of this clause shall apply to all artifacts defined in this standard.

4.1 Descriptive syntax

The syntax conventions specified in the following subclauses are used in this standard.

4.1.1 Lexical form syntax

A lexical form refers to:

— A name
— A datatype

The conventions illustrated in the following list regarding lexical forms shall be used:

— *Type names:* e.g., TimeRepresentation (no word separation, initial letter of each word capitalized)
— *Enumeration members and global constants:* e.g., PTP_SYNC_MESSAGE (underscore word separation, all letters capitalized)
— *Fields of structures or messages:* e.g., seconds, specialElement (no word separation, initial word not capitalized, initial letter capitalization on subsequent words)
— *Data set members and all other variables:* new_master (underscore word separation, no letters capitalized)
— *<local name for something>:* text enclosed in angle brackets, < >, is used where the standard needs to refer to something whose syntax or lexical form is dependent on the local implementation and language.

When a lexical form appears in text, as opposed to in a signature, a type, or a format definition, the form is to be interpreted as singular, plural, or possessive as appropriate to the context of the text.

4.2 Word usage

4.2.1 Shall

The word *shall*, equivalent to *is required to,* is used to indicate mandatory requirements, strictly to be followed in order to conform to the standard and from which no deviation is permitted.

4.2.2 Recommended

The word *recommended* is used to indicate flexibility of choice with a strong preference alternative.

4.2.3 Must

The use of the word *must* is deprecated and shall not be used when stating mandatory requirements. The word *must* is only used to describe unavoidable situations.