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                      Network Time Protocol (NTP)

Status of this Memo

   This RFC suggests a proposed protocol for the ARPA-Internet
   community, and requests discussion and suggestions for improvements.
   Distribution of this memo is unlimited.

Table of Contents

1. Introduction

   This document describes the Network Time Protocol (NTP), a protocol
   for synchronizing a set of network clocks using a set of distributed
   clients and servers. NTP is built on the User Datagram Protocol
   (UDP) [13], which provides a connectionless transport mechanism. It
   is evolved from the Time Protocol [7] and the ICMP Timestamp message
   [6] and is a suitable replacement for both.

   NTP provides the protocol mechanisms to synchronize time in principle
   to precisions in the order of nanoseconds while preserving a
   non-ambiguous date, at least for this century. The protocol includes
   provisions to specify the precision and estimated error of the local
   clock and the characteristics of the reference clock to which it may
   be synchronized. However, the protocol itself specifies only the
   data representation and message formats and does not specify the
   synchronizing algorithms or filtering mechanisms.

   Other mechanisms have been specified in the Internet protocol suite
   to record and transmit the time at which an event takes place,
   including the Daytime protocol [8] and IP Timestamp option [9]. The
   NTP is not meant to displace either of these mechanisms. Additional
   information on network time synchronization can be found in the

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References at the end of this document. An earlier synchronization
protocol is discussed in [3] and synchronization algorithms in [2],
[5], [10] and [12]. Experimental results on measured roundtrip delays
and clock offsets in the Internet are discussed in [4] and [11]. A
comprehensive mathematical treatment of clock synchronization can be
found in [1].

2. Service Model

The intent of the service for which this protocol is designed is to
connect a few primary reference clocks, synchronized by wire or radio
to national standards, to centrally accessible resources such as
gateways. These gateways would use NTP between them to cross-check
the primary clocks and mitigate errors due to equipment or
propagation failures. Some number of local-net hosts, serving as
secondary reference clocks, would run NTP with one or more of these
gateways. In order to reduce the protocol overhead, these hosts
would redistribute time to the remaining local-net hosts. In the
interest of reliability selected hosts might be equipped with less
accurate but less expensive radio clocks and used for backup in case
of failure of the primary and/or secondary clocks or communication
paths between them.

In the normal configuration a subnetwork of primary and secondary
clocks will assume a hierarchical organization with the more accurate
clocks near the top and the less accurate below. NTP provides
information that can be used to organize this hierarchy on the basis
of precision or estimated error and even to serve as a rudimentary
routing algorithm to organize the subnetwork itself. However, the
NTP protocol does not include a specification of the algorithms for
doing this, which is left as a topic for further study.

3. Protocol Overview

There is no provision for peer discovery, acquisition, or
authentication in NTP. Data integrity is provided by the IP and UDP
checksums. No reachability, circuit-management, duplicate-detection
or retransmission facilities are provided or necessary. The service
can operate in a symmetric mode, in which servers and clients are
indistinguishable yet maintain a small amount of state information,
or in an unsymmetric mode in which servers need maintain no client
state other than that contained in the client request. Moreover,
only a single NTP message format is necessary, which simplifies
implementation and can be used in a variety of solicited or
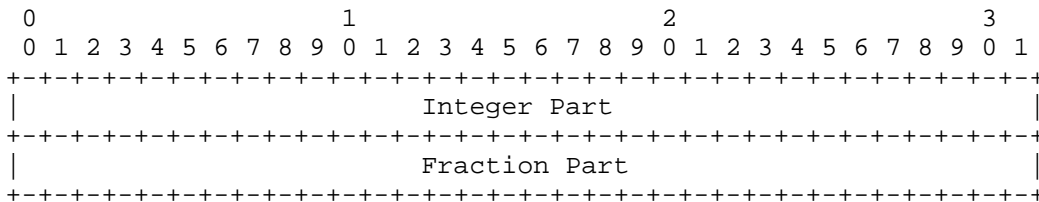unsolicited polling mechanisms.

In what may be the most common (unsymmetric) mode a client sends an

   NTP message to one or more servers and processes the replies as
   received. The server interchanges addresses and ports, fills in or
   overwrites certain fields in the message, recalculates the checksum
   and returns it immediately. Information included in the NTP message
   allows each client/server peer to determine the timekeeping
   characteristics of its other peers, including the expected accuracies
   of their clocks. Using this information each peer is able to select
   the best time from possibly several other clocks, update the local
   clock and estimate its accuracy.

   It should be recognized that clock synchronization requires by its
   nature long periods and multiple comparisons in order to maintain
   accurate timekeeping. While only a few comparisons are usually
   adequate to maintain local time to within a second, primarily to
   protect against broken hardware or synchronization failure, periods
   of hours or days and tens or hundreds of comparisons are required to
   maintain local time to within a few tens of milliseconds.
   Fortunately, the frequency of comparisons can be quite small and
   almost always non-intrusive to normal network operations.

4. State Variables and Formats

   NTP timestamps are represented as a 64-bit fixed-point number, in
   seconds relative to 0000 UT on 1 January 1900. The integer part is
   in the first 32 bits and the fraction part in the last 32 bits, as
   shown in the following diagram.

```
        0                   1                   2                   3
        0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                         Integer Part                          |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |                        Fraction Part                          |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   This format allows convenient multiple-precision arithmetic and
   conversion to Time Protocol representation (seconds), but does
   complicate the conversion to ICMP Timestamp message representation
   (milliseconds). The low-order fraction bit increments at about
   0.2-nanosecond intervals, so a free-running one-millisecond clock
   will be in error only a small fraction of one part per million, or
   less than a second per year.

   In some cases a particular timestamp may not be available, such as
   when the protocol first starts up. In these cases the 64-bit field
   is set to zero, indicating the value is invalid or undefined.

Following is a description of the various data items used in the
protocol. Details of packet formats are presented in the Appendices.

Leap Indicator

   This is a two-bit code warning of an impending leap-second to be
   inserted in the internationally coordinated Standard Time
   broadcasts. A leap-second is occasionally added or subtracted
   from Standard Time, which is based on atomic clocks, to maintain
   agreement with Earth rotation. When necessary, the corrections
   are notified in advance and executed at the end of the last day of
   the month in which notified, usually June or December. When a
   correction is executed the first minute of the following day will
   have either 59 or 61 seconds.

Status

   This is a six-bit code indicating the status of the local clock.
   Values are assigned to indicate whether it is operating correctly
   or in one of several error states.

Reference Clock Type

   This is an eight-bit code identifying the type of reference clock
   used to set the local clock. Values are assigned for primary
   clocks (locally synchronized to Standard Time), secondary clocks
   (remotely synchronized via various network protocols) and even
   eyeball-and-wristwatch.

Precision

   This is a 16-bit signed integer indicating the precision of the
   local clock, in seconds to the nearest power of two. For
   instance, a 60-Hz line-frequency clock would be assigned the value
   -6, while a 1000-Hz crystal clock would be assigned the value -10.

Estimated Error

   This is a 32-bit fixed-point number indicating the estimated error
   of the local clock at the time last set. The value is in seconds,
   with fraction point between bits 15 and 16, and is computed by the
   sender based on the reported error of the reference clock, the
   precision and drift rate of the local clock and the time the local
   clock was last set. For statistical purposes this quantity can be
   assumed equal to the estimated or computed standard deviation, as
   described in [12].

Estimated Drift Rate

   This is a 32-bit signed fixed-point number indicating the
   estimated drift rate of the local clock. The value is
   dimensionless, with fraction point to the left of the high-order
   bit. While for most purposes this value can be estimated based on
   the hardware characteristics, it is possible to compute it quite
   accurately, as described in [12].

Reference Clock Identifier

   This is a 32-bit code identifying the particular reference clock.
   The interpretation of its value depends on value of Reference
   Clock Type. In the case of a primary clock locally synchronized
   to Standard Time (type 1), the value is an ASCII string
   identifying the clock. In the case of a secondary clock remotely
   synchronized to an Internet host via NTP (type 2), the value is
   the 32-bit Internet address of that host. In other cases the
   value is undefined.

Reference Timestamp

   This is a 64-bit timestamp established by the server or client
   host as the timestamp (presumably obtained from a reference clock)
   most recently used to update the local clock. If the local clock
   has never been synchronized, the value is zero.

Originate Timestamp

   This is a 64-bit timestamp established by the client host and
   specifying the local time at which the request departed for the
   service host. It will always have a nonzero value.

Receive Timestamp

   This is a 64-bit timestamp established by the server host and
   specifying the local time at which the request arrived from the
   client host. If no request has ever arrived from the client the
   value is zero.

Transmit Timestamp

   This is a 64-bit timestamp established by the server host and
   specifying the local time at which the reply departed for the
   client host. If no request has ever arrived from the client the
   value is zero.

5. Protocol Operation

   The intent of this document is to specify a standard for data
   representation and message format which can be used for a variety of
   synchronizing algorithms and filtering mechanisms. Accordingly, the
   information in this section should be considered a guide, rather than
   a concise specification. Nevertheless, it is expected that a
   standard Internet distributed timekeeping protocol with concisely
   specified synchronizing and filtering algorithms can be evolved from
   the information in this section.

   5.1. Protocol Modes

      The distinction between client and server is significant only in
      the way they interact in the request/response interchange. The
      same NTP message format is used by each peer and contains the same
      data relative to the other peer. In the unsymmetric mode the
      client periodically sends an NTP message to the server, which then
      responds within some interval. Usually, the server simply
      interchanges addresses and ports, fills in the required
      information and sends the message right back. Servers operating in
      the unsymmetric mode then need retain no state information between
      client requests.

      In the symmetric mode the client/server distinction disappears.
      Each peer maintains a table with as many entries as active peers,
      each entry including a code uniquely identifying the peer (e.g.
      Internet address), together with status information and a copy of
      the Originate Timestamp and Receive Timestamp values last received
      from that peer. The peer periodically sends an NTP message to each
      of these peers including the latest copy of these timestamps. The
      interval between sending NTP messages is managed solely by the
      sending peer and is unaffected by the arrival of NTP messages from
      other peers.

      The mode assumed by a peer can be determined by inspection of the
      UDP Source Port and Destination Port fields (see Appendix A). If
      both of these fields contain the NTP service-port number 123, the
      peer is operating in symmetric mode. If they are different and
      the Destination Port field contains 123, this is a client request
      and the receiver is expected to reply in the manner described
      above. If they are different and the Source Port field contains
      123, this is a server reply to a previously sent client request.

5.2. Message Processing

   The significant events of interest in NTP occur usually near the
   times the NTP messages depart and arrive the client/server. In
   order to maintain the highest accuracy it is important that the
   timestamps associated with these events be computed as close as
   possible to the hardware or software driver associated with the
   communications link and, in particular, that departure timestamps
   be recomputed for each retransmission, if used at the link level.

   An NTP message is constructed as follows (see Appendix B). The
   source peer constructs the UDP header and the LI, Status,
   Reference Clock Type and Precision fields in the NTP data portion.
   Next, it determines the current synchronizing source and
   constructs the Type and Reference Clock Identifier fields. From
   its timekeeping algorithm (see [12] for examples) it determines
   the Reference Timestamp, Estimated Error and Estimated Drift Rate
   fields. Then it copies into the Receive Timestamp and Transmit
   Timestamp fields the data saved from the latest message received
   from the destination peer and, finally, computes the Originate
   Timestamp field.

   The destination peer calculates the roundtrip delay and clock
   offset relative to the source peer as follows. Let t1, t2 and t3
   represent the contents of the Originate Timestamp, Receive
   Timestamp and Transmit Timestamp fields and t4 the local time the
   NTP message is received. Then the roundtrip delay d and clock
   offset c is:

      $d = (t4 - t1) - (t3 - t2)$ and $c = (t2 - t1 + t3 - t4)/2$.

   The implicit assumption in the above is that the one-way delay is
   statistically half the roundtrip delay and that the intrinsic
   drift rates of both the client and server clocks are small and
   close to the same value.

5.3. Network Considerations

   The client/server peers have an opportunity to learn a good deal
   about each other in the NTP message exchange. For instance, each
   can learn about the characteristics of the other clocks and select
   among them the most accurate to use as reference clock, compute
   the estimated error and drift rate and use this information to
   manage the dynamics of the subnetwork of clocks. An outline of a
   suggested mechanism is as follows:

   Included in the table of timestamps for each peer are state

variables to indicate the precision, as well as the current
estimated delay, offset, error and drift rate of its local clock.
These variables are updated for each NTP message received from the
peer, after which the estimated error is periodically recomputed
on the basis of elapsed time and estimated drift rate.

Assuming symmetric mode, a polling interval is established for
each peer, depending upon its normal synchronization source,
precision and intrinsic accuracy, which might be determined in
advance or even as the result of observation. The delay and
clock-offset samples obtained can be filtered using
maximum-likelihood techniques and algorithms described in [12].

From time to time a local-clock correction is computed from the
offset data accumulated as above, perhaps using algorithms
described in [10] and [12]. The correction causes the local clock
to run slightly fast or slow to the corrected time or to jump
instantaneously to the correct time, depending on the magnitude of
the correction. See [5] and [11] for a discussion of local-clock
implementation models and synchronizing algorithms. Note that the
expectation here is that all network clocks are maintained by
these algorithms, so that manual intervention is not normally
required.

As a byproduct of the above operations an estimate of local-clock
error and drift rate can be computed. Note that the magnitude of
the error estimate must always be greater than that of the
selected reference clock by at least the inherent precision of the
local clock. It does not take a leap of imagination to see that
the estimated error, delay or precision, or some combination of
them, can be used as a metric for a simple min-hop-type routing
algorithm to organize the subnetwork so as to provide the most
accurate time to all peers and to provide automatic fallback to
alternate sources in case of failures.

A variety of network configurations can be included in the above
scenario. In the case of networks supporting a broadcast
function, for example, NTP messages can be broadcast from one or
more server hosts and picked up by client hosts sharing the same
cable. Since typical networks of this type have a very low
propagation delay, the roundtrip-delay calculation can be omitted
and the clients need not broadcast in return. Thus, the
requirement to save per-peer timestamps is removed, so that the
Receive Timestamp and Transmit Timestamp fields can be set to zero
and the local-clock offset becomes simply the difference between
the Originate Timestamp and the local time upon arrival. In the
case of long-delay satellite networks with broadcast capabilities,

an accurate measure of roundtrip delay is usually available from
the channel-scheduling algorithm, so the per-peer timestamps again
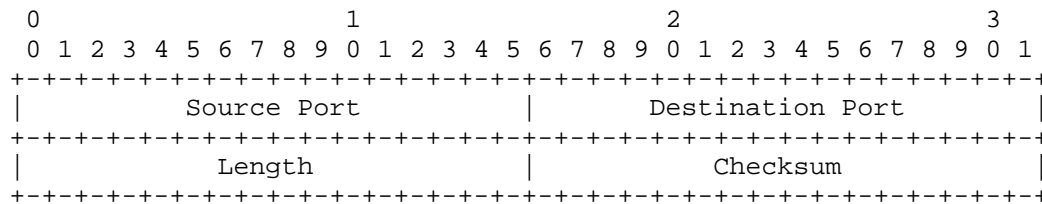can be avoided.

5.4. Leap Seconds

A standard mechanism to effect leap-second correction is not a
part of this specification. It is expected that the Leap
Indicator bits would be set by hand in the primary reference
clocks, then trickle down to all other clocks in the network,
which would execute the correction at the specified time and reset
the bits.

6. References

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    9. Su, Z. A Specification of the Internet Protocol (IP) Timestamp
        Option. DARPA Network Working Group Report RFC-781. SRI
        International, May 1981.

    10. Marzullo, K., and S. Owicki. Maintaining the Time in a
        Distributed System. ACM Operating Systems Review 19, 3 (July
        1985), 44-54.

    11. Mills, D.L. Experiments in Network Clock Synchronization. DARPA
        Network Working Group Report RFC-957, M/A-COM Linkabit, August
        1985.

    12. Mills, D.L. Algorithms for Synchronizing Network Clocks. DARPA
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Appendix A.   UDP Header Format

   An NTP packet consists of the UDP header followed by the NTP data
   portion. The format of the UDP header and the interpretation of its
   fields are described in [13] and are not part of the NTP
   specification. They are shown below for completeness.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Source Port          |       Destination Port        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Length             |           Checksum            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Source Port

   UDP source port number. In the case of unsymmetric mode and a
   client request this field is assigned by the client host, while
   for a server reply it is copied from the Destination Port field of
   the client request. In the case of symmetric mode, both the
   Source Port and Destination Port fields are assigned the NTP
   service-port number 123.

Destination Port

   UDP destination port number. In the case of unsymmetric mode and a
   client request this field is assigned the NTP service-port number
   123, while for a server reply it is copied form the Source Port
   field of the client request. In the case of symmetric mode, both
   the Source Port and Destination Port fields are assigned the NTP
   service-port number 123.
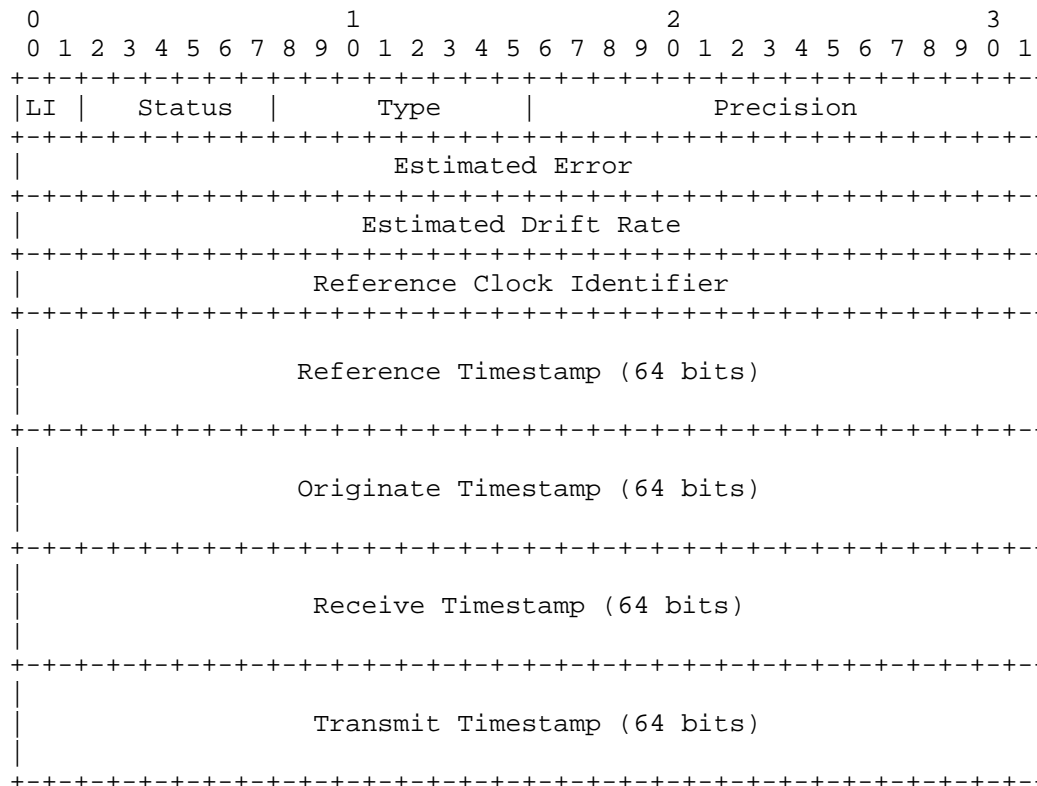
Length

   Length of the request or reply, including UDP header, in octets.

Checksum

   Standard UDP checksum.

Appendix B. NTP Data Format

   The format of the NTP data portion, which immediately follows the UDP
   header, is shown below along with a description of its fields.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|LI |   Status  |     Type      |            Precision          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Estimated Error                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Estimated Drift Rate                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Reference Clock Identifier                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                  Reference Timestamp (64 bits)                |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                  Originate Timestamp (64 bits)                |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                   Receive Timestamp (64 bits)                 |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                  Transmit Timestamp (64 bits)                 |
|                                                               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Leap Indicator (LI)

      Code warning of impending leap-second to be inserted at the end of
      the last day of the current month. Bits are coded as follows:

         00   no warning
         01   +1 second (following minute has 61 seconds)
         10   -1 second (following minute has 59 seconds)
         11   reserved for future use

   Status

      Code indicating status of local clock. Values are defined as
      follows:

                 0   clock operating correctly
                 1   carrier loss
                 2   synch loss
                 3   format error
                 4   interface (Type 1) or link (Type 2) failure
              (additional codes reserved for future use)

     Reference Clock Type
     (Type)

        Code identifying the type of reference clock. Values are defined
        as follows:

                 0   unspecified
                 1   primary reference (e.g. radio clock)
                 2   secondary reference using an Internet host via NTP
                 3   secondary reference using some other host or protocol
                 4   eyeball-and-wristwatch
              (additional codes reserved for future use)

     Precision

        Signed integer in the range +32 to -32 indicating the precision of
        the local clock, in seconds to the nearest power of two.

     Estimated Error

        Fixed-point number indicating the estimated error of the local
        clock at the time last set, in seconds with fraction point between
        bits 15 and 16.

     Estimated Drift Rate

        Signed fixed-point number indicating the estimated drift rate of
        the local clock, in dimensionless units with fraction point to the
        left of the high-order bit.

     Reference Clock
     Identifier

        Code identifying the particular reference clock. In the case of
        type 1 (primary reference), this is a left-justified, zero-filled
        ASCII string identifying the clock, for example:

            WWVB   WWVB radio clock (60 KHz)

         GOES   GOES satellite clock (468 HMz)
         WWV   WWV radio clock (2.5/5/10/15/20 MHz)
         (and others as necessary)

    In the case of type 2 (secondary reference) this is the 32-bit
    Internet address of the reference host. In other cases this field
    is reserved for future use and should be set to zero.

Reference Timestamp

    Local time at which the local clock was last set or corrected.

Originate Timestamp

    Local time at which the request departed the client host for the
    service host.

Receive Timestamp

    Local time at which the request arrived at the service host.

Transmit Timestamp

    Local time at which the reply departed the service host for the
    client host.