Precision Time Protocol *(PTPv1)*

The Precision Time Protocol, as defined in the IEEE-1588v1 standard, provides a method to precisely synchronize computers over a Local Area Network (LAN) to an accuracy that was previously unobtainable. On an existing LAN, PTP is capable of synchronizing multiple clocks to better than 10 microseconds RMS. A Network Time Server with a GPS or CDMA receiver and PTP is typically referred to as an "IEEE-1588 GrandMaster". This paper will describe the basic principles of PTP, various implementations of PTP, measurement methods, and synchronization results using a Tempus LX or Unison GrandMaster Clock.

PTP Synchronization

The protocol defines synchronization messages used between a Master and Slave clock similar to the Server and Client mode used in the Network Time Protocol (NTP). The Master is the provider of time, and the Slave synchronizes to the Master. A Grandmaster is a Master that is synchronized to a time reference such as GPS or CDMA.

Messages in the protocol include Master sync message, Master delay response message, and the Slave clock delay request messages. In addition to the messages, the Best Master Clock (BMC) algorithm allows multiple Masters to negotiate the best clock for the network.

Clock synchronization on the LAN requires at least one Master and one Slave. Multiple Slaves can synchronize to a single Master. The Master clock provides synchronization messages that the Slaves use to correct their local clocks. Precise timestamps are captured at the Master and Slave clocks. These timestamps are used to determine the network latency which is required to synchronize the Slave to the Master. There is a sync message transmitted typically every two seconds from the Master, and a delay request message from the Slave less frequently, about one request per minute.

Four timestamps are captured between the Master and Slave clock. The timestamps are required for the Slave offset calculation. The timestamps are commonly referred to as T1, T2, T3, and T4 (see Figure 1).

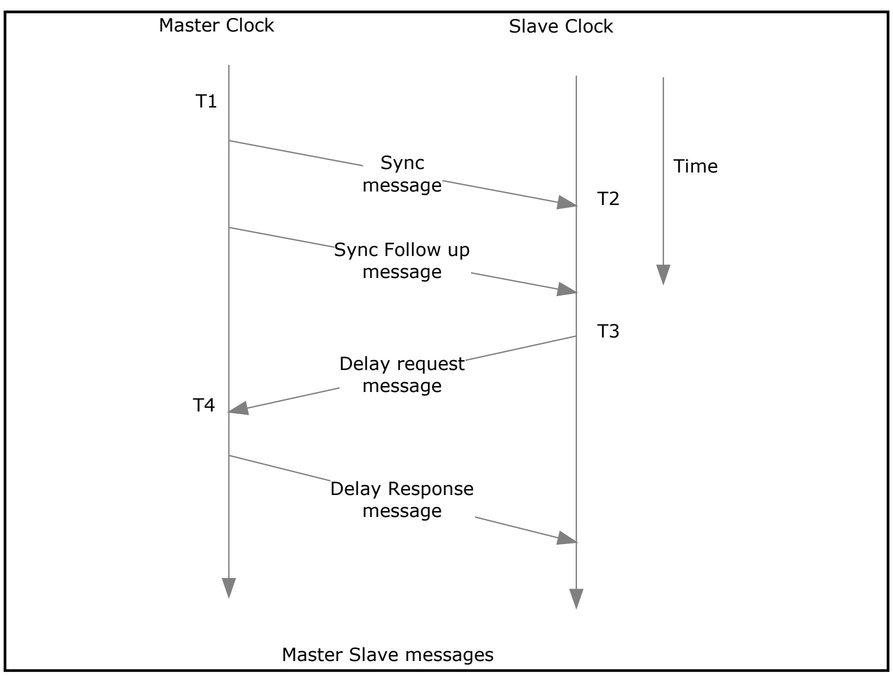

Figure 1. PTP Timestamps (T1 - T4)

Two delay paths must be calculated, the Master to Slave and the Slave to Master. First find the Master to Slave difference:

The first timestamp is T1. It is the precise time of the sync message from the Master. This timestamp is sent in the follow-up message since the time of T1 was sampled when the sync message was transmitted on the Ethernet port.

The second timestamp is T2. It is the precise time of the sync message as it is received at the Slave.

The Master to Slave difference can be calculated once T1 and T2 are available at the Slave:

Master to Slave difference = T2 - T1

Second, find the Slave to Master difference:

The third timestamp is T3. It is the precise time of the delay request message from the Slave. The fourth timestamp is T4. It is the precise time of the delay request message when received at the Master.

The Slave to Master difference can be calculated once T3 and T4 are available at the Slave.

Slave to Master difference = T4 - T3

The one-way delay can be calculated once the Master to Slave and Slave to Master difference is available at the Slave:

One way delay = (Master to Slave difference + Slave to Master difference) / 2

The offset is used to correct the Slave clock:

Offset = Master to Slave difference – One way delay
or
Offset = ((T2 - T1) - (T4 - T3)) / 2

Therefore, the following statements are true with respect to this algorithm, assuming constant network propagation delays and gradually changing operating conditions such as temperature:

The Slave clock utilizes the offset to adjust the time to agree with the Master clock. Typically, the Slave clock will use a clock tuning algorithm that can account for network propagation delays affecting the offset and the Slave clock crystal temperature and aging effect on its stability.

PTP Implementation

The IEEE-1588 protocol does not define how to implement PTP into a Master or Slave. The following paragraphs describe methods that have been adopted.

Software Implementation

Master and Slave software-only implementations use a PTP software daemon running on existing, non-specialized hardware such as a typical computer. Since the Master does not have a hardware clock, the PTP daemon running on the Slave must compensate for its own internal oscillator drift as well as for the oscillator drift of the Master. This degrades the time synchronization accuracy. Synchronization between the Master and Slave of 10 to 100 microseconds is achievable. Relative time to UTC is typically unavailable.

Hardware Implementation

Master and Slaves with hardware timestamping and a PTP software daemon provide time synchronization accuracies below 1 microsecond and are operating system and network load independent. In order to achieve this level of accuracy, the Master must have a hardware clock and both the Master and the Slave must be capable of PTP hardware timestamping. In addition, special PTP-enabled network switches must be used. Synchronization between the Master and Slave of 10 to 100 nanoseconds is achievable with PTP-enabled switches, 10 microseconds with existing, non-specialized switches. Time relative to UTC is available when the Master is coupled with a GPS receiver.

Hybrid Implementation

A hybrid architecture has been adopted with the Unison or Tempus LX IEEE-1588 Grandmaster (see Figure 2). A software PTP daemon is coupled with a hardware clock and a GPS or CDMA receiver to provide time relative to UTC. This hardware clock is also coupled to the operating system clock thus eliminating oscillator drift and improvement in stability (PTP Variance). The software timestamp is triggered by an Interrupt Request (IRQ) at the kernel level. The benefit here is that an application layer process such as PTP, NTP, or HTTP has little affect on the timestamps in the kernel space.

The advantage of a Hybrid Grandmaster is that you have the benefits of a hardware clock while being able to use your existing computers and network switches - no specialized Slave or PTP-enabled switches are required. Synchronization between the Master and Slave of 10 microseconds is achievable.

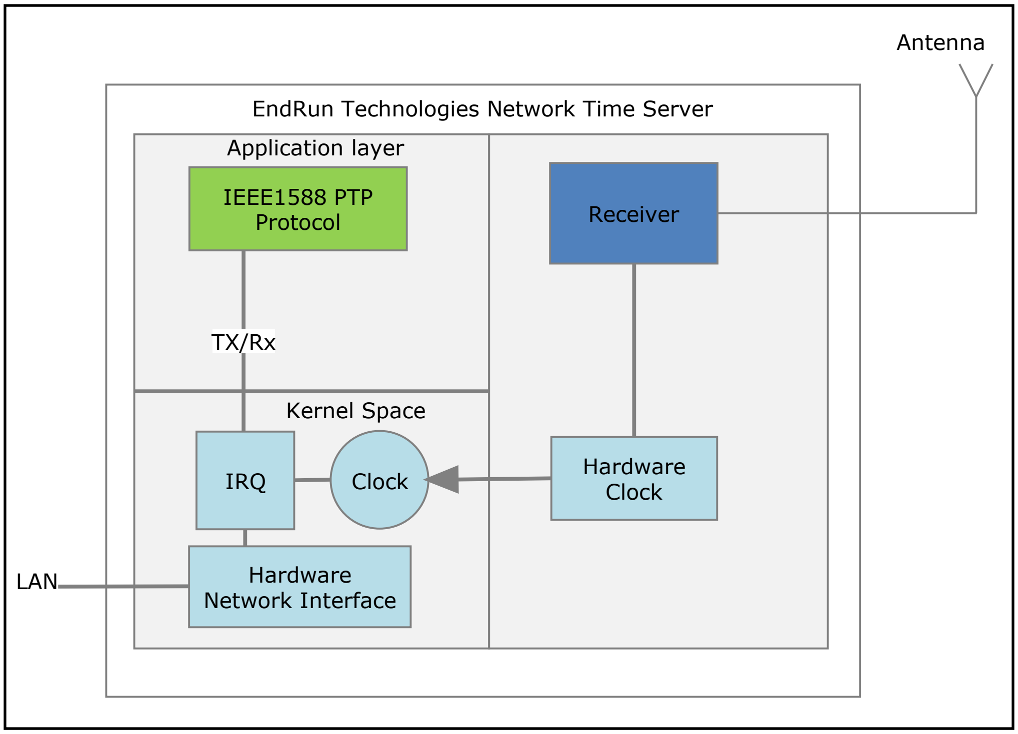

Figure 2. Software-Hardware Hybrid Implementation in the Unison and Tempus LX

Accuracy

The synchronization accuracy obtained at a PTP Slave is dependent on the Master, network architecture, PTP implementation, and the Slave. For instance, a small LAN with one switch can provide higher levels of synchronization between the Master and Slave than a LAN with multiple switches, routers, hubs, or wireless access points.

Typical Measurement Methods

The following are two typical measurement methods for determining the accuracy of a PTP Slave synchronized to a PTP Master. Both methods have shortcomings.

1. Statistics gathered at a Slave is a simple method of understanding synchronization capability, it however does not directly relate to the actual time of the Slave clock.

2. Hardware measurements comparing a Slave to a Master using lab equipment (i.e. time interval counter or oscilloscope) are valid techniques only if both the Master and Slave clocks provide 1 pulse per second (PPS) outputs as illustrated in Figure 3. This method can measure the difference between the phase of the 1PPS pulses. While this is valid it lacks the major time of day (days, hours, minutes, seconds) and can have an unknown offset of several seconds.

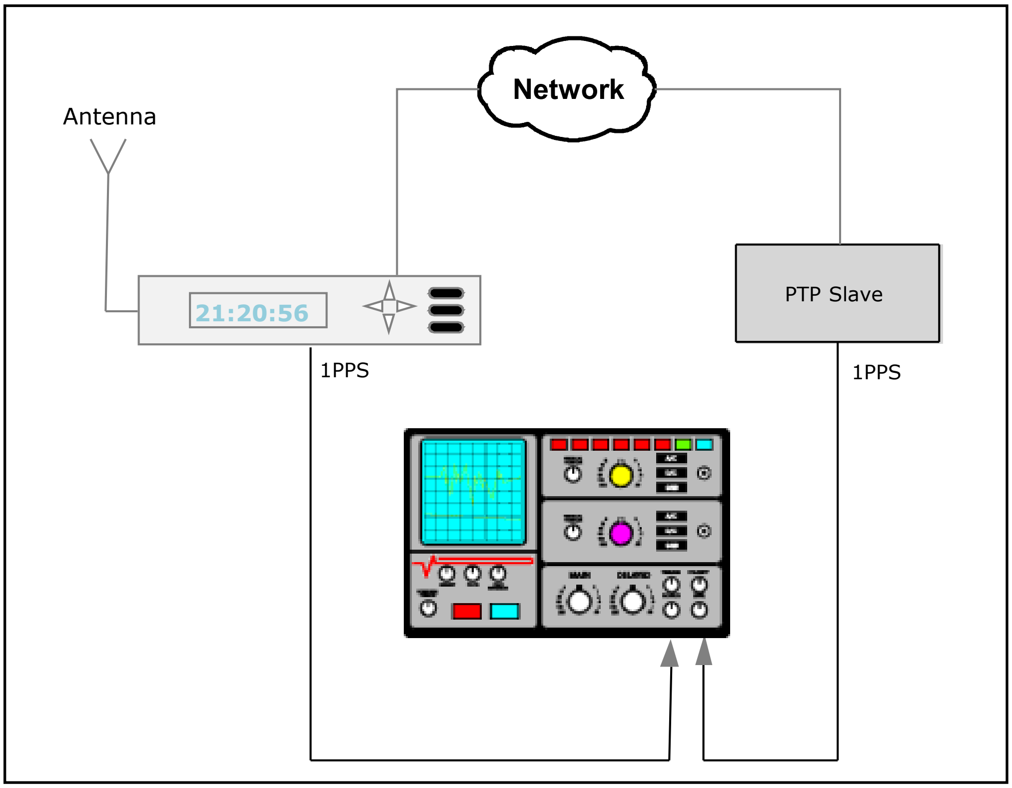

Figure 3. Typical Measurement Method for Comparing Slave to Master

EndRun PTP Time Synchronization Accuracy Measurement Method

In order to thoroughly test the time synchronization accuracy of a PTP system a measurement method was designed that would compare PTP time accuracy with an absolute time reference. This eliminates the problems with the more typical measurement methods described above.

PTP Slave Measurement Device

A special measurement device was designed and configured with both a PTP Slave clock and a time reference consisting of a GPS receiver and a hardware clock. A time compare register was used for comparing the time (nanoseconds through days) of the reference hardware clock versus the PTP Slave clock. The time compare was captured at 16 second intervals. Data was collected with the current time and the difference captured by the time compare register. This data was then collected in a data file on the system (see Figure 4) and later retrieved for accuracy and stability analysis.

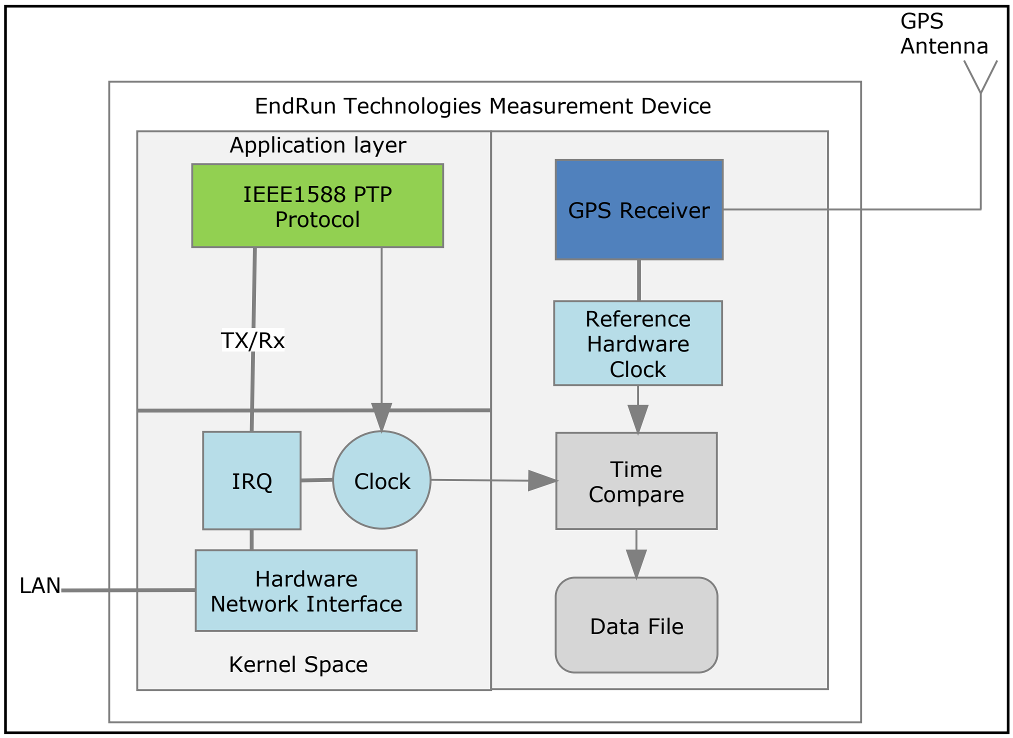

Figure 4. Special PTP Slave Measurement Device

GPS and CDMA Master-Slave Test Configurations

The test network was configured with a Tempus LX Grandmaster clock, the network element, and the PTP Slave Measurement Device (see Figure 5). The two test configurations (GPS and CDMA) are shown independently for a clear understanding of the network configuration (see Figures 6 and 7). With GPS, the measurements are considered to be in common view. Both of the GPS antennas are on the same roof within two meters of each other. With CDMA, the measurements are not in common view and an added CDMA base station offset uncertainty is introduced. The PTP clock configurations were defaulted at two second sync rates. The data collected was for a minimum of 24 hours on the LAN with typical daily use network loading.

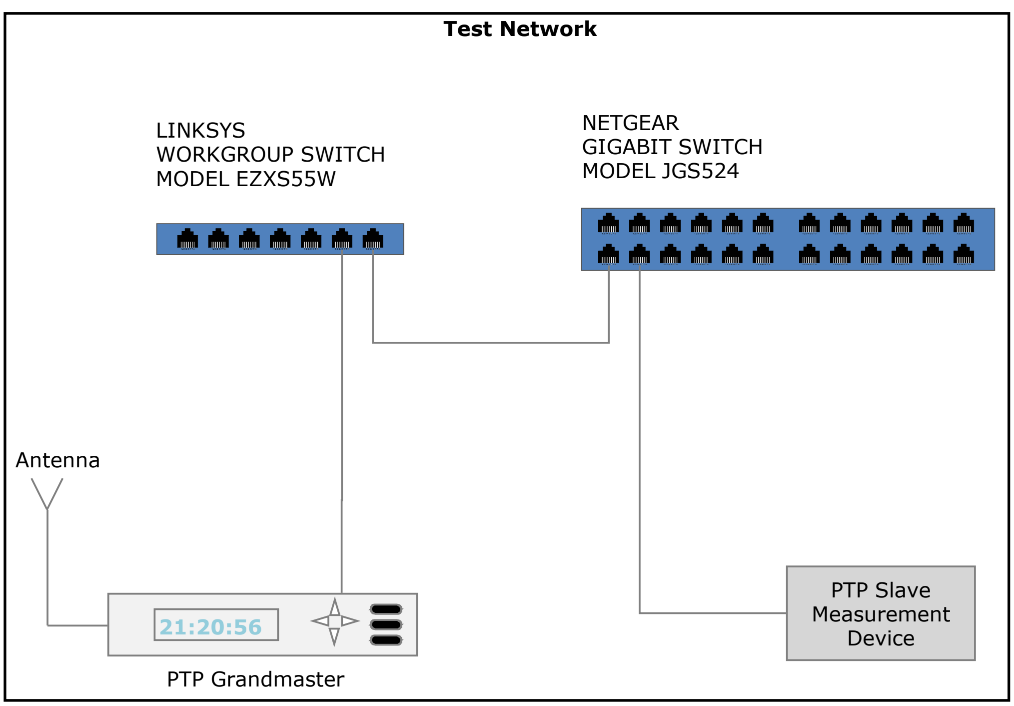

Figure 5. EndRun Test Network Configuration

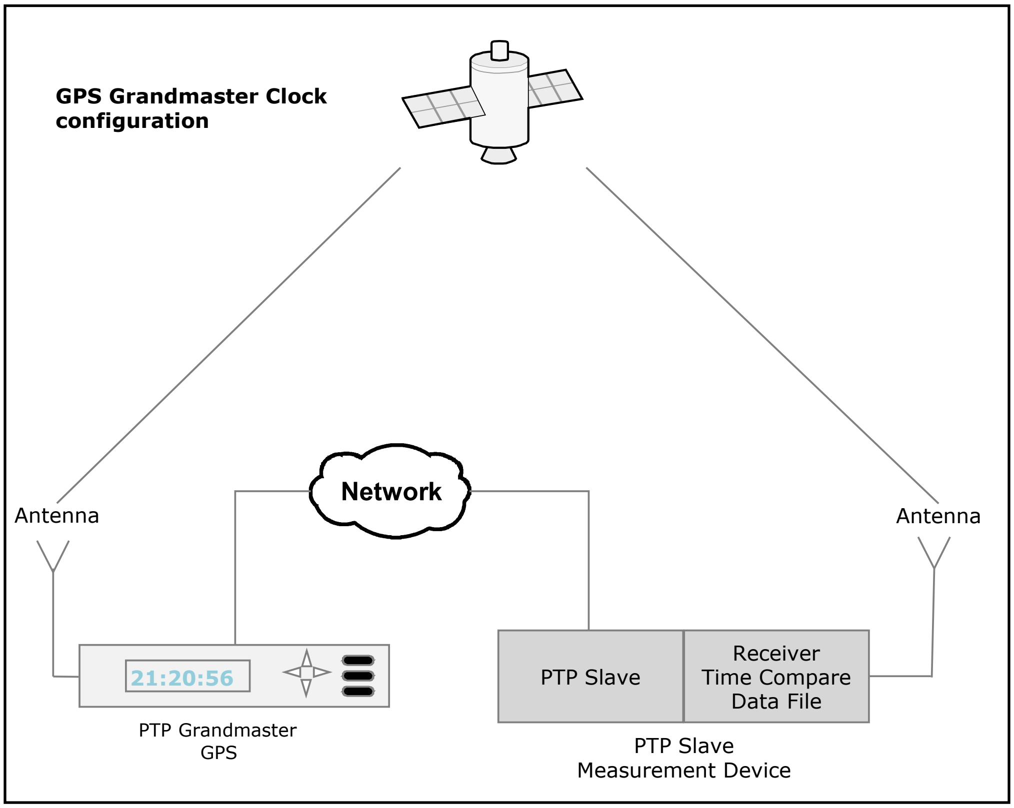

Figure 6. EndRun GPS Test with Tempus LX Grandmaster

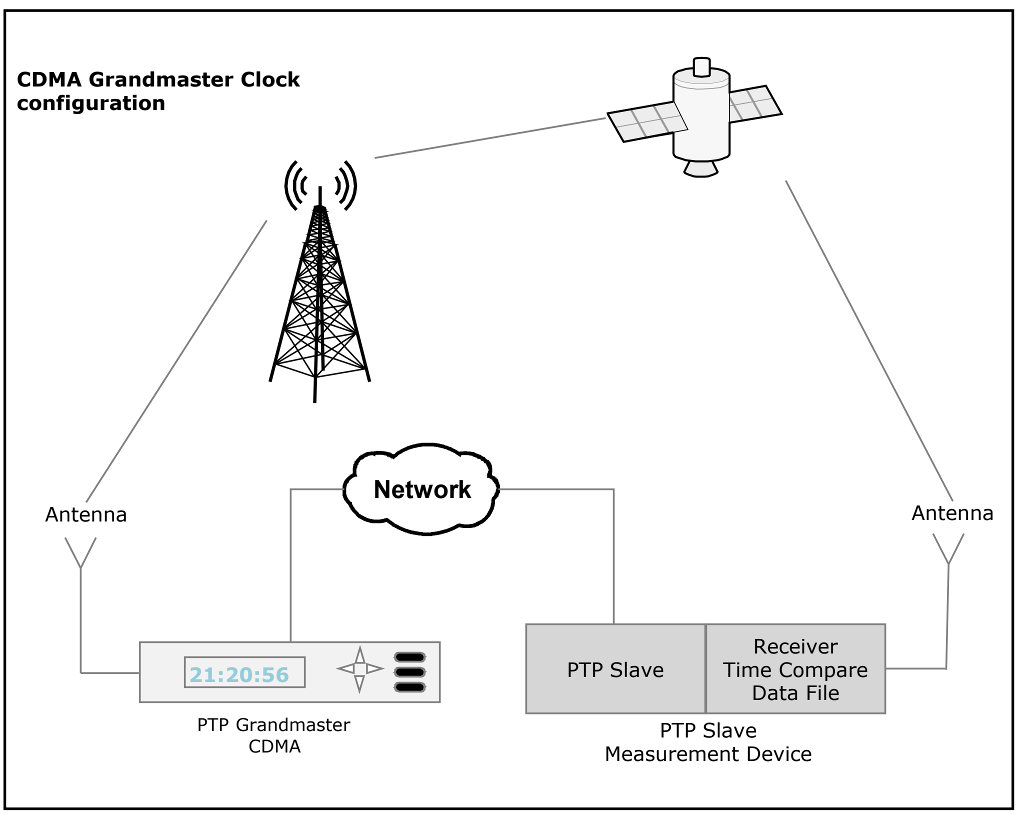

Figure 7. EndRun CDMA Test with Tempus LX Grandmaster

Measurement Analysis

The analysis of the time synchronization is a combination of the Tempus LX Grandmaster clock reference source (GPS or CDMA), the network element that affects Packet Delay Variation (PDV) and the Slave clock implementation.

The greatest variation is due to the network element affecting PDV. In this case PDV is the difference in packet delay from the Grandmaster to Slave, from one packet to the next. PDV is caused by a combination of distance between the Master and Slave, and the queue delay of the switches affected by network traffic.

The following plots shown include the PTP Slave offset from the GPS Grandmaster (Figure 8) and the Histogram of the PTP Slave locked to the GPS Grandmaster (Figure 9). The Slave measured by the GPS time compare shows a 5.24 microseconds RMS synchronization with a 1 microsecond mean offset.

Figures 10 and 11 show the PTP Slave offset from the CDMA Grandmaster and the Histogram of the PTP Slave locked to the CDMA Grandmaster. The Slave measured by the GPS time compare shows a 9.72 microseconds RMS synchronization with a -8.47 microseconds mean offset. This offset is attributed to the uncertainty of the distance to the CDMA base station and it is not in common view to GPS.

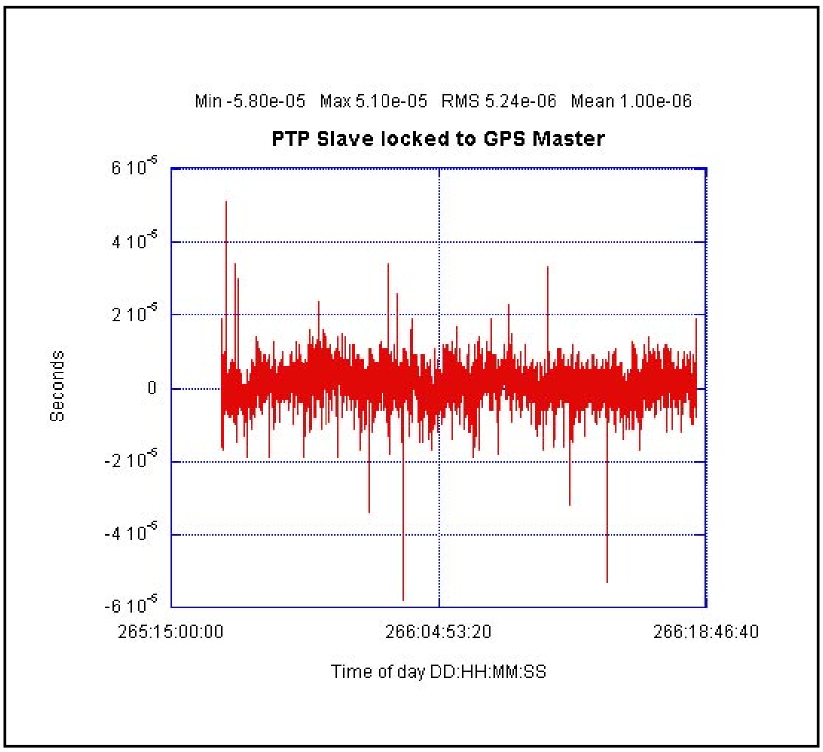

Figure 8. PTP Slave Locked to Tempus LX Grandmaster (GPS)

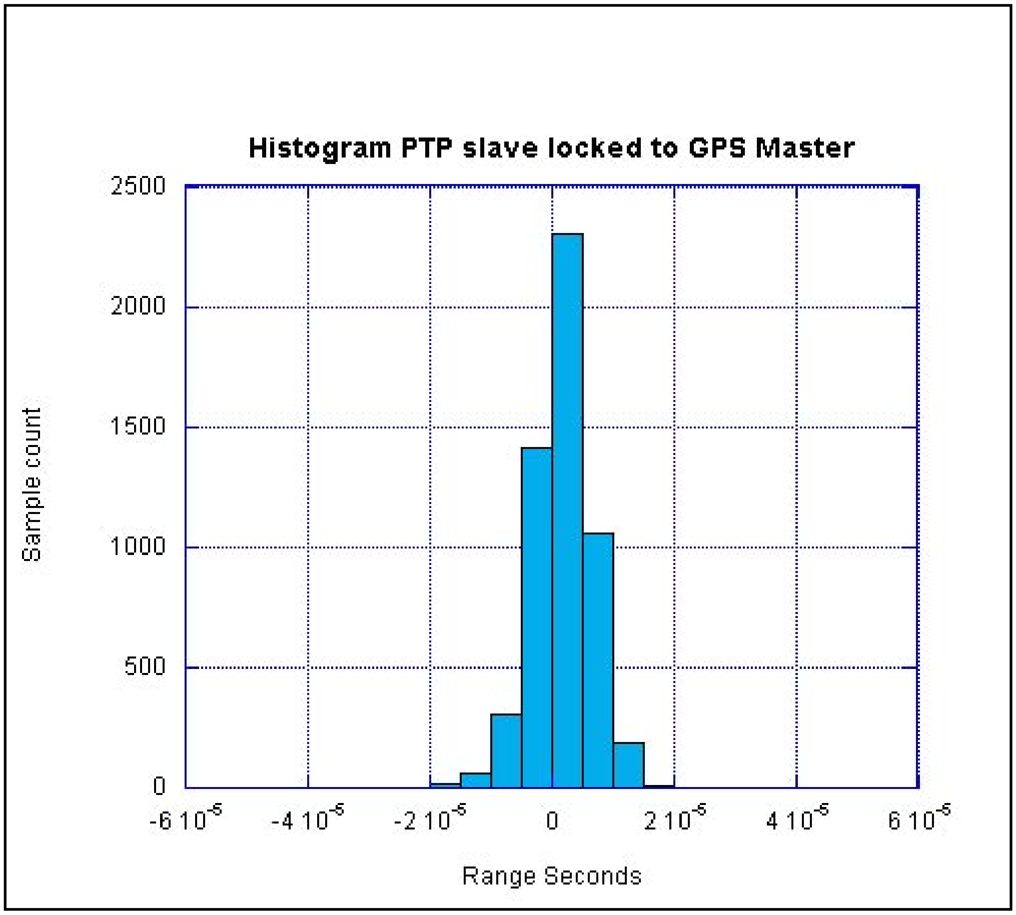

Figure 9. PTP Slave Locked to Tempus LX Grandmaster (GPS)

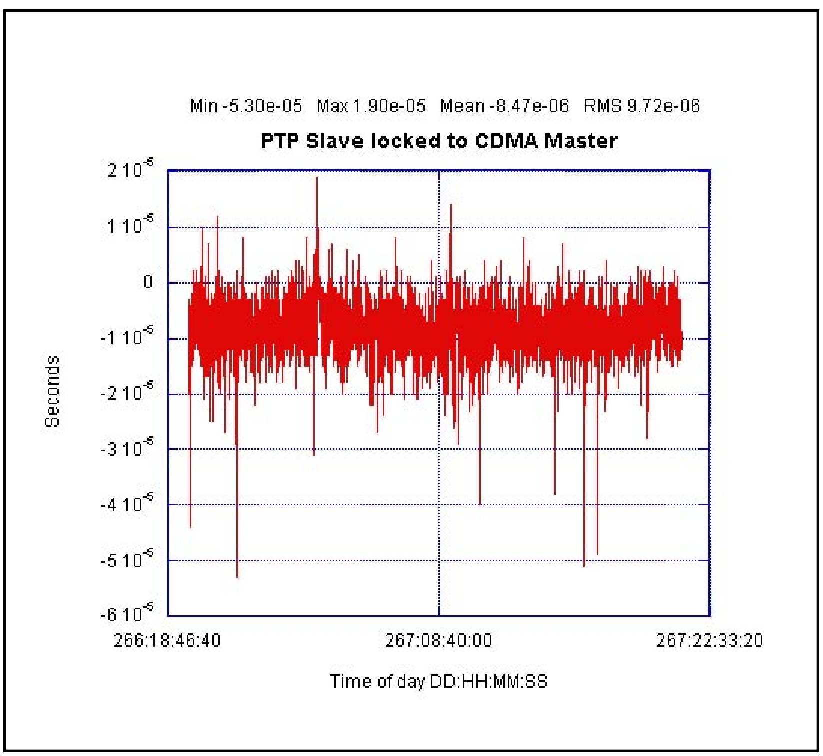

Figure 10. PTP Slave Locked to Tempus LX Grandmaster (CDMA)

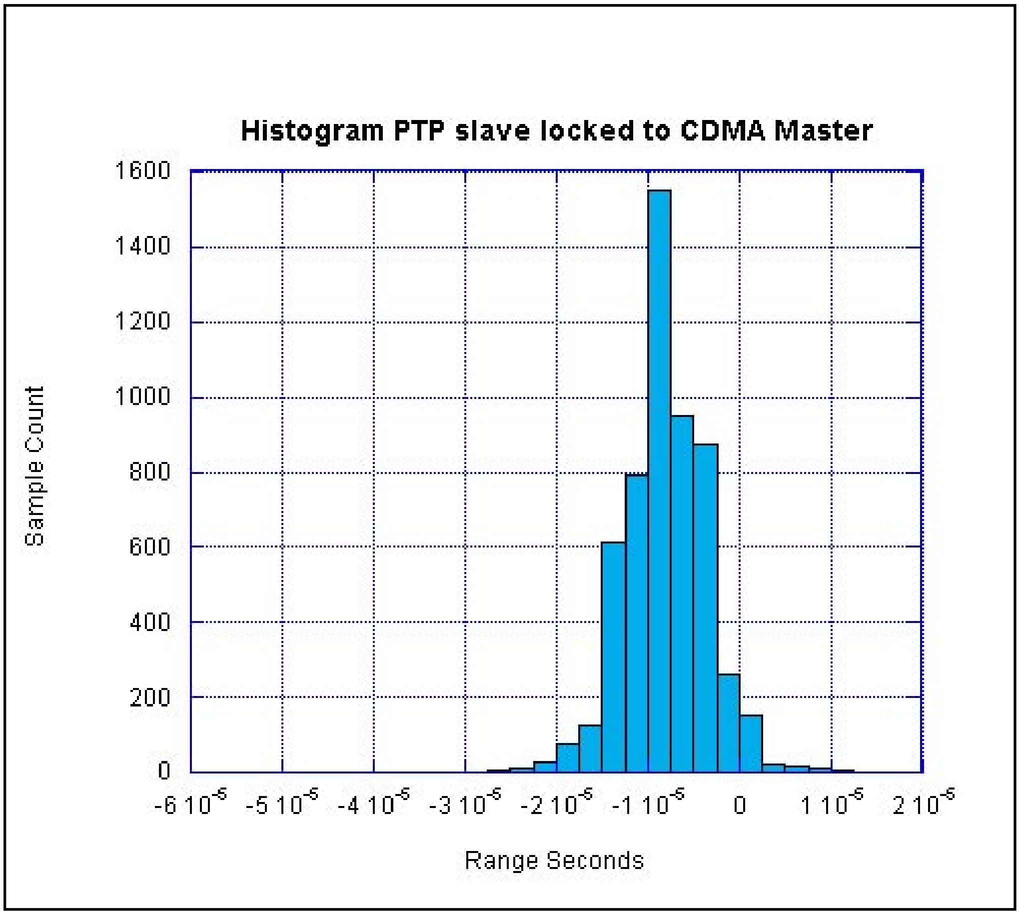

Figure 11. PTP Slave Locked to Tempus LX Grandmaster (CDMA)

Conclusion

PTP implemented on a LAN provides superior time synchronization than was previously available with other methods such as NTP. Even existing networks, with no specialized hardware, can take advantage of PTP and achieve network time synchronization accuracies below 10 microseconds RMS with a Tempus LX or Unison Grandmaster Clock (GPS or CDMA). The hybrid solution in the Tempus LX or Unison Network Time Servers provides time synchronization to UTC with better than 1 microsecond timestamp resolution.

EndRun TECHNOLOGIES
"Smarter Timing Solutions"
Santa Rosa, CA, USA
1-877-749-3878 or 707-573-8633
sales@endruntechnologies.com
www.endruntechnologies.com