

# IEEE 1588 for Frequency, Phase, and Time Distribution

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## In This Chapter

This section provides information about IEEE 1588 for frequency, phase, and time distribution.

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## Applicability

This section is applicable to all of the 7750 SR and 7450 ESS series, except for the SR-1, ESS-1, and ESS-6/6v. It is not applicable to the 7710 SR nor the 7950 XRS series. Description and examples are based on release 12.0.R2. The only software pre-requisites are IP reachability between the node and neighboring 1588 clocks.

IEEE 1588 has several hardware dependencies both for the basic functionality as well as the 1588 port based timestamping necessary for high accuracy time distribution. Please consult the related Alcatel-Lucent documentation for the details of all the hardware requirements.

## Summary

Defined in IEEE Std 1588™-2008 (1588v2), Precision Time Protocol (PTP) is a protocol that distributes frequency, phase and time over packet based networks<sup>1</sup>. The IEEE 1588 protocol has become the standard for distribution of high accuracy time. Following guidelines for specific network architectures allows the delivery of time to accuracies of one microsecond. This level of accuracy is required for mobile base stations using either Time Division Duplex technology and/or advanced LTE functions, as well as in the power industry for intelligent electronic device alignment.

More lenient architectures can still achieve 100 microseconds or better accuracies which can greatly enhance the usefulness of event logging and network one way delay measurements.

In addition, 1588 has been used to deliver a frequency reference for T1/E1 ports or for mobile base station frequency alignment. This is useful in environments where the transport network does not provide physical layer synchronization services.

The following 1588 capabilities are provided within the 7750 SR and 7450 ESS nodes:

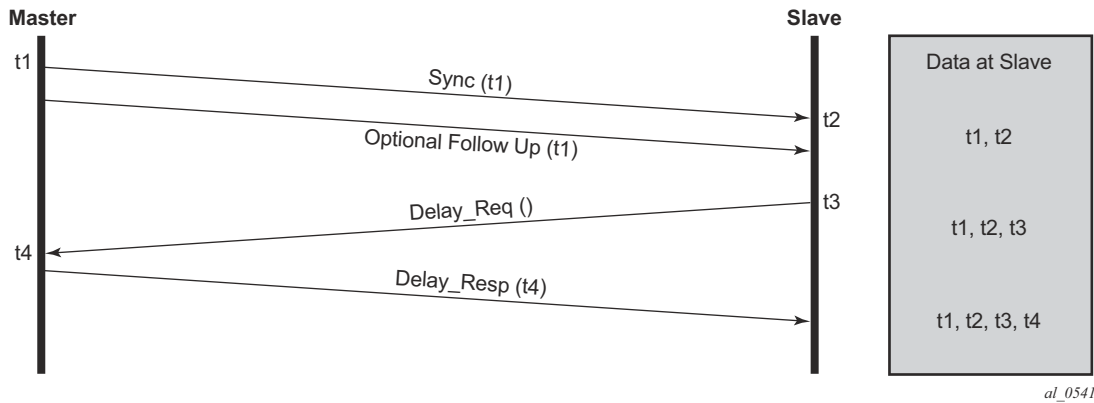
- CPM/CFM based 1588 master, boundary, and slave clock functionality
- Transport over Unicast UDP/IPv4 packets
- Access to 1588 process through base routing, IES, and VPRNs
- Port based timestamping of 1588 packets
- IEEE 1588 Profiles: 2008 standard default and ITU-T G.8265.1
- Utilization of 1588 derived time for NTP and System time.

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1. Many applications do not need time alignment but only phase alignment. However, phase is derived from time and so, for the remainder of the document, discussion refers to time but those references imply both time and phase.

## PTP Basics

PTP uses an exchange of four timestamps between a reference clock (master port) and the clock to be synchronized (slave port). A simplified illustration of this mechanism is shown in [Figure 5](#).



**Figure 5: PTP Messages and Timestamp Exchange**

The master sends a PTP Sync message containing a timestamp of when the Sync message is transmitted (t1) to the slave. In a two-step master clock, the t1 timestamp is sent in a Follow\_Up<sup>2</sup> message. The slave records the time it receives the Sync message (t2). At some point after receiving the Sync message, the slave sends a Delay\_Req message back to the master. The slave records the time of transmission of the Delay\_Req message (t3) locally. The master records the time it receives the Delay\_Req message (t4) and sends this timestamp back to the slave in a Delay\_Resp message.

After the four timestamp exchange the slave can calculate the mean path delay and the clock offset from master using the following two equations:

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2. Note the Follow\_Up message was defined to allow for implementations to generate a timestamp for the transmission of the Sync message but not have to try to insert that timestamp into the Sync message and update any frame checksums on the fly as it is in the process of transmission. While many recent implementations can perform the timestamping, update and checksum calculation on the fly, not all devices could perform this three step process with the desired accuracy. By using the Follow\_Up message to transmit the timestamp of the Sync message, the master port can still provide extremely accurate timestamps for the transmission of the Sync message to the slave port. Apart from the extra message required, there is no detriment to a master port using one-step clock versus a two-step clock procedures. All PTP clocks that have slave port capability must accept timing information from both types of master port. There is no requirement to force a clock that is a one-step clock to use two-step clock procedures on its master ports. The nodes covered by this example all support one-step clock master port procedures.

$$\text{mean\_path\_delay} = [(t4-t1) - (t3-t2)] / 2$$
$$\text{offset\_from\_master} = [(t2 - t1) - \text{mean\_path\_delay}]$$

These calculations can occur on every message exchange or some initial packet selection can be performed so that only optimal message exchanges are used. The latter is useful if there is variable delay between the master and slave ports.

If only frequency is necessary, then the slave may use one or both pairs of timestamps (t1, t2) and (t3, t4). The slave can monitor the change in the perceived delay master-to-slave (t2 - t1) or slave-to-master (t4 - t3) over time. If the delay (t2 - t1) decreases over time, it means the t2 timestamps are not progressing quickly enough and the slave clock frequency needs to be increased.

If time is necessary, then all four timestamps must be used. It is also important to note how the equation for offset uses the mean\_path\_delay. If the delays in the two directions are actually different, then the equation will introduce an error in the offset\_from\_master that is half of the difference of the two delays. The IEEE 1588 standard includes procedures to compensate for this asymmetry, if it is known, but if it is uncompensated it does introduce time error.

## PTP Deployment Architectures

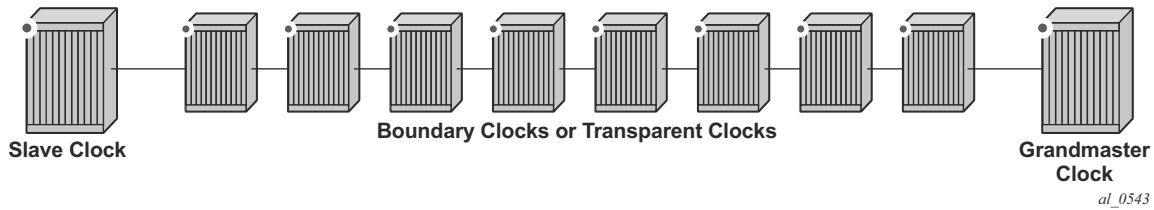
It is important to understand that there are very different topologies recommended for using 1588 for frequency distribution and using 1588 for time distribution.

Frequency distribution was developed for an architecture where there are mobile providers who have points of presence at the mobile telephony switching offices (MTSOs) and the cell site locations which depend on other parties for the connectivity between the MTSOs and the cell site locations. The mobile providers wanted a solution that could span the transport networks with minimal dependence on that network. This can be achieved by placing a 1588 grandmaster at the MTSO and a slave in a cell site router or directly in the basestation and distributing the timestamped packets between the two, as shown in [Figure 6](#). The transport network does introduce packet delay variation (PDV) to the 1588 messages which makes it more difficult to track the frequency of the grandmaster's clock. However, the slaves have been designed to perform packet selection and noise filtering to allow for the recovery of a frequency within the required accuracies of the mobile basestations. This architecture and the performance requirements are covered by the ITU-T G.826x series of recommendations.



**Figure 6: 1588 Topology for Frequency Distribution**

For time distribution, it has been recognized that the architecture used above is extremely unlikely to be successful. The fundamental reason is that the performance requirement is much tighter and the network introduces not only PDV but also potentially asymmetric delay which causes time error in the slave. The topology recommended for time distribution is what is sometimes referred to as “Full On-Path Support (OPS)”. Full OPS means that every network element between the grandmaster clock and the slave clock is either a 1588 boundary clock or a 1588 transparent clock, as shown in [Figure 7](#). Boundary clocks and transparent clocks process the 1588 messages and remove the PDV noise that would be present in a non 1588 network element. By using network elements that have very tight constraints on the time error they introduced, the network can be built to guarantee time accuracy under all network traffic conditions. This architecture and the performance requirements are covered by the ITU-T G.827x series of recommendations.



**Figure 7: 1588 Topology for Time Distribution**

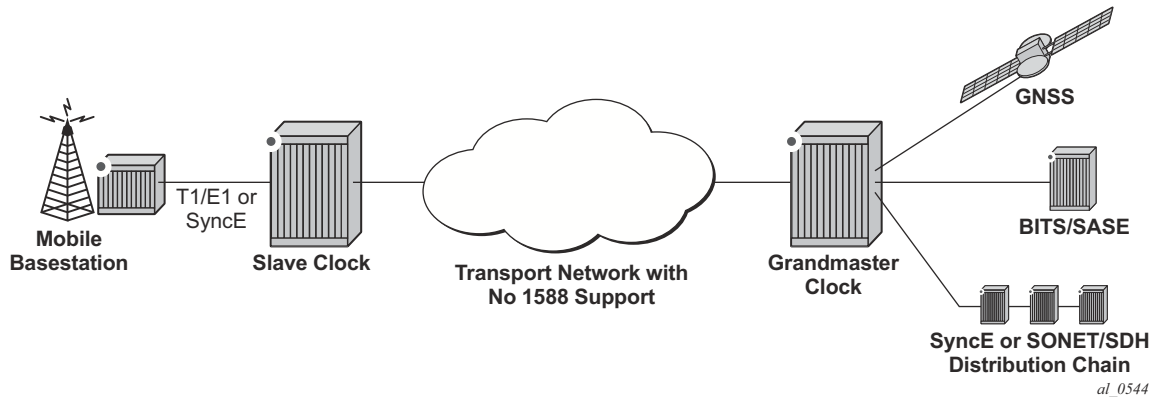
## PTP Profiles

The 1588v2 standard includes the concept of a PTP profile. A PTP profile allows standardization bodies or industry groups to adapt the 1588v2 standard to a particular application. A profile defines which aspects of the 1588v2 standard are included or excluded, along with configurable ranges and defaults necessary for the application.

The 1588 standard itself includes a **default** profile that can be used for either time or frequency distribution. The default profile was defined principally for multicast operation. However, it can be used with the unicast sessions as described below. The default profile supports all 1588 clock types and includes the Best Master Clock Algorithm (BMCA) that automatically builds the synchronization distribution hierarchy amongst the PTP clocks. The SR OS only supports the unicast session version of the default profile.

In the telecommunications industry, the ITU-T is the body that develops these profiles. They have generated a profile for frequency distribution (G.8265.1) and a profile for time distribution (G.8275.1). The frequency profile permits only grandmaster and slave clocks and can be used to extend a traditional physical layer synchronization distribution (SONET/SDH, PDH, or SyncE) with a final leg of 1588 messages. The frequency source of the 1588 grandmaster could be a GPS receiver, a central office BITS or SASE device or it could use the frequency recovered from a Synchronous Ethernet or SONET/SDH interface. This is shown in [Figure 8](#)

Because a 1588 distribution system is significantly noisier than a physical layer distribution system, it should only be used as the final segment to connect the end application into the synchronization network. It should not be used to connect two Synchronous Ethernet or SONET/SDH islands.



**Figure 8: Frequency Distribution with 1588 as Last Mile**

The important features defined in the G.8265.1 profile are:

- Only master clocks and slave clocks are allowed.
- Unicast Message Negotiation using Signaling messages from the slave clocks toward the master clocks is used to establish communications.
- PTP messages are encapsulated over UDP over IPv4.
- PTP clock class values are based on a mapping of traditional quality levels from SSM/ESMC<sup>3</sup>.

The slave clock uses an alternate BMCA to select the grandmaster clock from the available master clocks based on:

- Quality Level.
- Relative Priority.

The ITU-T has defined the first time distribution profile in G.8275.1. It uses an architecture of a Global Navigation Satellite System (GNSS) based grandmaster clock distributing time through a chain of boundary clocks to a final slave device and end application. It includes the use of Synchronous Ethernet and 1588 at the same time for optimal performance. Physical layer Synchronous Ethernet is an excellent tool for the distribution of an accurate and stable frequency. This frequency can be used to advance time between offset adjustments made using the 1588 information.

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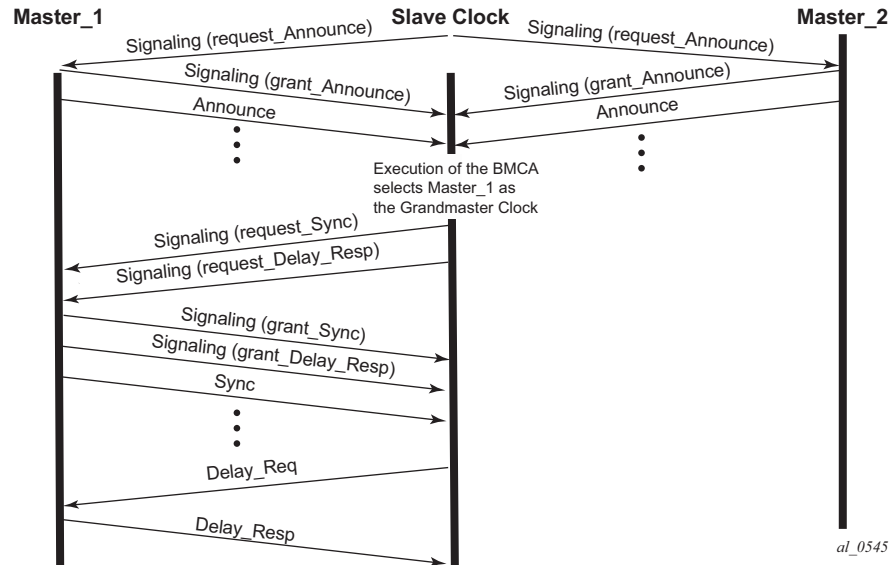
3. SSM stands for Synchronization Status Messages and ESMC stands for Ethernet Synchronization Messaging Channel. These are two capabilities in SDH/SONET and Synchronous Ethernet respectively for the relaying of source clock quality information.



## Unicast Message Negotiation

The initial IEEE 1588-2002 standard defined a multicast messaging model. IEEE 1588-2008 introduced the option of using unicast messaging with unicast discovery to establish a message exchange between a master and slave.

The typical unicast message flow between a master and slave is illustrated in [Figure 9](#).



**Figure 9: Unicast Message Negotiation**

A slave clock initiates unicast discovery by sending a Signaling message to one of its configured master clocks requesting the master send unicast Announce messages to the slave. The request includes the desired rate for the Announce messages and the duration over which the messages should be sent. If the master can support the request it replies with a Signaling message indicating that the session for unicast Announce messages has been granted.

From this point on, the master sends unicast Announce messages to the slave at the rate requested. A slave will generally establish an Announce message session with at least two master clocks.

The slave then uses the Announce messages it receives from all masters as input to the BMCA that determines which master clock is the best source for information. The selected master becomes the grandmaster clock to the slave. The slave then sends additional Signaling messages to the grandmaster to request unicast delivery of Sync and Delay\_Resp messages. Assuming the grandmaster clock has sufficient resources, the request is granted and unicast Sync and Delay\_Resp messages are sent from the grandmaster to the slave.

## Network Limits

As with the Announce messages, the rate at which the Sync and Delay\_Resp messages are sent and the duration of the unicast sessions is requested by the slave in the initial Signaling messages.

The unicast sessions for Announce, Sync and Delay Response messages have an expiry time. The slave renews all three sessions before this time is reached.

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## Network Limits

A common concern around 1588 is whether it will work on or over a specific customer network. For time distribution using full OPS as shown in [Figure 7](#), there are well defined limits on the number of network elements allowed in the distribution chain (see below). However, for the frequency distribution using the architecture shown in [Figure 6](#), it is a more difficult question to answer. There are so many different types of network elements and inter-node links that a simple limit on the number of network elements is not adequate. What has been specified is a limit to the noise that the network can introduce to the 1588 message flow between the grandmaster and slave clocks. This noise occurs as packet delay variation (PDV). The following sections provide some description of this PDV and a new metric that has been defined for PDV as well as the recommended limit to PDV for 1588 deployments.

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## Packet Delay Variation

If the packet delay through the packet network is constant, then it is relatively easy to use a series of timestamp exchanges to remove the delay as an unknown and track the master clock frequency. However, in most network technologies, the packet delay will be different for each individual packet. This PDV makes it more difficult to track the master clock since observations have both the master information and PDV noise included.

PDV is introduced when packets get placed in queues before they are forwarded. The time each packet sits in any one queue is influenced by multiple factors:

- the speed of the interface toward which the queue drains, for example 100Mbps versus 100Gbps,
- the traffic load on the interface, for example 20% versus 100% of line capacity,
- the distribution of packet sizes and priorities in the traffic load toward the interface, and
- the underlying physical technology used, xPON, xDSL, Ethernet, or microwave.

In addition, the load and packet distribution within the load will vary over time so the distribution of the PDV can shift rapidly such as when a network event triggers congestion or slowly, for example as end customers gradually come online over a period of several hours.

Also there are pipeline effects that can occur in a chain of queuing devices, where the small timing packets can catch up to a large packets moving across the network. Once behind such a packet, the timing packet can remain stuck behind that packet on all subsequent transmit queues.

QoS prioritization of packets helps reduce PDV significantly during congestion periods, but does not remove the PDV effects during lighter loading. This is due to the fact that a timing packet may be delivered to the egress queue for an interface while the interface is busy transmitting a packet. Pre-emption of packet transmissions is not used in today's networks.

Having stated all of the above, most of the time, the network will still present a percentage of packets that get across the network with minimal queuing delays. These are often referred to as 'lucky' or 'fastest' packets. Since these lucky packets are never waiting in queues or have minimal wait times, their transit across the network is relatively consistent. By running a selection filter on all 1588 packets to find these lucky packets, a level of variation of network delay can be removed or reduced significantly. Then the slave clocks have a much easier time determining the frequency of the grandmaster.

However, there will always be a limit to the amount of PDV that can be tolerated. The ITU has defined a metric to quantify the PDV, the limit of the PDV for a compliant network, and the required tolerance of a slave clock.

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### PDV Metrics

In order to know whether a particular timing-over-packet implementation will meet the performance targets in a given network deployment, it is desirable to both characterize the limits on the PDV that the implementation can tolerate and to measure the network against these limits. In 2012, the ITU-T published three documents that address these requirements:

- G.8260 defines the Floor Packet Percentage (FPP) metric.
- G.8261.1 defines a network limit for PDV in terms of FPP.
- G.8263 defines the input tolerance expected of a 1588 frequency slave in terms of FPP.

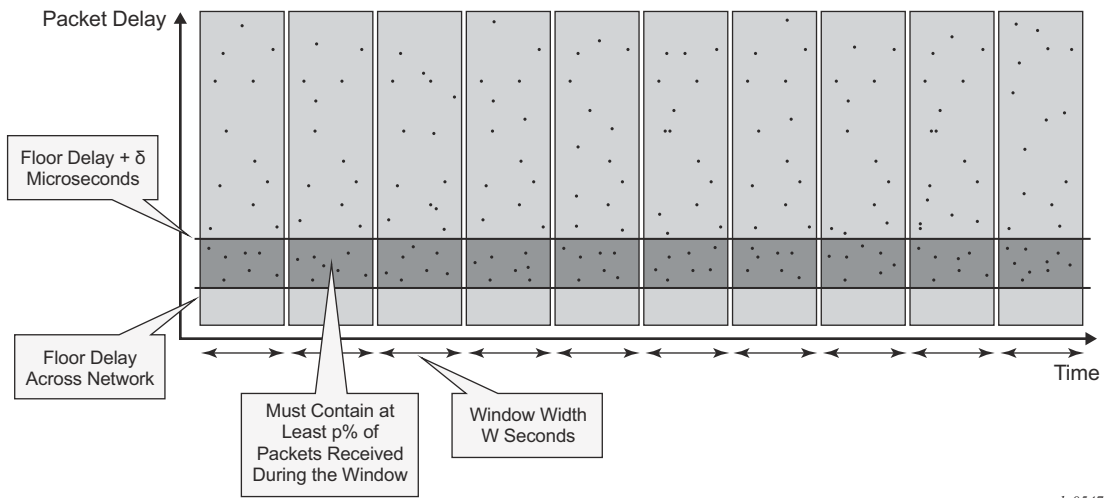
The Floor Packet Percentage (FPP) metric provides an indication of the guarantee that there are packets experiencing minimal delay across the network. The rationale behind this focus on 'fastest' packets is that many networks do provide good consistency of these packets in most operating conditions and because most slave clocks are capable of operating using only the information from these fastest packets.

There are four parameters associated with the metric:

- **W** is the width of the windows used to monitor for the presence of fastest packets.
- **Floor Delay** is a value that is as close as possible to the absolute minimum transit delay across the network. Every actual delay measurement must be equal to or larger than this value.

- $\delta$  is the range above the floor to be analyzed for the presence of fastest packets.
- $\rho$  is the percentage of all the packets received in a window whose delay must be within the range floor delay to floor delay +  $\delta$ .

Figure 10 illustrates how these parameters and the metric work. First the delays of all individual 1588 packets are plotted over the period of observation. Next the observation period is broken down into a series of consecutive windows of width  $W$  seconds. Then for each window a count is made of all the 1588 packets whose delays are within the range **floor delay** to **floor delay +  $\delta$**  and this count is compared with all the 1588 packets received during the window to turn the count into a percentage. Finally the percentage of each window is checked against the threshold percentage  $\rho$ . For the FPP metric to be met, every window must have a percentage greater or equal to the threshold. If even one single window does not meet this threshold then the metric condition is not met.



al\_0547

**Figure 10: Floor Packet Counting for FPP ( $n, W, \delta$ )**

Note: This metric is not perfect as it does not take into account slaves that use other aspects of the packet delay distribution (such as average delay), nor does it discuss the impact of reroutes, nor do the limits discuss how to apply these limits to the forward and backward message exchanges at the same time. However, it was agreed that this metric was a good start for the definitions of the network and slave limits. Expect to see timing test equipment vendors providing the tools to generate 1588 PDV profiles providing FPP based distributions.

## ITU-T Budget for Frequency

The network limit on PDV for frequency distribution is defined in G.8271.1 using the FPP metrics defined above.

In general most carrier grade networks with spans of up to 10 nodes and which do not exceed 80% load on their internode links should meet the requirement. However, very low (sub 50 Mbps) shaping or very long networks or last mile technologies such as xDSL or xPON may need to be studied to determine their acceptability.

A general strategy for rolling out 1588 frequency distribution is to evaluate the specific grandmaster and slave pairing in a lab environment using a network emulator to introduce controlled PDV. Once the grandmaster and slave have passed the lab tests, then field trial locations should be identified. Ideally, the sites should include locations where the PDV of the network will likely be at its worst. This would be sites with the most intervening network elements between the grandmasters and the slaves and include segments of the network that have a high load. The slaves' clocks should be deployed and monitored over several days to ensure that their frequency recovery engines can maintain lock with the grandmasters. During the initial field trails, it is beneficial to use external frequency test equipment at the slave locations to accurately monitor the frequency generated out of the slaves and ensure it stays within limits. As more sites are evaluated and confidence in the PDV environment increases, more deployments can be rolled out. In the deployed network, PTP frequency recovery slave states can be monitored to ensure the solution continues to work.

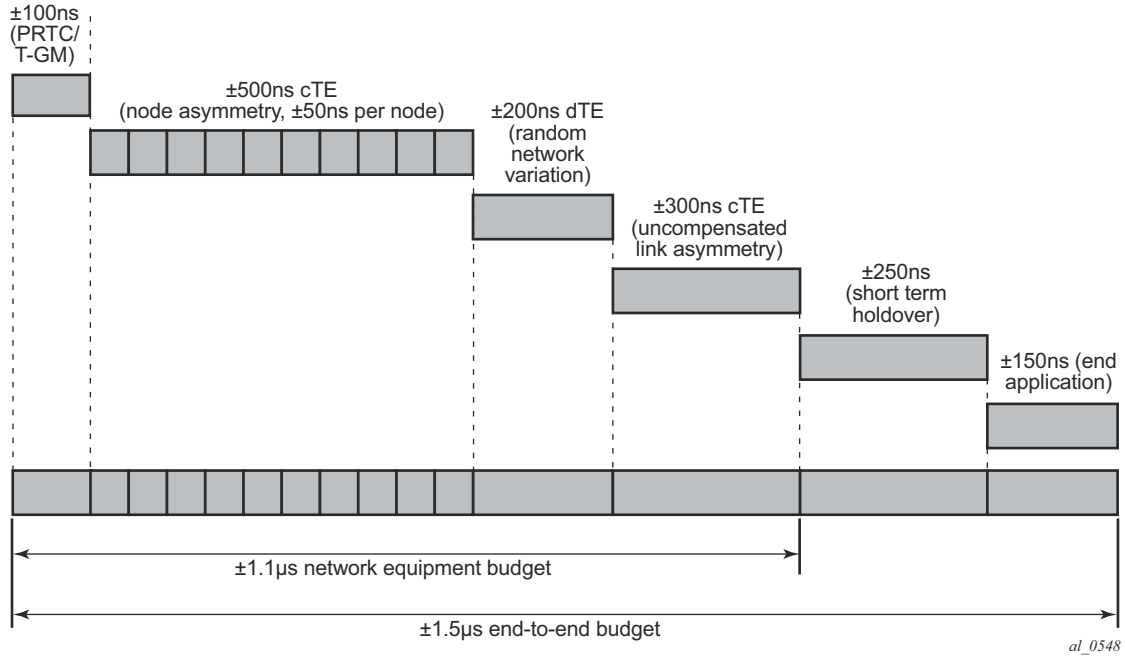
There may be some locations in the network where the PDV will be too large preventing the slaves to achieve or maintain lock. If it is possible to utilize an alternate network interface to obtain a frequency such as a leased T1 or E1 interface then that could be used. A last resort would be the deployment of a GNSS receiver at the location to provide the frequency reference.

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## ITU-T Budget for Time

The ITU-T has defined a topology for time distribution based on a full OPS environment. This means that every network element in the time distribution chain is a 1588 clock of some type. Currently the work has defined an environment using Boundary Clocks, but this might be modified in the future to include transparent clocks. The ITU-T tackled the time distribution problem in a more traditional way when compared with the frequency distribution. The ITU-T first defined specific network element clock performance constraints and then defined a longest chain network permitted to ensure that the solution meets the end to end budget. The breakdown of the chain and the budget is shown in [Figure 11](#).

## Network Limits



**Figure 11: G.8271.1 Time Error Budget**

The overall end to end budget is defined as  $\pm 1.5$  microseconds. From this the following allocations are made:

- $\pm 100 \text{ ns}$  Time error due to the GNSS receiver and the 1588 grandmaster.
- $\pm 500 \text{ ns}$  Constant Time error due to ten Telecom Boundary Clocks (50 ns limit per boundary clock).
- $\pm 200 \text{ ns}$  Dynamic Time error presented at the end of the boundary clock chain into the end slave.
- $\pm 300 \text{ ns}$  Time error due to errors in cable latency asymmetry compensation (see below).
- $\pm 150 \text{ ns}$  Time error due to the end slave and any internals of the basestation between the recovery and the presentation on the air interface.
- $\pm 200 \text{ ns}$  Time error in the end application during short term holdovers such as network topology re-arrangements.

Note there is discussion that some of these elements could be traded-off against each other. For example, if the link asymmetry needs a higher budget then the holdover budget would have to be less – implying a better end device or a shorter duration of holdover.

The link asymmetries are an important aspect of this budget. The network topology not only has to have the network elements that meet the clock specifications but it also needs to have links that

meet certain requirements. As explained above, the time offset calculation makes the assumptions that the master-to-slave latency is the same from the slave-to-master latency. When the latency is not equal, an error is introduced. Some analysis of network intersite connections may need to be performed to determine the budget for the link asymmetries.

## Configuration

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### IP Addressing for PTP Communication

The system supports communication to the PTP process on the CPM using any of the IPv4 local interface addresses or an IPv4 local loopback addresses. The system will record both the source and destination address information from the received Signaling message which establishes the unicast session. The system will then swap these addresses for use for the Sync and/or Delay\_Req messages generated toward the external clock.

The IP address becomes more significant when 1588 port based timestamping is enabled. The port level functionality will filter received PTP packets for a known IP address. This ensures that only PTP messages intended for the node are modified and not PTP messages merely transiting the node.

If the 1588 nodes are directly connected or it is ensured that the PTP messages for a peer shall always enter/exit the system through a single interface, then the IP address of that interface can be used for the PTP message communication. If the PTP messages from a peer could enter through more than one interface, then it may be easier to utilize a loopback address for the PTP message communication.

If using a loopback address and 1588 port based timestamping is also to be used, then the specific loopback address must be assigned to PTP for use using the source-address command. An example is provided in the “Port Based Timestamping” section below. Note: When a source address is defined for the PTP process within a given routing context, then the source address for all Signaling messages originating out of the node within that routing context shall use that address.

Note: The procedures to establish IP connectivity for the specific addresses used in these examples are not included.

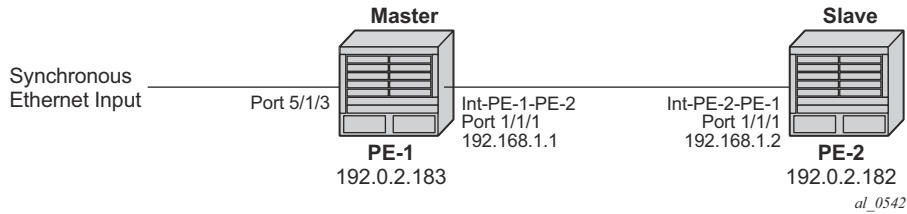
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### Master and Slave Clocks for Frequency

A typical deployment scenario for a system configured as an ordinary master to distribute frequency to an external slave clock, often a cell site router or a base station, is shown in [Figure 12](#). The central clock of the system is locked via its BITS ports or a Synchronous Ethernet port to an external source that is traceable to a primary reference. The frequency of the central clock is used to generate the timestamps contained in PTP event messages. The timestamps generated do not correlate to any standard epoch and therefore indicate an arbitrary timescale. As such it is only the rate of progression of the timestamps that has meaning.



The 7750 SR and the 7450 ESS can be configured as a 1588 slave clock for frequency recovery. In real deployments, it is more likely for the slave devices to be smaller cell site routers or basestations instead of another 7750 SR or 7450 ESS.



**Figure 12: Master and Slave Clocks for Frequency**

In the topology in [Figure 12](#), the systems will most likely be configured with the ITU-T G.8265.1 Profile.

For this example, a loopback address is used for PTP communication between the nodes.

## Ordinary Master Configuration

The steps to configure PE-1 as a PTP ordinary-clock master for frequency distribution using the G.8265.1 Telecom profile are outlined below:

Configure a /32 IPv4 system address on PE-1 and an interface to reach PE-2.

```
*A:PE-1#
configure
router
  interface "system"
    address 192.0.2.183/32
    no shutdown
  exit
  interface "int-PE-1-PE-2"
    address 192.168.1.1/30
    port 1/1/1
    no shutdown
  exit
exit
```

Configure an input reference for the central clock on PE-1. In this example, Synchronous Ethernet port 5/1/3 is used as the source for **ref2**.

```
*A:PE-1#
configure
port 5/1/3
  description "Sync-E reference for node"
  ethernet
  ssm
    code-type sonet
    no shutdown
  exit
exit
no shutdown
exit
system
  sync-if-timing
  begin
  ql-selection
  ref2
    source-port 5/1/3
    no shutdown
  exit
  commit
exit
exit
```

The default clock type is set to ordinary slave so that must be changed to ordinary master. The only other relevant configuration parameter for the master clock running the G.8265.1 profile is the network-type. The coding of the SSM/ESMC Quality Level into PTP clock Class must match the environment. The system supports both SONET and SDH networks. The default network-type

is sdh but for this example, the system is configured for the North American market so the network-type is set to sonet.

```
*A:PE-1#
  configure
    system
      ptp
        clock-type ordinary master
        network-type sonet
        no shutdown
      exit
    exit
```

---

## Ordinary Slave Configuration

To configure PE-2 as a PTP ordinary slave for frequency distribution using the G.8265.1 Telecom profile, firstly configure a /32 IPv4 system address on PE-2 and an interface to reach PE-1.

```
*A:PE-2#
  configure
    router
      interface "system"
        address 192.0.2.182/32
        no shutdown
      exit
      interface "int-PE-2-PE-1"
        address 192.168.1.2/30
        port 1/1/1
        no shutdown
      exit
    exit
```

As the default clock type is ordinary slave, PE-1 is configured as a peer clock, and the PTP process is enabled. In this example, the Quality Level encoding is also changed to sonet in order to match the North American market

```
*A:PE-1#
  configure
    system
      ptp
        network-type sonet
        peer 192.0.2.183 create
          no shutdown
        exit
      no shutdown
    exit
  exit
```

Usually a 1588 slave has at least two peers configured in order to provide redundant sources.

Configure PTP as the reference for the central clock on PE-2.

```
*A:PE-2#
  configure
    system
      sync-if-timing
        begin
          ql-selection
          ptp
          no shutdown
        exit
      commit
    exit
  exit
```

## Verification of Session Establishment

When PTP is set to no shutdown on PE-2, it initiates a PTP unicast session with PE-1. Correct session establishment can be verified by checking PTP related information as follows:

```
*A:PE-1# show system ptp unicast
=====
IEEE 1588/PTP Unicast Negotiation Information
=====
Router
  IP Address      Dir Type      Rate          Duration State   Time
-----
Base
  192.0.2.182    Tx  Announce 1 pkt/2 s  300      Granted 05/30/2014 06:08:38
  192.0.2.182    Tx  Sync     64 pkt/s   300      Granted 05/30/2014 06:08:43
  192.0.2.182    Rx  DelayReq 64 pkt/s   300      Granted 05/30/2014 06:08:43
  192.0.2.182    Tx  DelayRsp 64 pkt/s   300      Granted 05/30/2014 06:08:43
-----
PTP Peers          : 1
Total Packet Rate  : 192 packets/second
=====
```

```
*A:PE-2# show system ptp unicast
=====
IEEE 1588/PTP Unicast Negotiation Information
=====
Router
  IP Address      Dir Type      Rate          Duration State   Time
-----
Base
  192.0.2.183    Rx  Announce 1 pkt/2 s  300      Granted 05/30/2014 09:08:38
  192.0.2.183    Rx  Sync     64 pkt/s   300      Granted 05/30/2014 09:08:43
  192.0.2.183    Tx  DelayReq 64 pkt/s   300      Granted 05/30/2014 09:08:43
  192.0.2.183    Rx  DelayRsp 64 pkt/s   300      Granted 05/30/2014 09:08:43
-----
PTP Peers          : 1
Total Packet Rate  : 192 packets/second
=====
```

A **Pending** state indicates the system has sent a Unicast Request toward the peer but has not received a response. If the state remains **Pending**, then the IP connectivity between the systems should be verified.

To verify the slave frequency is operating properly, first check the high level information for PTP on PE-2. Note that the PTP Recovery State initially shows phase-tracking and then changes to locked. The time to achieve locked state varies based on the PDV.

```
*A:PE-2# show system ptp
=====
IEEE 1588/PTP Clock Information
=====
-----
Local Clock
-----
Clock Type       : ordinary,slave   PTP Profile      : ITU-T G.8265.1
Domain          : 4                Network Type     : sonet
Admin State     : up                Oper State       : up
Announce Interval : 1 pkt/2 s        Announce Rx Timeout: 3 intervals
Peer Limit      : none (Base Router)
Clock Id        : 00233efffe808250  Clock Class      : 255 (slave-only)
Clock Accuracy  : unknown           Clock Variance   : ffff (not computed)
Clock Priority1  : 128               Clock Priority2   : 128
PTP Port State  : slave             Last Changed     : 05/30/2014 09:08:42
PTP Recovery State: phase-tracking   Last Changed     : 05/30/2014 09:08:42
Frequency Offset : -2.704 ppb
-----
Parent Clock
-----
IP Address       : 192.0.2.183       Router           : Base
Parent Clock Id  : 00233efffe69f250  Remote PTP Port  : 1
GM Clock Id      : 00233efffe69f250  GM Clock Class   : 80 (prs)
GM Clock Accuracy : unknown          GM Clock Variance : ffff (not computed)
GM Clock Priority1: 128               GM Clock Priority2 : 128
-----
Time Information
-----
Timescale       : Arbitrary
Current Time    : 2014/05/30 14:12:52.9 (ARB)
Frequency Traceable : yes
Time Traceable  : no
Time Source     : other
=====
```

## IP Addressing for PTP Communication

In addition PTP packet statistics can be checked to verify reception of the PTP messages and the execution of the frequency slave:

```
*A:PE-2# show system ptp statistics
=====
IEEE 1588/PTP Packet Statistics
=====
```

	Input	Output
-----		
PTP Packets	5506	2742
Announce	23	0
Sync	2740	0
Follow Up	0	0
Delay Request	0	2740
Delay Response	2740	0
Signaling	3	3
Request Unicast Transmission TLVs	0	3
Announce	0	1
Sync	0	1
Delay Response	0	1
Grant Unicast Transmission (Accepted) TLVs	3	0
Announce	1	0
Sync	1	0
Delay Response	1	0
Grant Unicast Transmission (Denied) TLVs	0	0
Announce	0	0
Sync	0	0
Delay Response	0	0
Cancel Unicast Transmission TLVs	0	0
Announce	0	0
Sync	0	0
Delay Response	0	0
Ack Cancel Unicast Transmission TLVs	0	0
Announce	0	0
Sync	0	0
Delay Response	0	0
Other TLVs	0	0
Other	0	0
Event Packets timestamped at port	0	0
Event Packets timestamped at cpm	2740	2740
Discards	0	0
Bad PTP domain	0	0
Alternate Master	0	0
Out Of Sequence	0	0
Peer Disabled	0	0
Other	0	0
=====		
=====		
IEEE 1588/PTP Frequency Recovery State Statistics		
=====		
State	Seconds	
-----		
Initial	0	
Acquiring	0	
Phase-Tracking	43	
Locked	0	
Hold-over	0	

```

=====
IEEE 1588/PTP Event Statistics
=====
Event                                     Sync Flow Delay Flow
-----
Packet Loss                               0             0
Excessive Packet Loss                     0             0
Excessive Phase Shift Detected            0             0
Too Much Packet Delay Variation           0             0
=====
*

```

Secondly, the central clock status on the system can be checked:

```

*A:PE-2# show system sync-if-timing
=====
System Interface Timing Operational Info
=====
System Status CPM B                       : Master Locked
  Reference Input Mode                     : Non-revertive
  Quality Level Selection                   : Disabled
  Reference Selected                        : ptp
  System Quality Level                     : prs
  Current Frequency Offset (ppm)          : +0

Reference Order                             : bits ref1 ref2 ptp

Reference Mate CPM
  Qualified For Use                         : No
  Not Qualified Due To                     : LOS
  Selected For Use                         : No
  Not Selected Due To                     : not qualified

Reference Input 1
  Admin Status                             : down
  Rx Quality Level                         : unknown
  Quality Level Override                   : none
  Qualified For Use                         : No
  Not Qualified Due To                     : disabled
  Selected For Use                         : No
  Not Selected Due To                     : disabled
  Source Port                              : None

Reference Input 2
  Admin Status                             : down
  Rx Quality Level                         : unknown
  Quality Level Override                   : none
  Qualified For Use                         : No
  Not Qualified Due To                     : disabled
  Selected For Use                         : No
  Not Selected Due To                     : disabled
  Source Port                              : None

Reference BITS B
  Input Admin Status                       : down
  Rx Quality Level                         : failed
  Quality Level Override                   : none

```

## IP Addressing for PTP Communication

```
Qualified For Use           : No
  Not Qualified Due To      : disabled
Selected For Use           : No
  Not Selected Due To      : disabled
Interface Type             : DS1
Framing                    : ESF
Line Coding                 : B8ZS
Line Length                : 0-110ft
Output Admin Status        : down
Output Source              : line reference
Output Reference Selected  : none
Tx Quality Level           : N/A

Reference PTP
Admin Status               : up
Rx Quality Level           : prs
Quality Level Override     : none
Qualified For Use          : Yes
Selected For Use           : Yes
```

---

## Optional Configuration Items for Ordinary Master or Slave Configuration

The G.8265.1 profile is the default PTP profile on the system and it uses domain number value of 4. The domain number must match at both ends of the communication path or the PTP messages will be dropped. Some very old 1588 devices, may have the domain number set to zero which is the value used by the IEEE1588 default profile. In this case, the system would need to have its domain number changed to match that of the external slave.

```
configure
  system
    ptp
      shutdown
      domain 0
      no shutdown
    exit
  exit
```

Note that the domain number can only be adjusted if PTP is shutdown and only one common domain number is allowed for all 1588 messages to and from the system.

When using the system as a 1588 slave for frequency distribution, it is strongly recommended to use the default message rate of 64 pps for Sync and Delay\_Resp messages. If for some reason the parent 1588 peer cannot offer this rate, then the rate that the system requests must be adjusted. For example, if the maximum rate supported by the external 1588 grandmaster device (with an IP address of 192.0.2.166) only is 32 pps, then the system can be adjusted to request that rate as follows:



```

configure
  system
    ptp
      peer 192.0.2.166 create
        log-sync-interval -5
        no shutdown
      exit
    exit
  exit

```

Note that the Sync message rate can only be adjusted if the peer is shutdown.

The message rates are entered as the base 2 logarithm of the inter-message interval. So 32 pps has an inter message interval of 1/32 seconds and a log-sync-interval of -5.

The Announce message rate impact the speed at which PTP can detect communication failures and the speed at which the PTP topology is re-arranged. The default Announce rate is one message every two seconds and this should be adequate for networks with short chains of PTP clocks, for example G.8265.1 architectures. However, in network with longer chains of PTP clocks (for example, more than 5 boundary clocks), it may be desired to use a faster Announce message rate. In the following example, the slave is configured to request two Announce messages per second:

```

configure
  system
    ptp
      shutdown
      log-anno-interval -1
      no shutdown
    exit
  exit

```

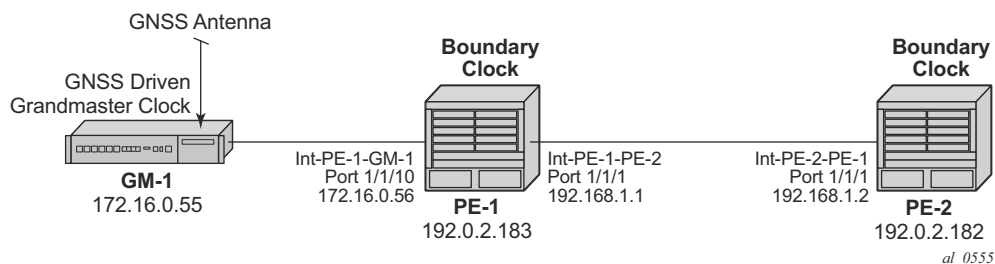
Note that the Announce rate can only be adjusted if PTP is shutdown. In addition, there is one common Announce rate for all unicast sessions; it cannot be configured on an individual peer basis.

## Boundary Clock

With the increase interest in high accuracy time distribution across networks, the system most likely takes on the role of a 1588 boundary clock. In this role, the system requests time from a GNSS driven grandmaster clock or from a neighboring boundary clock. The system only supports boundary clock configuration when the ptp profile is configured as the default profile.

In this mode of operation, it is strongly recommended to have Synchronous Ethernet physical layer frequency distribution configured at the same time.

The example in [Figure 13](#) shows a boundary clock (PE-1) communicating directly with the GNSS driven grandmaster (GM-1) and a second boundary clock (PE-2) communicating with the first boundary clock.



**Figure 13: Boundary Clock**

The steps to configure the systems as boundary clocks running the IEEE default profile are:

On PE-1, configure a /32 IPv4 system address, an interface to reach PE-2, and an interface to reach GM-1.

```
*A:PE-1#
configure
router
  interface "system"
    address 192.0.2.183/32
    no shutdown
  exit
  interface "int-PE-1-PE-2"
    address 192.168.1.1/30
    port 1/1/1
    no shutdown
  exit
  interface "int-PE-1-GM-1"
    address 172.16.0.56/30
    port 1/1/2
    no shutdown
  exit
exit
```

On PE-2, configure a /32 IPv4 system address and an interface to reach PE-1.

```
*A:PE-2#
configure
router
    interface "system"
        address 192.0.2.182/32
        no shutdown
    exit
    interface "int-PE-2-PE-1"
        address 192.168.1.2/30
        port 1/1/1
        no shutdown
    exit
exit
```

Configure both PE-1 and PE-2 to have physical layer frequency sources into their central clocks. PE-2 is configured to receive Synchronous Ethernet from PE-1 on the same port as is used for PTP. This commonality is not a requirement but might be common in the network topology.

On PE-1, configure the port toward PE-2 as a Synchronous Ethernet port. This will cause the port transmit timing to be sourced from the node timing. Also configure the port to transmit ssm codes using the sonet codes.

```
*A:PE-1#
configure card 1 mda 1 sync-e
configure port 1/1/1 ethernet
    code-type sonet
    no shutdown
exit
```

On PE-2, configure the port on towards PE-1 as a Synchronous Ethernet port and to use sonet codes and to be the reference into the central clock of PE-2.

```
*A:PE-2#
configure card 1 mda 1 sync-e
configure port 1/1/1
    ethernet
        ssm
            code-type sonet
            no shutdown
    exit
exit
configure system sync-it-timing
    begin
    ql-selection
    refl
        source-port 1/1/1
        no shutdown
    exit
commit
```

## IP Addressing for PTP Communication

```
exit
```

Next configure PE-1 as a boundary clock requesting service from GM-1 using the default profile. In this example, the interface address of GM-1 is used for the PTP communication.

```
*A:PE-1#
configure system ptp
shutdown
profile ieee1588-2008
clock-type boundary
peer 172.16.0.55 create
no shutdown
exit
no shutdown
exit
```

If it is desired to operate the network at the default for the G.8275.1 profile, then the Announce messages should be set to 8 pps and the Sync and Delay\_Resp messages should be set to 16 pps.

```
*A:PE-1#
configure system ptp
shutdown
log-anno-interval -3
peer 172.16.0.55
shutdown
log-sync-interval -4
no shutdown
exit
no shutdown
exit
```

Configure PE-2 as a boundary clock using PE-1 as its parent clock and the same set of 1588 parameters. In this example, PE-2 uses a loopback address of PE-1 for communication.

```
*A:PE-2#
configure system ptp
shutdown
profile ieee1588-2008
clock-type boundary
log-anno-interval -3
peer 192.0.2.183 create
shutdown
log-sync-interval -4
no shutdown
exit
no shutdown
exit
```

## IEEE 1588 for Frequency, Phase, and Time Distribution

On PE-1, validate the status of the PTP topology by checking the unicast sessions. Also validate the PTP process has elected GM-1 as both the parentClock and the grandmaster clock.

```
*A:PE-1# show system ptp unicast
=====
IEEE 1588/PTP Unicast Negotiation Information
=====
Router
  IP Address      Dir Type      Rate      Duration State      Time
-----
Base
  192.0.2.182    Tx Announce  8 pkt/s    300      Granted  05/30/2014 07:02:36
  192.0.2.182    Tx Sync      16 pkt/s   300      Granted  05/30/2014 07:02:37
  192.0.2.182    Rx DelayReq  16 pkt/s   300      Granted  05/30/2014 07:02:37
  192.0.2.182    Tx DelayRsp  16 pkt/s   300      Granted  05/30/2014 07:02:37
  172.16.0.55    Rx Announce  8 pkt/s    300      Granted  05/30/2014 07:02:42
  172.16.0.55    Rx Sync      16 pkt/s   300      Granted  05/30/2014 07:02:43
  172.16.0.55    Tx DelayReq  16 pkt/s   300      Granted  05/30/2014 07:02:43
  172.16.0.55    Rx DelayRsp  16 pkt/s   300      Granted  05/30/2014 07:02:43
-----
PTP Peers          : 2
Total Packet Rate  : 112 packets/second
=====
```

```
*A:PE-1# show system ptp
=====
IEEE 1588/PTP Clock Information
=====
-----
Local Clock
-----
Clock Type      : boundary      PTP Profile      : IEEE 1588-2008
Domain          : 0              Network Type     : sdh
Admin State     : up            Oper State       : up
Announce Interval : 8 pkt/s      Announce Rx Timeout: 3 intervals
Peer Limit      : none (Base Router)
Clock Id        : 00233efffe69f250  Clock Class      : 248 (default)
Clock Accuracy  : unknown        Clock Variance   : ffff (not computed)
Clock Priority1 : 128              Clock Priority2  : 128
PTP Recovery State: locked        Last Changed    : 05/30/2014 07:05:17
Frequency Offset : +50.305 ppb
-----
Parent Clock
-----
IP Address      : 172.16.0.55      Router           : Base
Parent Clock Id : 8887868584838281 Remote PTP Port  : 1
GM Clock Id     : 8887868584838281 GM Clock Class   : 7
GM Clock Accuracy : within 250 ns   GM Clock Variance : 0x6400 (3.7E-09)
GM Clock Priority1: 128      GM Clock Priority2 : 128
-----
Time Information
-----
Timescale       : PTP
Current Time    : 2014/05/30 15:07:01.1 (UTC)
Frequency Traceable : yes
Time Traceable  : yes
```

## IP Addressing for PTP Communication

Time Source : GPS

On PE-2, validate the PTP process has elected PE-1 as its parentClock and that the grandmaster clock is GM-1.

```
*A:PE-2# show system ptp
```

```
=====
IEEE 1588/PTP Clock Information
=====
```

```
-----
Local Clock
```

```
-----
Clock Type      : boundary      PTP Profile      : IEEE 1588-2008
Domain         : 0              Network Type     : sdh
Admin State    : up             Oper State       : up
Announce Interval : 8 pkt/s     Announce Rx Timeout: 3 intervals
Peer Limit     : none (Base Router)
Clock Id       : 00233efffe808250  Clock Class      : 248 (default)
Clock Accuracy : unknown          Clock Variance   : ffff (not computed)
Clock Priority1 : 128              Clock Priority2  : 128
PTP Recovery State: locked        Last Changed     : 05/30/2014 10:02:36
Frequency Offset : -9.345 ppb
-----
```

```
Parent Clock
```

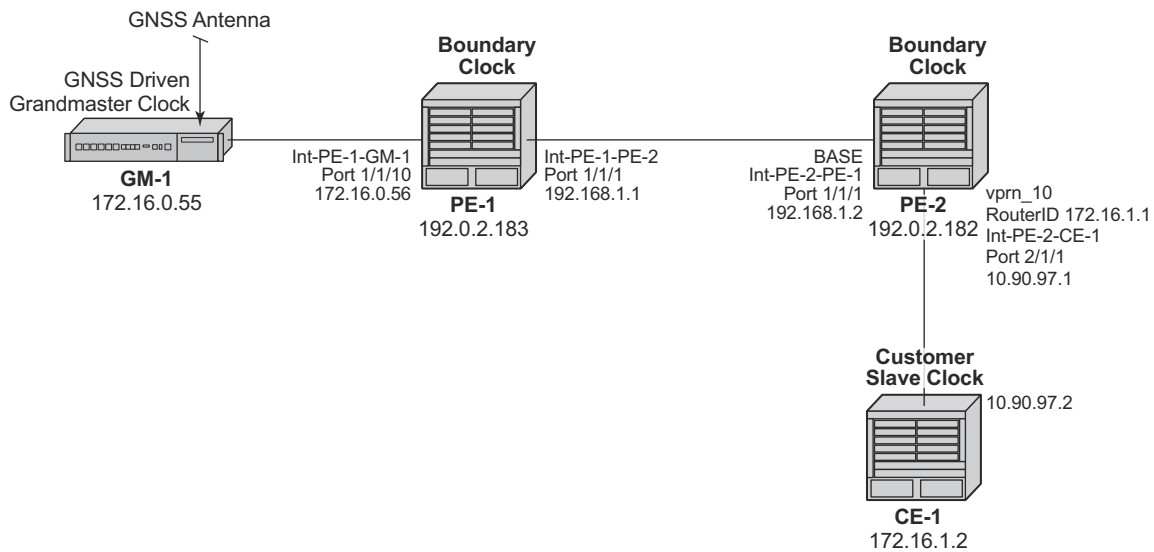
```
-----
IP Address      : 192.0.2.183      Router           : Base
Parent Clock Id : 00233efffe69f250 Remote PTP Port  : 1
GM Clock Id     : 8887868584838281 GM Clock Class   : 7
GM Clock Accuracy : within 250 ns  GM Clock Variance : 0x6400 (3.7E-09)
GM Clock Priority1: 128            GM Clock Priority2 : 128
-----
```

```
Time Information
```

```
-----
Timescale      : PTP
Current Time   : 2014/05/30 15:09:26.5 (UTC)
Frequency Traceable : yes
Time Traceable : yes
Time Source    : GPS
=====
```

## Boundary Clock with VPRN Access

The system supports access to the 1588 process through Base routing, IES, and VPRN contexts. This permits the system 1588 topology to be created and managed in one context with access for edge distribution through other contexts. For example, building on top of the base routing distribution shown in the previous example, access can be given to the 1588 process on PE-2 via a VPRN existing on that node. This allows the VPRN customer to have access to the high accuracy time available within the system in the customer edge equipment connecting into that node.



al\_0556

**Figure 14: Boundary Clocks with Edge VPRN Access**

For the example shown in [Figure 14](#), it is assumed that a VPRN service is already configured and operational on PE-2 providing connectivity between PE-2 and CE-1:

```
*A:PE-2#
configure service vprn 10 customer 1 create
  router-id 176.16.1.1
  autonomous-system 64496
  route-distinguisher 64496:10
  interface "int-PE-2-CE-1" create
    address 10.90.97.1/30
    sap 2/1/1 create
  exit
exit
no shutdown
exit
```

## IP Addressing for PTP Communication

To enable access to the PTP process via VPRN 10 in PE-2, PTP must be enabled within the VPRN context. To ensure that no more than 10 external clocks access the system PTP through this VPRN at any one time, a peer-limit may be defined.

```
*A:PE-2#
  configure service vprn 10
    peer-limit 10
    ptp no shutdown
  exit
```

To confirm PTP access with the VPRN, the PTP information with the VPRN context can be queried. Either of the following two commands can be used:

```
*A:PE-2# show system ptp unicast router 10
```

or

```
*A:PE-2# show service id 10 ptp unicast
```

These two commands provide the same information as shown below.

```
*A:PE-2# show system ptp unicast router 10
=====
IEEE 1588/PTP Unicast Negotiation Information
=====
Router
  IP Address      Dir Type      Rate      Duration State      Time
-----
10
  172.16.1.2      Tx  Announce 1 pkt/2 s  300      Granted 05/30/2014 12:40:53
  172.16.1.2      Tx   Sync    64 pkt/s   300      Granted 05/30/2014 12:40:59
  172.16.1.2      Rx  DelayReq 64 pkt/s   300      Granted 05/30/2014 12:40:59
  172.16.1.2      Tx  DelayRsp 64 pkt/s   300      Granted 05/30/2014 12:40:59
-----
PTP Peers          : 1
Total Packet Rate  : 192 packets/second
=====
```



## Port Based Timestamping

As described above, optimal performance is achieved when the 1588 port based timestamping (PBT) feature is used. This feature is not available on all hardware and the interfaces for PTP should be planned in advance if this feature is to be used.

Since 1588 messages ingress and egress the node through router interfaces, the configuration of the 1588 PBT feature is enabled within the router interface context. In the previous examples, if 1588 PBT is to be enabled on all the PTP interfaces the following commands are required.

On PE-1, enable 1588 PBT on the interface toward GM-1 and PE-2.

```
*A:PE-1#
  configure
    router
      interface "int-PE-1-PE-2"
        ptp-hw-assist
      exit
      interface "int-PE-1-GM-1"
        ptp-hw-assist
      exit
    exit
```

On PE-2, enable 1588 PBT on the interface toward PE-1 and CE-1.

```
*A:PE-2#
  configure
    router
      interface "int-PE-2-PE-1"
        ptp-hw-assist
      exit
    exit
  configure service vprn 10 customer 1
    interface "int-PE-2-CE-1"
      ptp-hw-assist
    exit
  exit
```

To verify 1588 PBT is active on the 1588 messages to the peers, check the timestamp point for the specific peer. It now indicates *port* rather than *cpm*.

On PE-1 for the CE-1 communication:

```
*A:PE-1# show system ptp peer 172.16.0.55
=====
IEEE 1588/PTP Peer Information
=====
Router           : Base
IP Address       : 172.16.0.55      Announce Direction : rx
Admin State      : up              G.8265.1 Priority   : n/a
Sync Interval    : 16 pkt/s
Local PTP Port   : 2               PTP Port State     : slave
```

## IP Addressing for PTP Communication

```
Clock Id          : 8887868584838281  Remote PTP Port   : 1
GM Clock Id      : 8887868584838281  GM Clock Class    : 7
GM Clock Accuracy : within 250 ns     GM Clock Variance : 0x6400 (3.7E-09)
GM Clock Priority1 : 128              GM Clock Priority2 : 128
Steps Removed    : 0                 Parent Clock      : yes
Tx Timestamp Point : port            Rx Timestamp Point : port
Last Tx Port     : 5/1/1             Last Rx Port      : 5/1/1
```

=====

On PE-1 the communication with the PE-2 will still be CPM timestamping since the port has not been configured to watch for the 'system' loopback address.

```
*A:PE-1# show system ptp peer 192.0.2.182
```

```
=====
IEEE 1588/PTP Peer Information
=====
```

```
Router          : Base
IP Address      : 192.0.2.182      Announce Direction : tx
Admin State     : n/a             G.8265.1 Priority  : n/a
Sync Interval   : n/a
Local PTP Port  : 3               PTP Port State     : master
Clock Id       : 00233efffe808250 Remote PTP Port    : 4
Tx Timestamp Point : cpm         Rx Timestamp Point : cpm
Last Tx Port    : 5/1/2         Last Rx Port       : 5/1/2
```

=====

In order to configure the **system** loopback address for PTP, enter the following on PE-1:

```
*A:PE-1#
  configure
    system security
      source-address application ptp "system"
    exit
  exit
```

Now the timestamp point on PE-1 will be the port.

```
*A:PE-1# show system ptp peer 192.0.2.182
```

```
=====
IEEE 1588/PTP Peer Information
=====
```

```
Router          : Base
IP Address      : 192.0.2.182      Announce Direction : tx
Admin State     : n/a             G.8265.1 Priority  : n/a
Sync Interval   : n/a
Local PTP Port  : 3               PTP Port State     : master
Clock Id       : 00233efffe808250 Remote PTP Port    : 4
Tx Timestamp Point : port         Rx Timestamp Point : port
Last Tx Port    : 5/1/2         Last Rx Port       : 5/1/2
```

=====

Repeat this configuration of system address for the base routing context on PE-2

```
*A:PE-2#
  configure
    system security
      source-address application ptp "system"
    exit
  exit
```

Now the timestamp point on PE-2 will be the port.

```
*A:PE-2# show system ptp peer 192.0.2.183
=====
IEEE 1588/PTP Peer Information
=====
Router           : Base
IP Address       : 192.0.2.183      Announce Direction : rx
Admin State     : up              G.8265.1 Priority  : n/a
Sync Interval   : 16 pkt/s
Local PTP Port  : 4
Clock Id        : 00233efffe69f250  PTP Port State     : slave
GM Clock Id     : 8887868584838281   Remote PTP Port    : 3
GM Clock Class  : 6
GM Clock Accuracy : within 100 ns    GM Clock Variance  : 0x6400 (3.7E-09)
GM Clock Priority1: 128              GM Clock Priority2  : 128
Steps Removed   : 1                Parent Clock        : yes
Tx Timestamp Point: port            Rx Timestamp Point  : port
Last Tx Port    : 1/1/2             Last Rx Port        : 1/1/2
=====
```

On PE-2, a loopback address must assigned for PTP communication as follows:

```
*A:PE-2#
configure service vprn 10
  interface "ptp_loopback"
    address 172.16.1.1/32
    loopback
  exit
source-address
  application ptp "ptp_loopback"
  exit
exit
```

## 1588 as NTP Local Clock (server)

If the system is configured as a boundary clock or slave clock then the time recovered from the 1588 slave port can be used as the source of system time on the node. This allows for higher accuracy and better stability in the timebase when compared to NTP. To enable this, PTP must be made the preferred server in the NTP context in the node.

Note that if the system is acting as an NTP server or peer to other NTP clocks, then turning on this feature will impact the existing NTP topology. The system shall advertise itself as an NTP Stratum 1 server to external clients and peers. Given the much higher accuracies achievable with PTP time distribution, this change in topology does not degrade the time in the clients and peers.

```
*A:PE-1#
    configure system time ntp
        server ptp prefer
    exit
```

To validate PTP is now being used for NTP time and system time, use the following command:

```
*A:PE-1# show system ntp all
=====
NTP Status
=====
Configured          : Yes          Stratum             : 1
Admin Status       : up           Oper Status         : up
Server Enabled     : No           Server Authenticate : No
Clock Source       : ptp
Auth Check         : Yes
Current Date & Time: 2014/05/30 17:53:11 UTC
=====

NTP Active Associations
=====
State      Remote      Reference ID      St Type  A  Poll Reach      Offset(ms)
-----
chosen     ptp             PTP              0  srvr - 64      .....YY 0.000
=====

NTP Clients
=====
vRouter      Address      Time Last Request Rx
-----
```

## Conclusion

The systems provide support for IEEE 1588 frequency and time distribution for the synchronization applications of the mobile networks. They can be configured as frequency distribution grandmasters and slave clocks or time distribution boundary and slave clocks.

Conclusion