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Enterprise Profile for the Precision Time Protocol With Mixed Multicast and Unicast Messages

Abstract

   This document describes a profile for the use of the Precision Time
   Protocol in an IPV4 or IPv6 Enterprise information system
   environment. The profile uses the End to End Delay Measurement
   Mechanism, allows both multicast and unicast Delay Request and Delay
   Response Messages.

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1. Introduction

The Precision Time Protocol ("PTP"), first standardized in IEEE 1588, has been designed in its first version (IEEE 1588-2002) with the goal to minimize configuration on the participating nodes. Network communication was based solely on multicast messages, which unlike NTP did not require that a receiving node ("slave clock") in IEEE 1588-2019 [IEEE1588] needs to know the identity of the time sources in the network (the Master Clocks). This document describes clock roles and port states using the terms master and slave in order to correspond to the terms used in IEEE 1588, on which this document is based. There is an active project in the IEEE to select alternative terms. When this project is completed, then master and slave will be replaced with the new alternative terms in an update to this document.

The "Best Master Clock Algorithm" (IEEE 1588-2019 [IEEE1588] Subclause 9.3), a mechanism that all participating PTP nodes must follow, set up strict rules for all members of a PTP domain to determine which node shall be the active sending time source (Master Clock). Although the multicast communication model has advantages in

smaller networks, it complicated the application of PTP in larger networks, for example in environments like IP based telecommunication networks or financial data centers. It is considered inefficient that, even if the content of a message applies only to one receiver, it is forwarded by the underlying network (IP) to all nodes, requiring them to spend network bandwidth and other resources, such as CPU cycles, to drop the message.

The third edition of the standard (IEEE 1588-2019) defines PTPv2.1 and includes the possibility to use unicast communication between the PTP nodes in order to overcome the limitation of using multicast messages for the bi-directional information exchange between PTP nodes. The unicast approach avoided that, in PTP domains with a lot of nodes, devices had to throw away more than 99% of the received multicast messages because they carried information for some other node. PTPv2.1 also includes PTP profiles (IEEE 1588-2019 [IEEE1588] subclause 20.3). This construct allows organizations to specify selections of attribute values and optional features, simplifying the configuration of PTP nodes for a specific application. Instead of having to go through all possible parameters and configuration options and individually set them up, selecting a profile on a PTP node will set all the parameters that are specified in the profile to a defined value. If a PTP profile definition allows multiple values for a parameter, selection of the profile will set the profile-specific default value for this parameter. Parameters not allowing multiple values are set to the value defined in the PTP profile. Many PTP features and functions are optional, and a profile should also define which optional features of PTP are required, permitted, or prohibited. It is possible to extend the PTP standard with a PTP profile by using the TLV mechanism of PTP (see IEEE 1588-2019 [IEEE1588] subclause 13.4), defining an optional Best Master Clock Algorithm and a few other ways. PTP has its own management protocol (defined in IEEE 1588-2019 [IEEE1588] subclause 15.2) but allows a PTP profile specify an alternative management mechanism, for example NETCONF.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

3. Technical Terms

  *Acceptable Master Table: A PTP Slave Clock may maintain a list of masters which it is willing to synchronize to.

*Alternate Master: A PTP Master Clock, which is not the Best
 Master, may act as a master with the Alternate Master flag set on
 the messages it sends.

*Announce message: Contains the Master Clock properties of a
 Master Clock. Used to determine the Best Master.

*Best Master: A clock with a port in the master state, operating
 consistently with the Best Master Clock Algorithm.

*Best Master Clock Algorithm: A method for determining which state
 a port of a PTP clock should be in. The algorithm works by
 identifying which of several PTP Master capable clocks is the
 best master. Clocks have priority to become the acting
 Grandmaster, based on the properties each Master Clock sends in
 its Announce Message.

*Boundary Clock: A device with more than one PTP port. Generally
 boundary Clocks will have one port in slave state to receive
 timing and then other ports in master state to re-distribute the
 timing.

*Clock Identity: In IEEE 1588-2019 this is a 64-bit number
 assigned to each PTP clock which must be unique. Often it is
 derived from the Ethernet MAC address, since there is already an
 international infrastructure for assigning unique numbers to each
 device manufactured.

*Domain: Every PTP message contains a domain number. Domains are
 treated as separate PTP systems in the network. Clocks, however,
 can combine the timing information derived from multiple domains.

*End to End Delay Measurement Mechanism: A network delay
 measurement mechanism in PTP facilitated by an exchange of
 messages between a Master Clock and Slave Clock.

*Grandmaster: the primary Master Clock within a domain of a PTP
 system

*IEEE 1588: The timing and synchronization standard which defines
 PTP, and describes the node, system, and communication properties
 necessary to support PTP.

*Master Clock: a clock with at least one port in the master state.

*NTP: Network Time Protocol, defined by RFC 5905, see RFC 5905
 [RFC5905]

*Ordinary Clock: A clock that has a single Precision Time Protocol
 (PTP) port in a domain and maintains the timescale used in the
 domain. It may serve as a Master Clock, or be a slave clock.

*Peer to Peer Delay Measurement Mechanism: A network delay
 measurement mechanism in PTP facilitated by an exchange of
 messages between adjacent devices in a network.

*Preferred Master: A device intended to act primarily as the
 Grandmaster of a PTP system, or as a back up to a Grandmaster.

*PTP: The Precision Time Protocol, the timing and synchronization
 protocol defined by IEEE 1588.

*PTP port: An interface of a PTP clock with the network. Note that
 there may be multiple PTP ports running on one physical
 interface, for example, a unicast slave which talks to several
 Grandmaster clocks in parallel.

*PTPv2.1: Refers specifically to the third version of PTP defined
 by IEEE 1588-2019.

*Rogue Master: A clock with a port in the master state, even
 though it should not be in the master state according to the Best
 Master Clock Algorithm, and does not set the alternate master
 flag.

*Slave clock: a clock with at least one port in the slave state,
 and no ports in the master state.

*Slave Only Clock: An Ordinary Clock which cannot become a Master
 Clock.

*TLV: Type Length Value, a mechanism for extending messages in
 networked communications.

*Transparent Clock. A device that measures the time taken for a
 PTP event message to transit the device and then updates the
 message with a correction for this transit time.

*Unicast Discovery: A mechanism for PTP slaves to establish a
 unicast communication with PTP masters using a configures table
 of master IP addresses and Unicast Message Negotiation.

*Unicast Negotiation: A mechanism in PTP for Slave Clocks to
 negotiate unicast Sync, announce and Delay Request Message Rates
 from a Master Clock.

4. Problem Statement

This document describes a version of PTP intended to work in large
enterprise networks. Such networks are deployed, for example, in
financial corporations. It is becoming increasingly common in such
networks to perform distributed time tagged measurements, such as
one-way packet latencies and cumulative delays on software systems
spread across multiple computers. Furthermore, there is often a
desire to check the age of information time tagged by a different
machine. To perform these measurements, it is necessary to deliver a
common precise time to multiple devices on a network. Accuracy
currently required in the Financial Industry range from 100
microseconds to 100 nanoseconds to the Grandmaster. This profile
does not specify timing performance requirements, but such
requirements explain why the needs cannot always be met by NTP, as
commonly implemented. Such accuracy cannot usually be achieved with
a traditional time transfer such as NTP, without adding non-standard
customizations such as hardware time stamping, and on path support.
These features are currently part of PTP, or are allowed by it.
Because PTP has a complex range of features and options it is
necessary to create a profile for enterprise networks to achieve
interoperability between equipment manufactured by different
vendors.

Although enterprise networks can be large, it is becoming
increasingly common to deploy multicast protocols, even across
multiple subnets. For this reason, it is desired to make use of
multicast whenever the information going to many destinations is the
same. It is also advantageous to send information which is unique to
one device as a unicast message. The latter can be essential as the
number of PTP slaves becomes hundreds or thousands.

PTP devices operating in these networks need to be robust. This
includes the ability to ignore PTP messages which can be identified
as improper, and to have redundant sources of time.

Interoperability among independent implementations of this PTP
profile has been demonstrated at the ISPCS Plugfest ISPCS [ISPCS].

5. Network Technology

This PTP profile SHALL operate only in networks characterized by UDP
RFC 768 [RFC0768] over either IPv4 RFC 791 [RFC0791] or IPv6 RFC
8200 [RFC8200], as described by Annexes D and E in IEEE 1588
[IEEE1588] respectively. If a network contains both IPv4 and IPv6,
then they SHALL be treated as separate communication paths. Clocks
which communicate using IPv4 can interact with clocks using IPv6 if
there is an intermediary device which simultaneously communicates
with both IP versions. A Boundary Clock might perform this function,

for example. A PTP domain SHALL use either IPv4 or IPv6 over a
communication path, but not both. The PTP system MAY include
switches and routers. These devices MAY be Transparent Clocks,
boundary Clocks, or neither, in any combination. PTP Clocks MAY be
Preferred Masters, Ordinary Clocks, or Boundary Clocks. The Ordinary
Clocks may be Slave Only Clocks, or be master capable.

Note that clocks SHOULD always be identified by their clock ID and
not the IP or Layer 2 address. This is important in IPv6 networks
since Transparent Clocks are required to change the source address
of any packet which they alter. In IPv4 networks some clocks might
be hidden behind a NAT, which hides their IP addresses from the rest
of the network. Note also that the use of NATs may place limitations
on the topology of PTP networks, depending on the port forwarding
scheme employed. Details of implementing PTP with NATs are out of
scope of this document.

PTP, like NTP, assumes that the one-way network delay for Sync
Messages and Delay Response Messages are the same. When this is not
true it can cause errors in the transfer of time from the Master to
the Slave. It is up to the system integrator to design the network
so that such effects do not prevent the PTP system from meeting the
timing requirements. The details of network asymmetry are outside
the scope of this document. See for example, ITU-T G.8271 [G8271].

6. Time Transfer and Delay Measurement

Master Clocks, Transparent Clocks and Boundary Clocks MAY be either
one-step clocks or two-step clocks. Slave clocks MUST support both
behaviors. The End to End Delay Measurement Method MUST be used.

Note that, in IP networks, Sync messages and Delay Request messages
exchanged between a master and slave do not necessarily traverse the
same physical path. Thus, wherever possible, the network SHOULD be
traffic engineered so that the forward and reverse routes traverse
the same physical path. Traffic engineering techniques for path
consistency are out of scope of this document.

Sync messages MUST be sent as PTP event multicast messages (UDP port
319) to the PTP primary IP address. Two step clocks SHALL send
Follow-up messages as PTP general messages (UDP port 320). Announce
messages MUST be sent as multicast messages (UDP port 320) to the
PTP primary address. The PTP primary IP address is 224.0.1.129 for
IPv4 and FF0X:0:0:0:0:0:0:181 for Ipv6, where X can be a value
between 0x0 and 0xF, see IEEE 1588 [IEEE1588] Annex E, Section E.3.

Delay Request Messages MAY be sent as either multicast or unicast
PTP event messages. Master Clocks SHALL respond to multicast Delay
Request messages with multicast Delay Response PTP general messages.

Master Clocks SHALL respond to unicast Delay Request PTP event messages with unicast Delay Response PTP general messages. This allow for the use of Ordinary Clocks which do not support the Enterprise Profile, if they are slave Only Clocks.

Clocks SHOULD include support for multiple domains. The purpose is to support multiple simultaneous masters for redundancy. Leaf devices (non-forwarding devices) can use timing information from multiple masters by combining information from multiple instantiations of a PTP stack, each operating in a different domain. Redundant sources of timing can be ensembled, and/or compared to check for faulty Master Clocks. The use of multiple simultaneous masters will help mitigate faulty masters reporting as healthy, network delay asymmetry, and security problems. Security problems include man-in-the-middle attacks such as delay attacks, packet interception / manipulation attacks. Assuming the path to each master is different, failures malicious or otherwise would have to happen at more than one path simultaneously. Whenever feasible, the underlying network transport technology SHOULD be configured so that timing messages in different domains traverse different network paths.

7. **Default Message Rates**

The Sync, Announce and Delay Request default message rates SHALL each be once per second. The Sync and Delay Request message rates MAY be set to other values, but not less than once every 128 seconds, and not more than 128 messages per second. The Announce message rate SHALL NOT be changed from the default value. The Announce Receipt Timeout Interval SHALL be three Announce Intervals for Preferred Masters, and four Announce Intervals for all other masters.

The logMessageInterval carried in the unicast Delay Response message MAY be set to correspond to the master ports preferred message period, rather than 7F, which indicates message periods are to be negotiated. Note that negotiated message periods are not allowed, see forbidden PTP options (Section 13).

8. **Requirements for Master Clocks**

Master Clocks SHALL obey the standard Best Master Clock Algorithm from IEEE 1588 [IEEE1588]. PTP systems using this profile MAY support multiple simultaneous Grandmasters if each active Grandmaster is operating in a different PTP domain.

A port of a clock SHALL NOT be in the master state unless the clock has a current value for the number of UTC leap seconds.

If a unicast negotiation signaling message is received it SHALL be ignored.

9. Requirements for Slave Clocks

Slave clocks MUST be able to operate properly in a network which contains multiple Masters in multiple domains. Slaves SHOULD make use of information from the all Masters in their clock control subsystems. Slave Clocks MUST be able to operate properly in the presence of a Rogue Master. Slaves SHOULD NOT Synchronize to a Master which is not the Best Master in its domain. Slaves will continue to recognize a Best Master for the duration of the Announce Time Out Interval. Slaves MAY use an Acceptable Master Table. If a Master is not an Acceptable Master, then the Slave MUST NOT synchronize to it. Note that IEEE 1588-2019 requires slave clocks to support both two-step or one-step Master clocks. See IEEE 1588 [IEEE1588], subClause 11.2.

Since Announce messages are sent as multicast messages slaves can obtain the IP addresses of a master from the Announce messages. Note that the IP source addresses of Sync and Follow-up messages may have been replaced by the source addresses of a Transparent Clock, so, slaves MUST send Delay Request messages to the IP address in the Announce message. Sync and Follow-up messages can be correlated with the Announce message using the clock ID, which is never altered by Transparent Clocks in this profile.

10. Requirements for Transparent Clocks

Transparent Clocks SHALL NOT change the transmission mode of an Enterprise Profile PTP message. For example, a Transparent Clock SHALL NOT change a unicast message to a multicast message. Transparent Clocks SHOULD support multiple domains. Transparent Clocks which syntonize to the master clock will need to maintain separate clock rate offsets for each of the supported domains.

11. Requirements for Boundary Clocks

Boundary Clocks SHOULD support multiple simultaneous PTP domains. This will require them to maintain servo loops for each of the domains supported, at least in software. Boundary Clocks MUST NOT combine timing information from different domains.

12. Management and Signaling Messages

PTP Management messages MAY be used. Management messages intended for a specific clock, i.e. the IEEE 1588 [IEEE1588] defined attribute targetPortIdentity.clockIdentity is not set to All 1s, MUST be sent as a unicast message. Similarly, if any signaling

messages are used they MUST also be sent as unicast messages
whenever the message is intended for a specific clock.

13. Forbidden PTP Options

Clocks operating in the Enterprise Profile SHALL NOT use peer to
peer timing for delay measurement. Grandmaster Clusters are NOT
ALLOWED. The Alternate Master option is also NOT ALLOWED. Clocks
operating in the Enterprise Profile SHALL NOT use Alternate
Timescales. Unicast discovery and unicast negotiation SHALL NOT be
used.

14. Interoperation with IEEE 1588 Default Profile

Clocks operating in the Enterprise Profile will interoperate with
clocks operating in the Default Profile described in IEEE 1588
[IEEE1588] Annex J.3. This variant of the Default Profile uses the
End to End Delay Measurement Mechanism. In addition, the Default
Profile would have to operate over IPv4 or IPv6 networks, and use
management messages in unicast when those messages are directed at a
specific clock. If either of these requirements are not met than
Enterprise Profile clocks will not interoperate with Annex J.3
Default Profile Clocks. The Enterprise Profile will not interoperate
with the Annex J.4 variant of the Default Profile which requires use
of the Peer to Peer Delay Measurement Mechanism.

Enterprise Profile Clocks will interoperate with clocks operating in
other profiles if the clocks in the other profiles obey the rules of
the Enterprise Profile. These rules MUST NOT be changed to achieve
interoperability with other profiles.

15. Profile Identification

The IEEE 1588 standard requires that all profiles provide the
following identifying information.

        PTP Profile:
        Enterprise Profile
        Version: 1.0
        Profile identifier: 00-00-5E-00-01-00

        This profile was specified by the IETF

        A copy may be obtained at
        https://datatracker.ietf.org/wg/tictoc/documents

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providing feedback on this draft.

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17. IANA Considerations

There are no IANA requirements in this specification.

18. Security Considerations

Protocols used to transfer time, such as PTP and NTP can be important to security mechanisms which use time windows for keys and authorization. Passing time through the networks poses a security risk since time can potentially be manipulated. The use of multiple simultaneous masters, using multiple PTP domains can mitigate problems from rogue masters and man-in-the-middle attacks. See sections 9 and 10. Additional security mechanisms are outside the scope of this document.

PTP native management messages SHOULD not be used, due to the lack of a security mechanism for this option. Secure management can be obtained using standard management mechanisms which include security, for example NETCONF NETCONF [RFC6241].

General security considerations of time protocols are discussed in RFC 7384 [RFC7384].

19. References

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