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PRECISION CLOCK SYNCHRONIZATION PROTOCOL FOR NETWORKED MEASUREMENT AND CONTROL SYSTEMS

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This second edition cancels and replaces the first edition published in 2004. It constitutes a technical revision.

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

IEEE Std	FDIS	Report on voting
1588 (2008)	65C/510/FDIS	65C/517/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.

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IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

Sponsor

Technical Committee on Sensor Technology (TC-9)

of the

IEEE Instrumentation and Measurement Society

Approved 27 March 2008

IEEE-SA Standards Board

Abstract: A protocol is provided in this standard that enables precise synchronization of clocks in measurement and control systems implemented with technologies such as network communication, local computing, and distributed objects. The protocol is applicable to systems communicating via packet networks. Heterogeneous systems are enabled that include clocks of various inherent precision, resolution, and stability to synchronize. System-wide synchronization accuracy and precision in the sub-microsecond range are supported with minimal network and local clock computing resources. Simple systems are installed and operated without requiring the management attention of users because the default behavior of the protocol allows for it.

Keywords: boundary clock, clock, distributed system, master clock, measurement and control system, real-time clock, synchronized clock, transparent clock

IEEE Introduction

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 clocks communicate with each other over a communication network. The protocol generates a master–slave relationship among the clocks in the system. All clocks ultimately derive their time from a clock known as the grandmaster clock. In its basic form, this protocol is intended to be administration free.

History

Measurement and control applications are increasingly using distributed system technologies such as network communication, local computing, and distributed objects. Without a standardized protocol for synchronizing the clocks in these devices, 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 following needs of measurement and control systems:

- Spatially localized
- Microsecond to sub-microsecond accuracy and precision
- Administration free
- Accessible for both high-end devices and low-cost, low-end devices

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PRECISION CLOCK SYNCHRONIZATION PROTOCOL FOR NETWORKED MEASUREMENT AND CONTROL SYSTEMS

1. Overview

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 is applicable to systems communicating by local area networks supporting multicast messaging including, but not limited to, Ethernet. The protocol enables heterogeneous systems that include clocks of various inherent precision, resolution, and stability to synchronize to a grandmaster clock. The protocol supports system-wide synchronization accuracy in the sub-microsecond range with minimal network and local clock computing resources. The default behavior of the protocol allows simple systems to be installed and operated without requiring the administrative attention of users. The standard includes mappings to User Datagram Protocol (UDP)/Internet Protocol (IP), DeviceNet, and a layer-2 Ethernet implementation. It includes formal mechanisms for message extensions, higher sampling rates, correction for asymmetry, a clock type to reduce error accumulation in large topologies, and specifications on how to incorporate the resulting additional data into the synchronization protocol. The standard permits synchronization accuracies better than 1 ns. The protocol has features to address applications where redundancy and security are a requirement. The standard defines conformance and management capability. There is provision to support unicast as well as multicast messaging. The standard includes an annex on recommended practices. Annexes defining communication-medium-specific implementation details for additional network implementations are expected to be provided in future versions of this standard.

1.2 Purpose

Measurement and control applications are increasingly employing distributed system technologies such as network communication, local computing, and distributed objects. Many of these applications will be enhanced by having an accurate system-wide 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, the Network Time Protocol (NTP) targets large distributed computing systems with millisecond synchronization requirements. The protocol in this standard specifically addresses the needs of measurement and control and operational systems in the fields of test and measurement, industrial automation, military systems, manufacturing systems, power utility systems, and certain telecommunications applications. These applications need:

- Spatially localized systems with options for larger systems
- Microsecond to sub-microsecond accuracy
- Administration-free operation
- Applicability for both high-end devices and low-cost, low-end devices
- Provisions for the management of redundant and fault-tolerant systems

Several different application areas such as industrial automation, telecommunication, semiconductor manufacturing, military systems, and utility power generation have emerged that require the standard to be revised.

1.3 Layout of the document

This standard, which defines the Precision Time Protocol (PTP), is divided into 19 clauses:

Clause	**Purpose**
1	Provides the scope and benefits of this standard
2	Lists references to other standards
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 data types used in this standard
6	Provides an overview of PTP
7	Defines characteristics of PTP entities
8	Defines PTP data sets
9	Defines PTP for ordinary and boundary clocks
10	Defines PTP for transparent clocks
11	Specifies PTP time computations and corrections
12	Specifies how to syntonize and synchronize clocks
13	Defines the format of messages passed between participating clocks
14	Specifies type, length, value (TLV) formats
15	Specifies management TLVs
16	Defines general optional features of this standard
17	Defines state configuration options of this standard
18	Defines forward and backward compatibility between versions
19	Defines requirements for conformance

Annexes are provided as follows:

Annex	**Purpose**
Annex A	Using PTP
Annex B	Defines timescales and epochs in PTP
Annex C	Examples of timing computations and message fields
Annex D	Defines mappings of PTP to User Datagram Protocol (UDP) over Internet Protocol version 4 (IPv4)
Annex E	Defines mappings of PTP to UDP over Internet Protocol version 6 (IPv6)
Annex F	Defines mappings of PTP over IEEE 802.3
Annex G	Defines mappings of PTP to DeviceNet™[1]
Annex H	Defines mappings of PTP to ControlNet™[2]
Annex I	Defines mappings of PTP to PROFINET™[3]
Annex J	Default PTP Profile
Annex K	Defines an experimental security option
Annex L	Defines an experimental cumulative frequency TLV
Annex M	Bibliography

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEC 61158-3-2:2007, Industrial communication networks—Fieldbus specifications—Part 3-2: Data-link layer service definition—Type 2 elements.[4]

IEC 61158-4-2:2007, Industrial communication networks—Fieldbus specifications—Part 4-2: Data-link layer protocol specification—Type 2 elements.

IEC 61158-5-2:2007, Industrial communication networks—Fieldbus specifications—Part 5-2: Application layer service definition—Type 2 elements.

IEC 61158-5-10:2007, Industrial communication networks—Fieldbus specifications—Part 5-10: Application layer service definition—Type 10 elements.

IEC 61158-6-2:2007, Industrial communication networks—Fieldbus specifications—Part 6-2: Application layer protocol specification—Type 2 elements.

IEC 61158-6-10:2007, Industrial communication networks—Fieldbus specifications—Part 6-10: Application layer protocol specification—Type 10 elements.

[1]DeviceNet™ is a trade name of Open DeviceNet Vendor Association, Inc. This information is given for the convenience of users of this standard and does not constitute an endorsement by the IEEE or IEC of these products. Equivalent products may be used if they can be shown to lead to the same results.
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IEC 61784-1:2007, Industrial communication networks—Profiles—Part 1: Fieldbus profiles.

IEC 61784-2:2007, Industrial communications networks—Profiles—Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3.

IEC 62026-3:2008, Low-voltage switchgear and controlgear—Controller-device interfaces (CDIs)—Part 3: DeviceNet.

IEEE Std 802®, IEEE Standard for Local and Metropolitan Area Networks: Overview and Architecture.[5, 6]

IEEE Std 802.1AB™, IEEE Standard for Local and Metropolitan Area Networks—Part 1AB: Station and Media Access Control Connectivity Discovery.

IEEE Std 802.1Q™-2005, IEEE Standard for Local and Metropolitan Area Networks—Part 1Q: Virtual bridged local area networks.

IEEE Std 802.3™-2005, IEEE Standard for 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.

ISO/IEC 10646:2003, Information technology—Universal Multiple-Octet Coded Character Set (UCS)[7].

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