IEEE-1588 Precision Time Protocol: Essential to next-generation test systems

By Paul Skoog

Future test environments need effective tools for enabling highly accurate synchronization over Ethernet LANs. Because IEEE-1588 can provide precise synchronization using packets, it's a logical option for synchronizing test equipment deployed on a packet network.

Next-generation test systems are converging on Ethernet as the primary interconnect for data acquisition and instrument control. The relatively recent IEEE-1588 Precision Time Protocol (PTP) standard designed to synchronize distributed and large channel count measurement systems over networks such as Ethernet is an essential part of this convergence. So what factors make PTP effective in next-generation test environments? And is PTP always the best choice in those environments, compared to sync alternatives like Inter-Range Instrumentation Group (IRIG) and Network Time Protocol (NTP)? Very often, the answer to the second question is "yes."

Master-slave synchronization

PTP is an IEEE protocol commonly deployed in Ethernet that uses packet timestamps to synchronize a slave (a PTP-enabled clock) with a master. This master (also a PTP-enabled clock) may be called a grandmaster if connected directly to a timing source such as a GPS receiver. Masters and slaves use a special packet exchange procedure to compensate for the time it takes packets to traverse the network. Devices determine packet delay by time-stamping special PTP packets' departure and arrival. They then exchange these observed times with each other in follow-up PTP packets. By comparing packets' observed departure and arrival times at each end, devices compute delays and adjust their internal clocks accordingly.

PTP also specifies special network switches called *boundary clocks* and *transparent clocks* that further mitigate packet delay effects. Boundary clocks are very precise clocks and switches that handle regular network traffic like any other switch. The clock is both a slave to a single upstream master and a master to potentially multiple downstream slaves, each of which can be a master to its own slaves. PTP packets synchronize each slave to its master; however, the PTP packets themselves do not pass through the boundary clock. Masters originate new timing packets. Without PTP packet queuing, there is no queuing delay in transferring synchronization across segment boundaries.

Transparent clocks mitigate queuing effects in a different way. They compensate for the internal queuing delays of PTP packets in the switch and adjust the appropriate PTP packets' timestamps directly. A PTP slave has no knowledge of the transparent clock and can precisely synchronize to its master with the PTP packets it receives.

PTP advantages

PTP offers key advantages over other synchronization technologies such as IRIG and NTP. IRIG, for example, employs a dedicated analog connection between the clock and each slave. PTP requires no such point-to-point connection, potentially providing weight, installation/infrastructure, and cost benefits. PTP also can achieve submicrosecond accuracy, which IRIG cannot.

Like PTP, NTP also uses packet timestamps to sync network elements. However, time-stamping is done in software, not hardware, which causes asymmetric processing delays that reduce time transfer accuracy. Also, the lack of special switches like boundary clocks and transparent clocks to mitigate queuing effects further contributes to asymmetric delays and time transfer errors. PTP-enabled devices can autodiscover other PTP-enabled devices to form optimized timing networks, a feature NTP lacks. NTP enables NTP timeserver autodiscovery, but does not ensure that these sources or the paths to them are optimal. Table 1 compares the three technologies based on key performance metrics and features.

IRIG advantages

Even with all these benefits, however, there are still occasions when IRIG or NTP would be more suitable than PTP. For example, IRIG deployments can be simpler and less time-consuming, especially if 10 µs accuracy is sufficient and there are only a few elements to synchronize. If slaves are far apart, then it may be simpler to connect an IRIG source at each location and be done with it. PTP networks must be tested to make sure performance is within desired limits, and networks may need to be reconfigured if performance is not what is desired. It helps if PTP devices include features such as output 1 Pulse Per Second (PPS) signals to simplify measuring both packet delay and master-slave sync offsets.

NTP is generally unsuited for next-generation test instrumentation applications. Millisecond performance may be inadequate and NTP's performance can vary widely, which are primary reasons why PTP was invented for instrumentation synchronization.

Topology is key

In general, flat network topologies yield better synchronization performance than deep hierarchical networks. Using fewer cascaded network components reduces Packet Delay Variation (PDV). PDV is a critical metric of network performance because if delay did not vary, a constant offset could compensate for it. The greater the delay and the greater the delay variation, the more difficult it is to maintain synchronization between master and slave.

To maintain synchronization performance, IEEE-1588-optimized switches (that is, boundary clocks and transparent clocks) should be used where data and timing packets pass through a single egress port. Ideally, timing packets should be kept isolated from data packets until they converge at the slave.

Accurate PDV measurements can be obtained using the hardware time-stamping capability of PTP test devices. It is essential to measure the reception and transmission of packets at the slave using a reference source tightly coupled to the master. This can be done using the same external reference signal as the master (GPS, for example) or by integrating a PDV measurement capability in the master clock, such as in the integrated measurement setup shown in Figure 1.

The master-slave sync offset can be determined by comparing their respective hardware-generated PPS signals. Errors can be viewed using a frequency counter, oscilloscope, or a grandmaster equipped with an integrated time interval measurement input. Plotting a slave PPS as a histogram (Figure 2) shows the statistical nature of the slave synchronization to a master, best described by its mean and standard deviation.

	IEEE-1588	IRIG	NTP
Peak error network type	100 ns to 100 µs	10 µs Dedicated coaxial	1-100 ms Ethernet
Typical extent	A few subnets	1 mile over coaxial	LAN/WAN
Style	Master/slave	Master/slave	Peer ensemble client-server
Protocols	UPD/IP multicast	–	UDP/IP unicast (mainly)
Latency correction	Yes	PTP networks	Yes
Network administration	Self-organizing	Configured	Configured
Hardware at time client	Required for highest accuracy	Required	No
Default update interval	~ 2 seconds	1 PPS	Varies, seconds to hours

Table 1

Figure 3 shows the effects of cascading COTS switches in a PTP timing network. This plot is a set of PPS histograms for the same slave device being synchronized separately through three individual switches and then through the cascade of the three. The cascade PPS performance closely follows the RSS (square root of the sum of the squares) of the individual switches as measured separately. This similarity shows how it is possible to characterize end-to-end network performance by characterizing its individual components, which would help in network planning or when measuring the actual cascade across its endpoints is difficult because of network size. The data also shows how a flat network benefits from tighter synchronization: Compare the tight PPS distribution for a single switch with the much wider composite distribution. Also note the varied performance of different switches.

Figure 4 shows how IEEE-1588 packets' PDV changes over the course of a workday in a production network in response to data traffic loading as measured at a single slave. In this example, packet delay varied within a range of 100-700 µs. PDV is low outside of business hours, and a "floor" of about 100 µs delay remains constant regardless of the time of day. In other words, 100 µs is attributable to nontraffic factors such as switch processing delays and distance.

Figure 5 shows the IEEE-1588 slave accuracy for the same network as Figure 4 over the same period. Clearly, PDV impacts synchronization accuracy. As PDV goes up, precision degrades, going from a range of less than 100 ns error during periods when there is almost no PDV to more than 200 ns during periods of peak PDV. If this error was not acceptable, deploying a transparent clock or boundary clock at key network choke points may improve slave synchronization accuracy.

A worthy candidate

PTP's many advantages make IEEE-1588 a worthy candidate for syncing next-generation test systems. These systems are typically deployed over Ethernet networks, which, by definition, mean much of the timing infrastructure is already in place. However, test engineers cannot simply take precision timing for granted with PTP as they often can with IRIG. While high accuracy is possible (exceeding IRIG levels, in fact), achieving and sustaining that accuracy may require some effort in terms of network configuration and testing. What will simplify that task is the steadily increasing stream of robust PTP-enabled devices now entering the market. **ECD**

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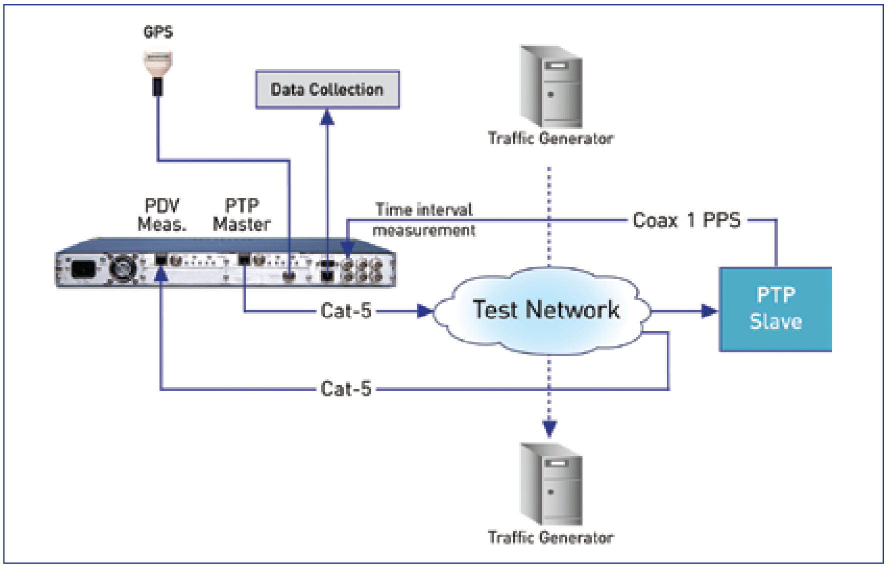


Figure 1

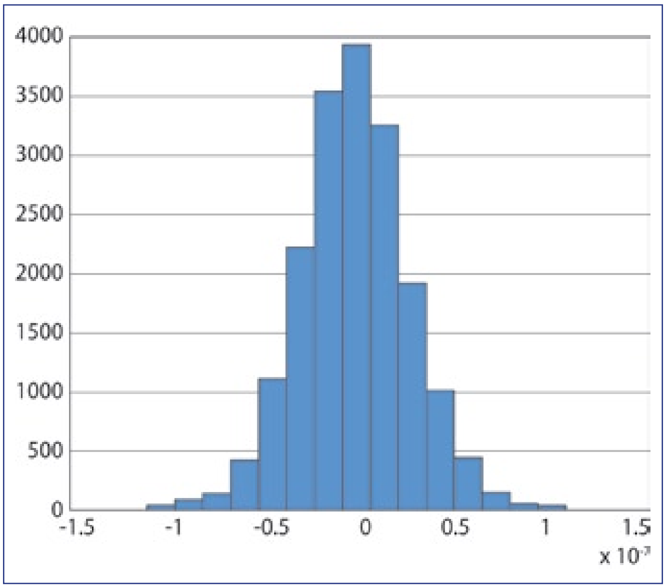


Figure 2

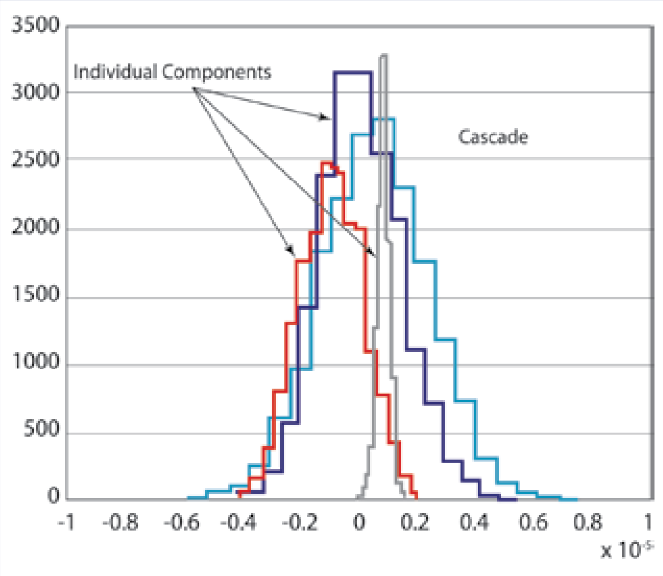
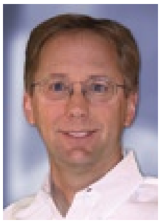


Figure 3



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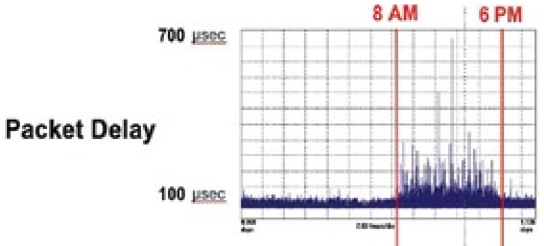
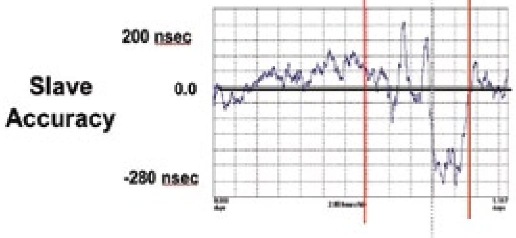


Minimum packet delay remains constant but Packet Delay Variation (PDV) changes over time (diurnal)

Figure 4



IEEE-1588 slave performance can be correlated with PDV variations

Figure 5