WHITE PAPER

Establishing Traceability to UTC

This paper will show that the NTP and PTP timestamps from EndRun Technologies Network Time Servers are traceable through the National Institute of Standards and Technologies (NIST), and the United States Naval Observatory (USNO) to Coordinated Universal Time (UTC) maintained by the International Bureau of Weights and Measures (BIPM).

WHAT IS TRACEABILITY?

Metrology is the science of measurement. Calibration is a comparison between measurements, with one measurement being of known correctness called the reference (or standard). Traceability refers to an unbroken chain of calibrations relating an instrument's measurements to a known reference. It is important to note that traceability is the property of a measurement result, not of an instrument. The official definition of traceability is contained in the International Vocabulary of Metrology - Basic and General Concepts and Associated Terms (VIM; 2008):

Metrological Traceability: property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty.

In other words, traceability is the property of a measurement result, such as an NTP or PTP timestamp, whereby the result can be related to a reference, such as UTC(NIST), through an unbroken chain of comparisons, all having stated uncertainties.

This paper will document the unbroken chain of comparisons from the point of the NTP/PTP timestamp measurement back to UTC. Each link in the chain has an associated uncertainty which is composed of time offset and jitter. The uncertainty of the entire traceability chain is typically computed as the square root of the sum of the squares of the individual uncertainties. This means that the largest uncertainty tends to dominate the result. Improving links in the traceability chain with small uncertainties has a minimal effect on the overall result.

NOTE: An uncertainty is another way of stating accuracy. For example, a timestamp that is traceable to UTC with an uncertainty of 100 nanoseconds means that the timestamp is accurate to UTC to within 100 nanoseconds.

METROLOGICAL AND LEGAL TRACEABILITY

Metrological traceability in the VIM (above) is the only type of traceability defined in an international standards document. Metrological traceability requires measurements and uncertainty calculations. The numbers in this paper satisfy this requirement up to the point of the NTP/PTP timestamps generated by the Time Server. You will need to continue the traceability chain up to the point of the timestamps generated by your workstations.

Legal traceability means that you must be prepared to convince a jury in an adversarial proceeding that your time was correct at some instant in the past. The exact amount of evidence required to prove traceability in a court of law varies from case to case. If you have established metrological traceability for a given time period, then you have also established legal traceability for that time period. To prove this in court some recordkeeping, such as log files, is essential. The question of how extensive your policies and procedures need to be in order to prove traceability must be decided based on your specific requirements and is beyond the scope of this paper.

GPS-SYNCHRONIZED NETWORK TIME SERVERS

The UTC traceability chain for NTP/PTP timestamps using the Global Positioning System (GPS) is shown in Figure 1 and Table 1.

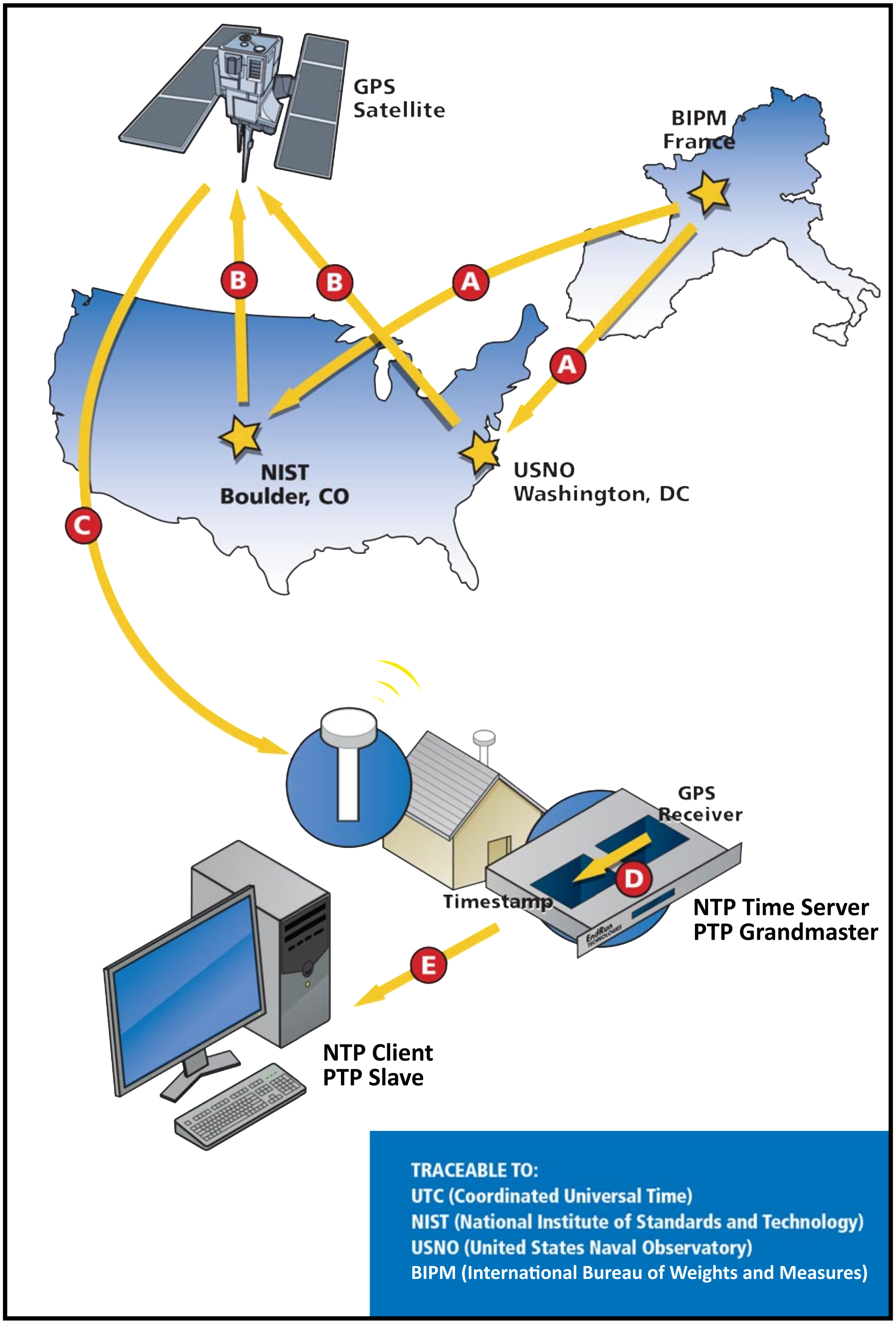
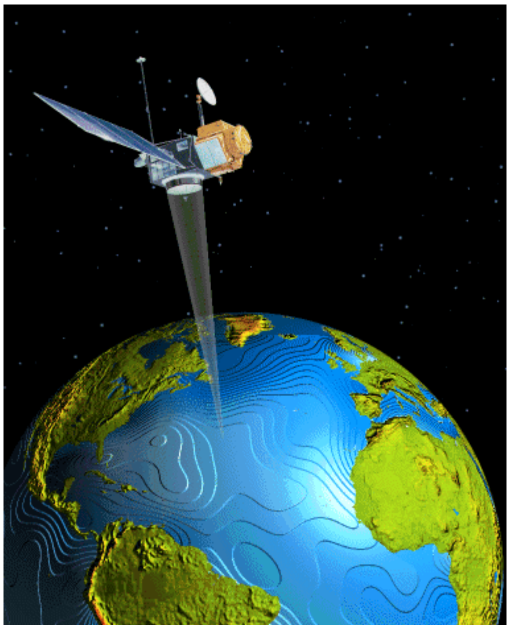


Figure 1. GPS-Synchronized Network Time Server UTC Traceability Chain

Table 1. GPS-Synchronized Network Time Server Traceability Chain

Link	Reference	Compared To	Uncertainty
A	UTC per BIPM *Circular-T*	UTC(NIST or USNO)	< 10 nanoseconds
B	UTC(NIST or USNO)	GPS Satellite Transmissions	< 10 nanoseconds
C	GPS Satellite Transmissions	GPS Receiver Inside Network Time Server	< 30 nanoseconds
D	GPS Receiver Inside Network Time Server	NTP Server Timestamps	< 10 microseconds*
		PTP Grandmaster Timestamps	< 8 nanoseconds*
E	Network Time Server NTP/PTP Timestamps	NTP Client	< 2 milliseconds (LAN)
		PTP Slave	< 100 nanoseconds (LAN)

*This chain shows that the NTP/PTP timestamps generated by an EndRun GPS-synchronized Time Server are traceable to UTC. The overall uncertainty is computed as the square root of the sum of the squares of the individual uncertainties. In this case, the overall uncertainty is 10 microseconds for NTP and 34 nanoseconds for PTP timestamps applied by the Time Server and Grandmaster. The uncertainty of application-level timestamps is based on a typical time transfer uncertainty (2 milliseconds for NTP and 100 nanoseconds for PTP), the Client/Slave clock quality and respective operating system latencies.



Uncertainties of the Transmitted and Received GPS Signal

BIPM calculates the international unit for time (SI second) by averaging clock data from over 70 international timing laboratories that collectively form the UTC timescale. BIPM generates UTC only on paper, however, through a monthly publication called the *Circular-T*. The international timing laboratories maintain physical, real-time versions of UTC that are constantly steered to agree to UTC per the *Circular-T* report. For example, NIST generates UTC(NIST) and USNO generates UTC(USNO), and both timescales agree within nanoseconds of BIPM's UTC computations. The uncertainty introduced by Link A is less than 10 nanoseconds.

The time component of GPS is directly referenced to the USNO timescale that automatically establishes traceability to UTC(USNO). NIST continually measures signals from the GPS constellation and compares it to UTC(NIST) that establishes traceability to NIST. The resulting data (the uncertainties) are then published and made available to end users after the fact. The uncertainty introduced by Link B is also less than 10 nanoseconds.

Link C is GPS receiver dependent. The GPS receiver resident in an EndRun Sonoma Time Server adds less than 30 nanoseconds of uncertainty to the chain. EndRun's Meridian II Precision TimeBase has a calibrated GPS timing receiver that adds less than 10 nanoseconds of uncertainty.

Links A, B and C encompass the entire GPS transmitted and received signal. In NTP applications, the uncertainty of the GPS transmitted signal is insignificant because uncertainties introduced by your computer network are much larger. In PTP applications, the GPS uncertainty is more significant as the network uncertainties are minimized.

Uncertainties of Timestamp Measurements

Link D is the uncertainty introduced by the NTP and PTP timestamp mechanism inside the Time Server. The Sonoma's embedded operating system minimizes the internal latencies for NTP timestamps to less than 10 microseconds. Hardware-based PTP timestamping eliminates operating system latencies resulting in only 8 nanoseconds of uncertainty.

Continuing the Traceability Chain...

Link E represents uncertainties due to delays in your network environment. The link is composed of the workstation's NTP Client or PTP Slave timestamping NTP or PTP packets sent to and received from the Time Server, packet processing, clock synchronization, and ultimately generating application-level transaction timestamps. For NTP, this link represents the largest uncertainty in the traceability chain (typically ½ to 2 milliseconds). For more complex and wide area networks (WANS) uncertainties of several tens of milliseconds or more are possible. The hardware-based PTP protocol operating in a network with PTP-aware elements (i.e. transparent and/or boundary clocks), significantly reduces the uncertainty (typically 100 nanoseconds within a LAN). (For an overview of how your network configuration will affect the accuracy of the NTP timestamps generated by your workstations read the White Paper at www.endruntechnologies.com/pdf/NTP-Intro.pdf.)

CDMA-SYNCHRONIZED NETWORK TIME SERVERS

The CDMA cell phone system basically acts as a repeater of GPS timing information. To establish UTC traceability for CDMA Network Time Servers, two links are inserted into the GPS traceability chain as shown in Figure 2 and Table 2.

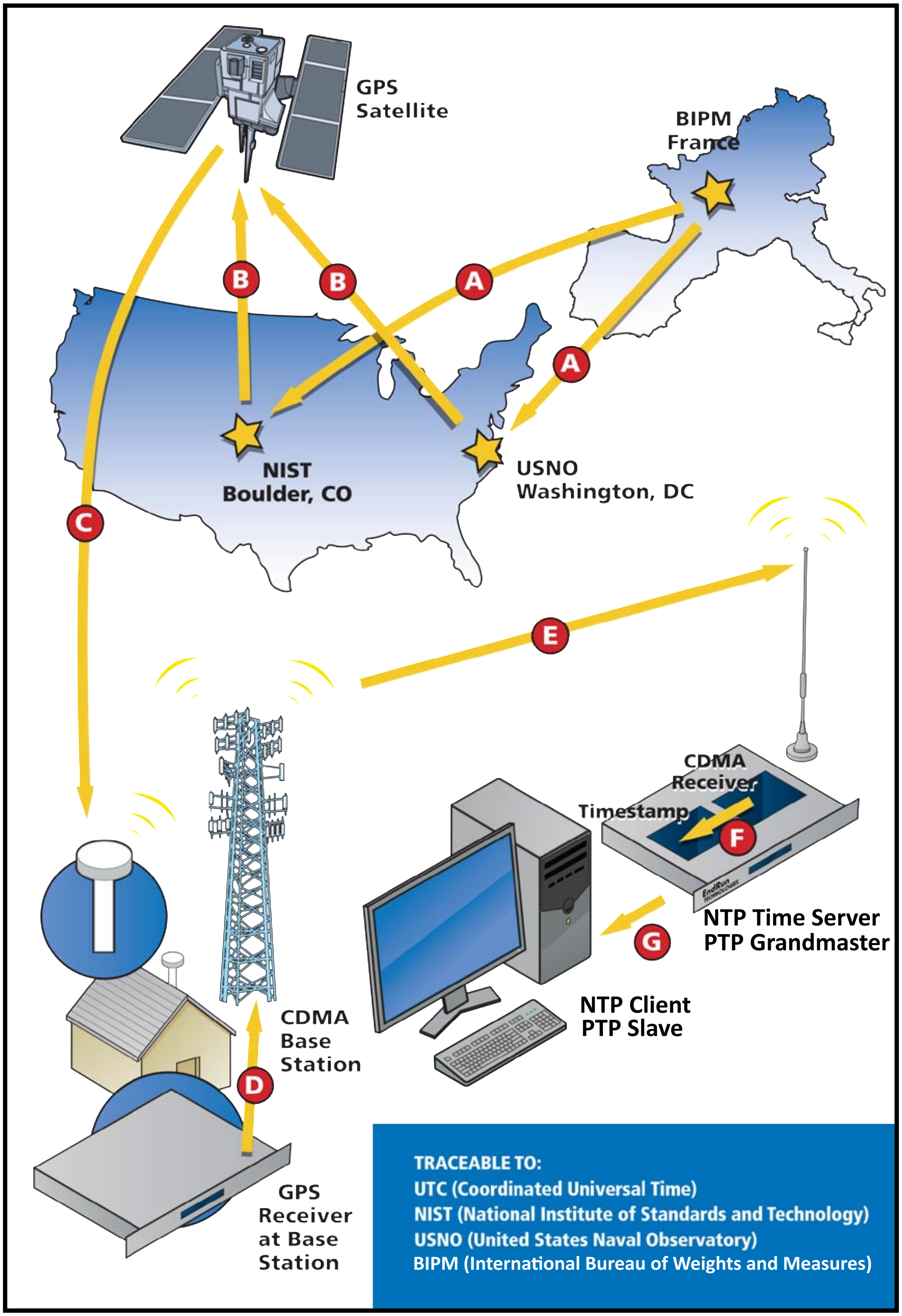


Figure 2. CDMA-Synchronized Network Time Server UTC Traceability Chain

Table 2. CDMA-Synchronized Network Time Server Traceability Chain

Link	Reference	Compared To	Uncertainty (Stated)
A	UTC per BIPM *Circular-T*	UTC(NIST or USNO)	< 10 nanoseconds
B	UTC(NIST or USNO)	GPS Time from Satellite Transmissions	< 10 nanoseconds
C	GPS Time from Satellite Transmissions	GPS Receiver at CDMA Base Station	< 100 nanoseconds
D	GPS Receiver at CDMA Base Station	CDMA Base Station Transmissions	< 1 microsecond < 10 us worst-case
E	CDMA Base Station Transmissions	CDMA Receiver Inside Network Time Server	< 10 microseconds < 101 us worst-case
F	CDMA Receiver Inside Network Time Server	NTP Server Timestamps PTP Grandmaster Timestamps	< 10 microseconds* < 8 nanoseconds*
G	Network Time Server NTP/PTP Timestamps	NTP Client PTP Slave	< 2 milliseconds (LAN) < 100 nanoseconds (LAN)

*This traceability chain shows that NTP/PTP timestamps generated by an EndRun CDMA-Synchronized Time Server are traceable to UTC managed by BIPM. The overall uncertainty is computed as the square root of the sum of the squares of the individual uncertainties. In this case the overall uncertainty is 14 microseconds for NTP and 10 microseconds for PTP timestamps generated by the Time Server and Grandmaster. This uncertainty number will degrade up to 101 microseconds for rural locations. The uncertainty of application-level timestamps is based on the time transfer uncertainty (2 milliseconds for NTP and 100 nanoseconds for PTP), the Client/Slave clock quality and respective operating system latencies.

Uncertainties of the Transmitted GPS Signal

The uncertainties introduced by Links A and B are detailed in the section on GPS Network Time Servers. In NTP applications, the uncertainty of the GPS transmitted signal is insignificant because uncertainties introduced by your computer network are much larger. In PTP applications, the GPS uncertainty is more significant as the network uncertainties are minimized.

Uncertainties of the Received GPS Signal and the Transmitted CDMA Signal

Link C is GPS receiver-dependent. Each CDMA base station has a GPS receiver that maintains the time for the CDMA cellular system and acts as a "repeater" of GPS time. The GPS receivers at these base stations are usually high quality, redundant, and have high performance OCXO or atomic (rubidium) oscillators. The worst-case uncertainty for a receiver such as this is 100 nanoseconds.

The CDMA specification ANSI/TIA/EIA-95-B states in Section 1.2 CDMA System Time: "All base station digital transmissions are referenced to a common CDMA system-wide time scale that uses the Global Positioning System (GPS) time scale, which is traceable to and synchronous with Coordinated Universal Time (UTC)." The CDMA specification mandates that the accuracy of each base station's time be within +/- 10 microseconds of GPS time, even during periods of GPS unavailability up to 24 hours. Such GPS outages could arise from damage to the antenna/cable or signal interference and would be considered relatively rare events. If the GPS receiver were to become unsynchronized it would drift away from perfect time very slowly. Once it got to over 10 microseconds, the base station would be taken off-line as it would cause problems for the overall cellular phone system. Therefore, the uncertainty of the CDMA transmitted signal is 10 microseconds (Link D).

Uncertainty of CDMA Received Signal at End User's Site

The CDMA Time Server is synchronous with the CDMA base station transmission from one to tens of microseconds, depending on location. Location is not a factor with the GPS Time Servers because the internal GPS receiver determines its position based on signals received from multiple GPS satellites. The CDMA Receiver does not know its position relative to the CDMA base station so Link E is the uncertainty due to the unknown distance of the Time Server from the base station. There is a propagation delay of about 5 microseconds per mile when receiving the CDMA cell phone signal. In urban environments there are many base stations packed closely together so most end users will be within a mile and 5 microseconds of the transmitted signal time.

EndRun specifies the accuracy of its CDMA receiver to be within 10 microseconds of UTC when locked (typical). This assumes the CDMA receiver is within 2 miles of a base station, which is true in the majority of cases. In suburban or rural areas the base stations are spaced further apart so the propagation delay increases and receiver accuracy degrades. At our suburban test facility the CDMA receiver is synchronous within 20 microseconds of UTC. Our rural facility is within 90 microseconds of UTC as the base station is nearly 18 miles away.

Uncertainties of NTP Timestamp Measurements
Link F is the uncertainty introduced by the NTP and PTP timestamp mechanism inside the Time Server. The EndRun Sonoma's embedded operating system minimizes the internal latencies for NTP timestamps to less than 10 microseconds. Hardware-based PTP timestamping eliminates operating system latencies resulting in only 8 nanoseconds of uncertainty.

Continuing the Traceability Chain...
Link G represents uncertainties due to delays in your network environment. The link is composed of the workstation's NTP Client or PTP Slave timestamping NTP or PTP packets sent to and received from the Time Server, packet processing, clock synchronization, and ultimately generating application-level transaction timestamps. For NTP, this link represents the largest uncertainty in the traceability chain (typically ½ to 2 milliseconds). For more complex and wide area networks (WANS), uncertainties of several tens of milliseconds or more are possible. The hardware-based PTP protocol operating in a network with PTP-aware elements (i.e. transparent and/or boundary clocks), significantly reduces the uncertainty (typically 100 nanoseconds within a LAN). (For an overview of how your network configuration will affect the accuracy of the NTP timestamps generated by your workstations read the White Paper at www.endruntechnologies.com/pdf/NTP-Intro.pdf.)

SUMMARY
The NTP and PTP timestamps generated by the EndRun Technologies' GPS and CDMA Time Servers are traceable through NIST and USNO to the UTC timescale managed by BIPM.

The uncertainties inherent in both the GPS and CDMA traceability chains, up to the point of the NTP timestamps, are negligible when compared with the final link in the chain - the uncertainty introduced by your network environment. For PTP, the uncertainties in the GPS and CDMA traceability chains, up to the point of the PTP timestamps, are more significant as the uncertainty of the network environment is much smaller.

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