IT'S ABOUT (PRECISION) TIME

With the transition to IP networks for all aspects of the signal processing path, accurate timing becomes more difficult, due to the fundamentally asynchronous, non-deterministic nature of packet-based networks. Fortunately, a solution is available, in the form of IEEE 1588 Precision Time Protocol (PTP). When used properly, this technology can synchronize device clocks to within nanoseconds across a large network with many hundreds of nodes. When these clocks are derived from GPS (Global Positioning System) signals, PTP can provide a very accurate and stable timebase for all types of signals within modern media operations.

Introduction

Video signals have always depended on precise synchronization along the entire delivery chain from camera to consumer display, whether in analog, digital or compressed formats. Timing drives every aspect of signal delivery, particularly synchronizing video to audio to achieve "lip sync."
With the transition to IP networks for all aspects of the signal processing path, accurate timing becomes more difficult, due to the fundamentally asynchronous, non-deterministic nature of packet-based networks. Fortunately, a solution is available, in the form of IEEE 1588 Precision Time Protocol (PTP). When used properly, this technology can synchronize device clocks to within nanoseconds across a large network with many hundreds of nodes. When these clocks are derived from GPS (Global Positioning System) signals, PTP can provide a very accurate and stable timebase for all types of signals within modern media operations.

Why PTP?

The simple answer is that PTP is required by modern media standards, including SMPTE ST 2110 for IP video production and AES67 for IP audio. But that doesn't explain the reasoning behind the decisions of the standards groups. To delve deeper, it makes sense to begin with a brief look at the history of video and audio signal processing and to see why synchronization and timing are so important.

First and foremost, video signals are built on a foundation of timing. Each frame of a video signal is built up of thousands or millions of pixels, each of which requires a data value to be generated by a camera or delivered to a display in the correct order and at precisely the correct time. Video signals contain sync signals that indicate the start of each video scan line and the locations of every line within each video frame. These sync signals are used by the receiving device to properly place each pixel in the appropriate location within the video image. In traditional video networks based on SDI, sync signals are normally generated centrally and distributed to each device in the form of a "black burst" or "tri-level sync" signal in order to "genlock" the devices to "house sync." For digital audio, a similar function is performed using a DARS (Digital Audio Reference Signal). In traditional studio architectures, distributing these sync signals requires separate, overlay networks that connect to every device, adding considerable cost and complexity to the overall system.

With Ethernet networks, which are inherently bi-directional, it is possible to distribute a common time signal using IEEE 1588 PTP to every device without a separate overlay sync network. Each device can then accurately synchronize its internal clock to a single master clock. This clock time can then be used to accurately achieve media signal synchronization by means of the SMPTE Epoch, explained below.

Figure 1 shows a network made up of multiple devices that all share a common clock using PTP derived from GPS. Using this clock, each device can be referenced to the SMPTE Epoch, and hence to each other, without any need for an overlay clock distribution network. Contrast this with a traditional setup, which would have required one sync distribution path for video and another one for audio. Clearly, a PTP-based solution is much simpler.

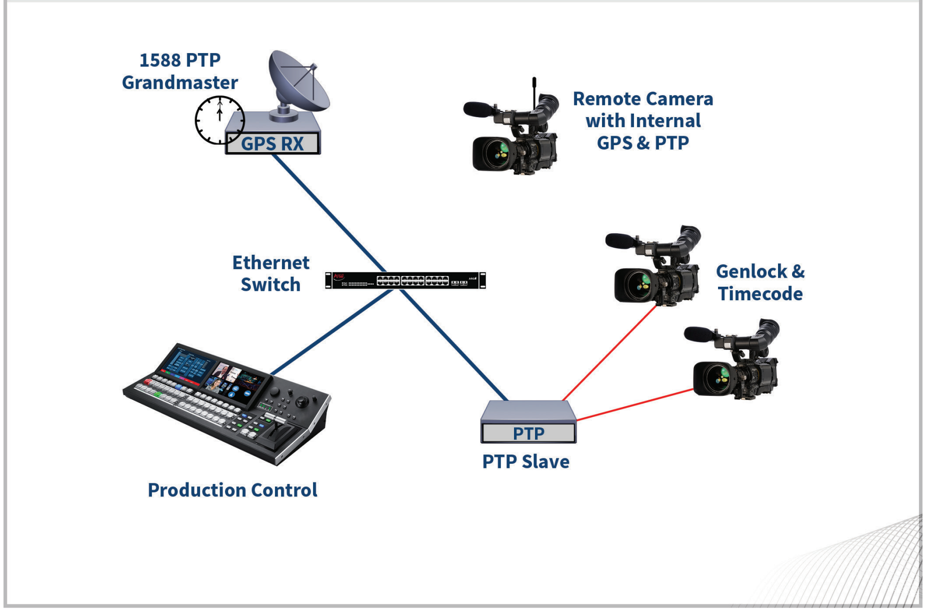
Using the SMPTE Epoch for Synchronization

In order to genlock a group of cameras or sync several microphones, two things are needed: a synchronized clock and a phase reference for each type of media signal. This second requirement is the purpose of an "epoch," which is a (very) specific point in time that can serve as a common time reference for multiple signals. The SMPTE standard ST 2059-1:2015 "Generation and Alignment of Interface Signals to the SMPTE Epoch" provides this reference point, which is precisely 1970-01-01T00:00:00 TAI (Midnight, January 1st 1970 International Atomic Time).

With an epoch, it becomes possible to calculate the phase of any periodic signal that can be referenced to that epoch. As defined in SMPTE and other standards, every media signal type (e.g. video or audio) has a defined alignment point. Every signal is then defined to have its alignment point occur simultaneously with every other signal's alignment point at the precise moment of the epoch. From this common origin, the time of occurrence of any future alignment point for any signal can then be simply calculated as a multiple of the exact period of the signal. Using this basic concept, each device can align itself to a common, aligned reference simply by knowing the (precise) current time, as referenced to the common epoch.

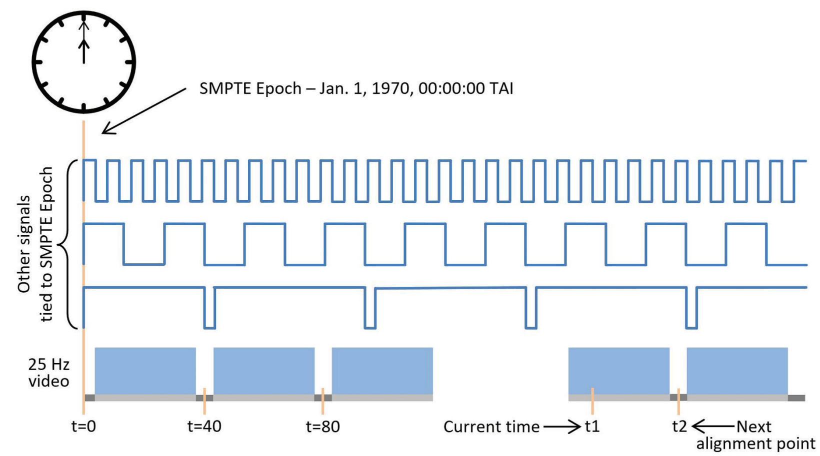
Perhaps a quick example will help to explain this concept. Consider a 25 Hz SD video signal that has a period of 40 msec. As defined in ST 2059-1, the alignment point for the digital version of this signal is horizontal sample 732 of line 1 of this video signal. By definition, this alignment point occurred precisely at the time of the epoch. Another alignment point occurred exactly 40 msec later, followed by another one in at 80 msec, and so forth, as shown in **Figure 2**. To get in phase with this signal, all that a device needs to do is calculate how many milliseconds have occurred since the epoch, and then divide the result by 40. The remainder of this division gives the number of milliseconds since the last occurrence of the alignment point (shown as t1 in figure 2), which can in

FIGURE 1. USING THE SMPTE EPOCH AND PTP FOR SYNCHRONIZATION



turn be used to calculate the time when the next alignment point will occur (t2 in figure 2). Then, all a device needs to do is align its internal video sync reference to that alignment point, and, presto, it becomes synced to every other device referenced to the common epoch.

FIGURE 2. ALIGNING TO THE SMPTE EPOCH



Benefits of PTP

With precise time distribution, the need for setting clocks across multiple devices is eliminated, much like systems that run NTP, only significantly more accurate. In addition, PTP provides a number of other benefits that are extremely advantageous for media networks, including:

- **Multiple Media Formats –** Using the clock/epoch system described above, any device can accurately calculate the precise current phase of any media signal (video, audio, etc.) – even signals with different time bases (such as 50 and 59.94 Hz video). There is no requirement to have one flavor of PTP for U.S. media networks and a different flavor for European media networks – both systems can work from the same precision timing signal.

- **No Sync Overlay Network –** Since the PTP clock signals are distributed over Ethernet connections that can also be used for media signals, there is no longer any need to install an overlay network to distribute synchronization. This can greatly reduce the complexity of cabling systems, particularly ones that connect cameras to their control units.

- **Suitable for any IP-connected Device –** Interface cards and modules that provide the timestamping function required for PTP are widely available on the market. As PTP becomes entrenched in other markets (financial services, electric power distribution, and factory automation, for example) the availability of these components and the appropriate network infrastructure devices will continue to increase.

- **Accurate for Media Applications** - With accuracy levels better than 1 microsecond, PTP offers much better precision than what is required to support video synchronization, and plenty of margin for audio applications. For example, PTP can provide accuracy better than one-tenth of a sampling period for a 96 kHz audio signal, which is suitable for any known practical application.

- **Synchronize Multiple Locations –** PTP grandmasters are commonly tied to GPS signals, making it possible to deliver accurate clock signals to multiple locations – even ones separated by hundreds of miles. Since each location can use the same SMPTE Epoch and a clock locked to the same GPS reference, each location can share precisely synchronized video and audio signals with other locations, eliminating the need to distribute a sync signal from one location to another.

PTP System Components

Distributing PTP over an IP/Ethernet network requires some specialized equipment, both in the form of common core equipment and within the end devices. The major system components include:

- **Grandmaster Clock –** Normally installed in pairs for redundancy, a grandmaster provides a single, common source for PTP clock signals in the network (called a PTP Domain). Only one grandmaster can be active at one time, so all the devices execute a common algorithm to ensure that one and only one device becomes the grandmaster. This process also ensures that if the active grandmaster fails that another device will take over.

- **Transparent or Boundary Clocks –** Delivering the signal from the grandmaster to the end devices (called slaves in PTP specs) is the responsibility of boundary clocks and transparent clocks. These functions are normally built into network equipment such as IP routers and Ethernet switches.

  Transparent clocks allow PTP packets to flow through a device while adding a correction factor to the packet that represents the amount of time that the packet spent in transit through the device. Using this value, the end device can precisely calculate the amount of network delay between the device's input and the Grandmaster's output, allowing an accurate PTP time to be calculated.

  Boundary clocks act as a slave device to an upstream (grand)master, and as a master device to downstream end devices (called slaves). These allow the output of a grandmaster to be shared with multiple downstream devices without overloading the grandmaster. Accuracy levels are close to what can be achieved with transparent clocks.

  While it is possible to run a small network with only a few devices using switches that don't support transparent or boundary clocks, the overall accuracy of the delivered clocks will be degraded. Networks with more than a handful of devices or with multiple switches should use transparent or boundary clocks to ensure signal integrity.

- **Hardware Timestamping –** In order to precisely synchronize devices within a microsecond, precise measurements must be made of the times that packets enter or leave a specific network interface. This requires timestamp measurement hardware to be built into every network interface that can gather the data used by the PTP algorithm.

  Software timestamping is not accurate enough to properly implement PTP, due to the timing inaccuracies that can occur within protocol stacks. Accuracy of a few milliseconds or better is certainly possible with software, which is why NTP (Network Time Protocol) can be implemented using interfaces that don't support hardware timestamping. PTP requires more than a thousand times better accuracy than NTP, so hardware support is essential.

Live concerts and remote production can benefit from PTP.

PTP Applications for Media

As mentioned at the beginning of this document, PTP is required by a variety of standards used throughout the media production industry, including SMPTE ST 2110:2017 "Professional Media over Managed IP Networks" and AES67 "High-performance streaming audio-over-IP interoperability." The primary use of PTP in these standards is to provide a stable timebase that can be used to synchronize video, audio and other signals so that they can be processed easily and delivered to local and remote audiences.

Consider the needs of an audio production within a live concert venue. Many times, several sets of speakers need to be coordinated, so that their sound outputs reach all members of the audience without annoying echoes or, worse, canceling each other out due to phase mismatch. Achieving the best sound for the largest portion of the audience requires adding delay to some of the speaker outputs so that their sounds are in phase with those emitted by other speakers in the venue. Speaker arrays can also be adjusted to maximize their "sound field" output in specific directions by adjusting the timing of the audio signals fed into each speaker element. PTP provides a stable timebase that allows accurate synchronization of all the speakers.

Remote video production can also benefit from PTP, which enables every camera, microphone and signal processing device to be tied to a common clock. When these signals are transported across a long-haul link back to the television production facility, the timing relationships between the signals are used to allow accurate switching between video signals and proper video/audio signal alignment.

Because PTP clocks are used to generate the timestamps within each video and audio data packet, these embedded timing relationships can be used wherever the IP media signals are delivered.

There are other applications beyond the media space that will benefit from IP routers and Ethernet switches that support PTP. For example, financial services firms and markets need accurate timestamps for securities trading and record keeping. Factory automation systems often need to have machines working in lockstep for a variety of tasks. Electric power utilities need to accurately control the phases of high voltage sources and signals across their networks, to avoid damaging current surges. Many other applications, including automobile systems, will benefit from accurate, reliable PTP-enabled networks.

Looking Forward

As IP video and audio technology moves rapidly into the domain of IP networking, IEEE-1588 Precision Time Protocol will become absolutely essential to all facets of media production. This fundamental enabling technology permits hundreds and even thousands of devices to work together in absolute synchronization and support all of the timing relationships that are so critical to properly formatted media signals. Network infrastructure, including Ethernet switches and other devices will need to natively support PTP functions to deliver the highest levels of accuracy that can be achieved with the technology. hitless protection switching has a "can't-miss" future in high reliability networking.

Leap Seconds and PTP

The SMPTE epoch is identical to the one used for IEEE-1588, which is referenced to the TAI (International Atomic Time) epoch used by labs worldwide with the most accurate atomic clocks. Another epoch that is commonly used is the GPS (Global Positioning System) epoch which is 0000 UT (midnight) on January 6, 1980, and is offset from TAI by a constant 19 seconds. The epoch used for Coordinated Universal Time (UTC) is closely related to TAI, except that the epoch for UTC is 1972-01-01T00:00:00Z, or exactly 63,072,010 seconds later than the SMPTE epoch. The Network Time Protocol (NTP) is also based on UTC. The difference between UTC and SMPTE/PTP time is not fixed, it changes every time a leap second occurs.

Leap seconds are used to match a clock to the speed of the Earth's rotation. A normal day is 86,400 seconds (60 x 60 x24), but in reality, it takes the earth an extra millisecond or so to complete a full revolution. The amount of deviation isn't constant – some days the earth revolves faster and other days slower, depending on the season, earthquakes, and a host of other natural processes. Adjusting for leap seconds can cause headaches for different applications, so the SMPTE system does not use them.   Instead, the clock used for measuring time from the SMPTE epoch increases linearly, with no leap seconds added. UTC takes a different approach, and adds leap seconds whenever they are needed by designating a single day to last 86,401 seconds. The last leap second occurred at midnight UTC between December 31, 2016 and January 1, 2017. Since this date, the difference between TAI time and UTC is 37 seconds.

Related Products

ARG Quarra PTP Ethernet Switches


ARG Quarra 10G PTP Ethernet Switch

ARG Quarra 1G PTP Ethernet Switch

The ARG Quarra family supports the SMPTE ST 2110-10 standard for System Timing and Definition and ST 2059-2 permitting interoperable use of IP-based media equipment with conventional genlocked SDI equipment. ARG Quarra switches are designed for audio/video broadcast, defense and security, finance, utilities, telecom, and enterprise IT applications in which accurate timing and control are required.

About Artel

Artel Video Systems is a world-class provider of innovative, real-time, multimedia delivery solutions serving global markets. Today the majority of the live events in the US traverse Artel products to support their mission critical work-flows. Artel's expertise in IP- and fiber-based technologies spans more than 30 years and has established Artel as a trusted partner in the development of reliable, standards-based, IP infrastructures. Artel's integrated solutions include fiber and IP based multimedia delivery, precision timing, OTT, and data networking. An employee-owned business since 2014. More information is available at www.artel.com.

World Headquarters
5B Lyberty Way
Westford, MA 01886
USA
Tel: (978) 263-5775
Fax: (978) 263-9755
Artel.com | info@artel.com

November 2017

AR207-900002-00_A