NETWORK BASED TIMING MECHANISMS TO SUPPORT PRECISE ALIGNMENT OF REAL-TIME STREAMS

Bob Kovach
Sr. Program Manager
IPtec, Inc.
5673 W. Las Positas Blvd. Suite 207
Pleasanton, CA 94588
bkovach@iptec-inc.com

ABSTRACT

The efforts to implement the distribution of real-time information streams via IP packet-based networks in the range environment have largely utilized the recovery of timing information via implicit techniques, such as adaptive clock recovery. These techniques allowed the alignment of streams with disparate delay characteristics to accuracies on the order of 1 millisecond. With the availability of techniques to distribute high accuracy timing information to network nodes, the capability to recover and align real time streams on the order of microseconds is possible.

This paper will focus on a methodology to perform precision stream alignment that utilizes timestamping and the IEEE 1588 Precision Time Protocol (PTP) as a clock source. IEEE 1588 is currently utilized in cellular networks to deliver synchronization to remote network elements, providing superior accuracy and stability.

The paper will review expectations for performance and discuss considerations in system level design to optimize timing distribution performance and ultimately stream alignment accuracy. System elements and their effect on performance will be identified and characterized.

Finally, a TM Gateway implementation example which utilizes PTP coupled with hardware-assisted timestamping techniques to align recovered TM streams to a high degree of accuracy will be described. Real world results for clock accuracy and expectations for stream alignment accuracy will be shared.

.

KEYWORDS

Telemetry Over IP (TMoIP), IP networking, Stream Alignment, PTP, IEEE – 1588, Telemetry Gateway

INTRODUCTION

In test range scenarios the situation often arises where a number of streams from diverse sources need to be processed. Due to the differences in transit time through the range network, the sources will arrive at different times at the processing station, resulting in the temporal misalignment of the recovered streams.

The main requirement for stream alignment is to match significant instants of events from multiple test sources located at remote sites. Due to a number of causes, the latency of propagation of the signal from each source to the destination can be significantly different. When multiple streams are terminated at a destination they will be mis-aligned due to the different latency characteristics of the network paths for each stream.

Performing stream alignment allows the information from each of the remote sources to be observed simultaneously (within a defined tolerance) at the destination, which simplifies the monitoring and analysis of test data.

This document describes a mechanism for performing temporal alignment of serial streams when transported via packet-based networks. The method details the insertion of timestamp information into information streams generated by a Telemetry Gateway device that enables the transport of serial telemetry streams via packet-based IP network infrastructures. The timestamps are referenced a clock source which, when the source has sufficient accuracy, enable the alignment of recovered streams with high degrees of precision.

The techniques described in this paper only mediate alignment issues introduced by the ground transport mechanism. In a perfect world, all information streams are timestamped at the source, which would enable the correction of all latency variations from the encoding through frame generation, downlink, and ground transport. However, in the bulk of existing implementations the streams are not timestamped at the source, so these variations cannot be corrected. It is recommended that this situation be studied in future RCC efforts.

The current state of the art for packet-based telemetry transport via IP networks is defined by the TMoIP standard [7], which defines a method for transporting telemetry streams via UDP packets, using adaptive clock recovery. Adaptive clock recovery supports regeneration of the telemetry clock at the receiver using buffering techniques. This clock recovery scheme has the benefit that the source clock rate does not have to be user configured, simplifying user setup. While the configuration is simplified, there is no inherent method to identify absolute instants of time with any degree of accuracy, or to align the streams with absolute certainty.

A scheme to align streams using clock recovery can by implemented using buffer management techniques to align streams whose delay characteristics are different due to the different stream rates. Since the nature of adaptive clock recovery involves the implementation of a buffer at the stream recovery element, the buffer level can be managed to ensure that streams with different native signaling rates are aligned. Using this scheme, the alignment accuracy is limited to 1 millisecond. Emerging applications require alignment accuracies on the order of 10 μseconds or better. For this, a method to support high accuracy stream alignment is required.

The requirement for the alignment of streams to a high degree of accuracy is not limited to telemetry applications. In the last several years, the backhaul of broadcast video streams from remote locations to the studio has migrated to IP networks. An initiative to support studio distribution of video streams is currently underway by SMPTE which defines specifications for precision alignment of video, audio and ancillary streams [8], [9]. The SMPTE methodology also makes use of next generation clock sources and timestamping techniques to support stream alignment. Utilizing the SMPTE standards as a model for alignment of telemetry streams provides the following benefits:

1. The alignment methods will be based on common standards.
2. Technical advances in the methods and component elements will be shared across applications.
3. The path to alignment of telemetry streams with video streams will be defined.

To enable precision stream alignment, the next generation solution will utilize the following building blocks:

1. Timing Source – The timing source will enable the distribution of a high accuracy clock to end nodes via the IP network, and provide an accurate source for the generation of timestamps.
2. Timestamping – Packets will be timestamped from the Timing Source. As the accuracy of the timestamp is dependent on the accuracy of the timing reference from which the timestamps are derived, it is important to understand design decisions that drive the accuracy and stability of the Timing Source.
3. Network Protocol – The network protocol to enable inclusion of timestamps in the network information packets. It is desired to leverage existing protocols, which speeds vendor implementation and enhances inter-operability between vendors.
4. Clock Recovery – The Clock Recovery algorithm will enable both the recovery of the source clock and the alignment of the telemetry streams from diverse sources.
5. Test Method - The overall performance of the alignment method must be characterized. To support this requirement, a test methodology will be described.

SOLUTION DESCRIPTION

The following sections described a proposed implementation to enable enhanced precision in the alignment of telemetry streams. The implementation follows the strategy outlined previously to use standards-based building blocks where possible, and leveraging work performed in other industries. Please refer to Figure 1 below in the following discussion.

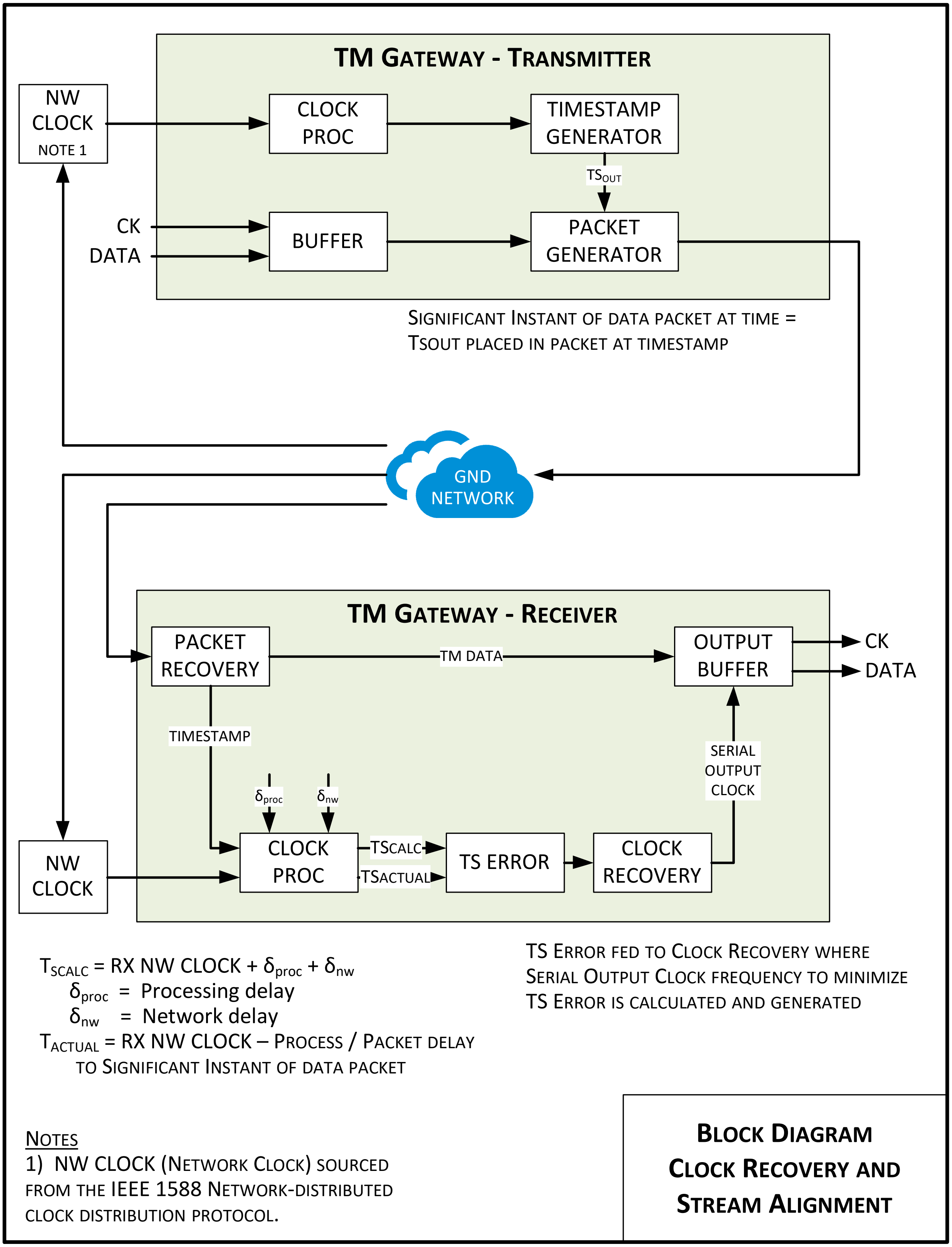

Figure 1- Block Diagram

NETWORK CLOCK

A key component in the proposed implementation is the Network Clock. The accuracy and repeatability in stream alignment will ultimately be driven by the quality of the Network Clock. For this reason, careful attention must be paid to the selection of the technology and vendor of this system element.

Legacy TM infrastructures distributed the system clock via the synchronization standards defined by the Range Commanders Council (RCC). The IRIG implementation distributes timing information both in the form of pulse rates and signaling information using timecodes embedded in the baseband signal. IRIG timing is distributed via an overlay network, typically using a coax cable infrastructure. Distribution of IRIG timing in packet-based networks is typically performed by encoding the baseband signal and regenerating it at network endpoints. Unfortunately, this method suffers from the same latency effects that are introduced by adaptive clock recovery techniques.

As network topologies evolved from a TDM-based infrastructure to packet-based configurations, the need has arisen for a timing distribution method that supports accuracies greater than the IRIG, and also lends itself to distribution via an IP infrastructure. To complete the convergence of timing and information streams across the IP infrastructure, the telemetry community (along with the video community) has been migrating to network distribution of timing streams. In this type of architecture, IRIG timing is either replaced with network timing, or IRIG timing is used to generate network timing using an IRIG-to-NTP/PTP gateway device. In this case, the IRIG generator, NTP server and IEEE 1588 timing source are normally receiving the timing information from the same timing clock source. The only difference is how the timing information is delivered to the telemetry gateway units. Two standards are in current use: NTP and IEEE 1588 (PTP).

NTP (Network Timing Protocol) and its simplified version SNTP (Simple Network Timing Protocol) support synchronization of computer clock times in computer networks. The accuracy of NTP is 1 – 10 milliseconds and is not judged to be usable to enable the precision stream alignment requirements addressed in this paper.

IEEE 1588 extends the accuracy of network distributed timing levels greater than NTP. A detailed description of IEEE 1588 will not be presented here, as a number of sources exist that provide this information [2], [5]. To summarize, IEEE 1588 enhances the basic mechanism defined by NTP to upgrade the stated clock accuracy to $\pm$ 50 nanoseconds. IEEE 1588 has been selected as the Network Clock source to support the SMPTE requirements and is the source that will be used for the telemetry application described here.

The ultimate accuracy and stability of IEE 1588 (or any network-distributed timing mechanism) is affected by the network topology, packet performance, and vendor implementation. SMPTE has performed a number of interoperability tests between different vendors [1], as well has evaluated the effects of different network topologies.

Another consideration is the effects on clock accuracy in the WAN environment. In a WAN environment, extreme variations packet delay can occur, which impact the accuracy of the Network Clock [3].

Additional implementation details such as the clock performance in individual implementations also contribute to the performance of the Network Clock [4], [6].

The fundamental statement that can be made is that, since the timestamps are derived from the Network Clock, the timestamp accuracy and, ultimately the stream alignment performance, is intimately tied to the performance of the Network Clock. Any flaw in the Network Clock will translate in an error in stream alignment. For this reason, it is important to:

1. Characterize key performance metrics in Network Clock element and select component accordingly.
2. Consider network topology impact on performance forecast.
3. Evaluate effects of intervening network elements.

TIMESTAMP GENERATION

The ultimate timing accuracy of the timestamping method is dependent upon two factors: The accuracy of the clock source, and the accuracy of the timestamp mechanism. Utilizing IEEE 1588 as the distribution mechanism provides a clock source of the greatest accuracy. Timestamping can be performed in software or hardware. Due to the unpredictability of software mechanisms, utilizing software timestamping degrades the timing accuracy by several orders of magnitude. For instance, a software-based IEEE 1588 implementation results in a nominal timing accuracy of 10 μseconds, which is a significant impact to the native accuracy of $\pm$ 50 nanoseconds.

To ensure the maximum timing accuracy, the proposed solution utilizes the IEEE 1588 timing protocol coupled with hardware-based timestamping to minimize timing degradation. The IEEE 1588 clock is ingested at the TM Gateway Transmitter (NW CLOCK) and at the TM Gateway Receiver (NW CLOCK) and fed to the clock processing (CLOCK PROC) block where the timestamping hardware captures the IEEE 1588 clock at an instant that is known to the precision of 1 nanosecond.

After network timing capture, the timestamps are passed to their respective blocks for packet processing, in the case of the Transmitter, or for clock extraction and stream generation, in the case of the Receiver.

PACKET CONSTRUCTION

In the Transmit path, this timestamp is fed to a hardware block that assembles the timestamp and input data into an IP packet (PACKET GENERATOR) for transmission to the network. All processing including packet generation and scheduling, is performed in hardware.

Packet construction will utilize existing standards. As was noted previously, SMPTE has defined a set of recommendations for timestamping video and associated streams; the SMPTE recommendations are based on RTP (RFC 3550) for the Layer 3 protocol [10].

CLOCK RECOVERY AND STREAM ALIGNMENT

In the Receiver the timestamp is extracted from the incoming packet in the PACKET RECOVERY block. This timestamp indicates the specific point in time (Significant Instant) that indicates the first bit in the data packet. By aligning the Significant Instant for all packets to the same timing reference, stream alignment with the network timing source and with all other streams is achieved.

The receive timestamp is fed to the CLOCK PROC block where the network time for the Receiver is also fed. The Receiver ingests network timing with the same accuracy as the Transmitter, again using hardware techniques. These timing instants are processed with two configuration variables that enable the user to adjust the output timing. The configuration variables are:

> δ_{proc} – Processing Delay – Processing delay of Transmit and Receive Clock processing blocks. This value is fixed internally.
>
> δ_{nw} – Network Delay – Transit delay through the network. This should be greater than the longest network delay, in order to ensure that packets with the longest network delay can be aligned with packets with shorter network delays.

The CLOCK PROC block generates two values: The Calculated Timestamp, which is calculated based on the timestamp value recovered from the inbound packet, and the Actual Timestamp which is calculated based on the network clock at the Receiver. A difference between the two timestamps is interpreted as a timestamp error, which is calculated in the TS ERROR block.

The results of the TS ERROR block are fed to the CLOCK RECOVERY block, which generates the Serial Output Clock, the clock that is used to clock the recovered TM stream out the TM Rx port. The CLOCK RECOVERY block includes a programmable clock generator to provide the output clock for the recovered telemetry stream. Programming the clock generator such that the timestamp error is zero will ensure that all traffic exits the receive interface at the same time relative to the network clock, resulting in the alignment of all output streams to the network clock, and ultimately to each other.

TEST METHODOLOGY

The proposed test methodology will enable baseline testing of streams alignment and provides a basis for additional refinement. The test methodology consists of the following functions:

1. Generate two test streams with known delay characteristics and feed to a TM Transmitter.

2. Transport the test streams to a TM Receiver.
3. Measure the delay in real time using an oscilloscope.

Please refer to Figure **2** below in the following discussion.

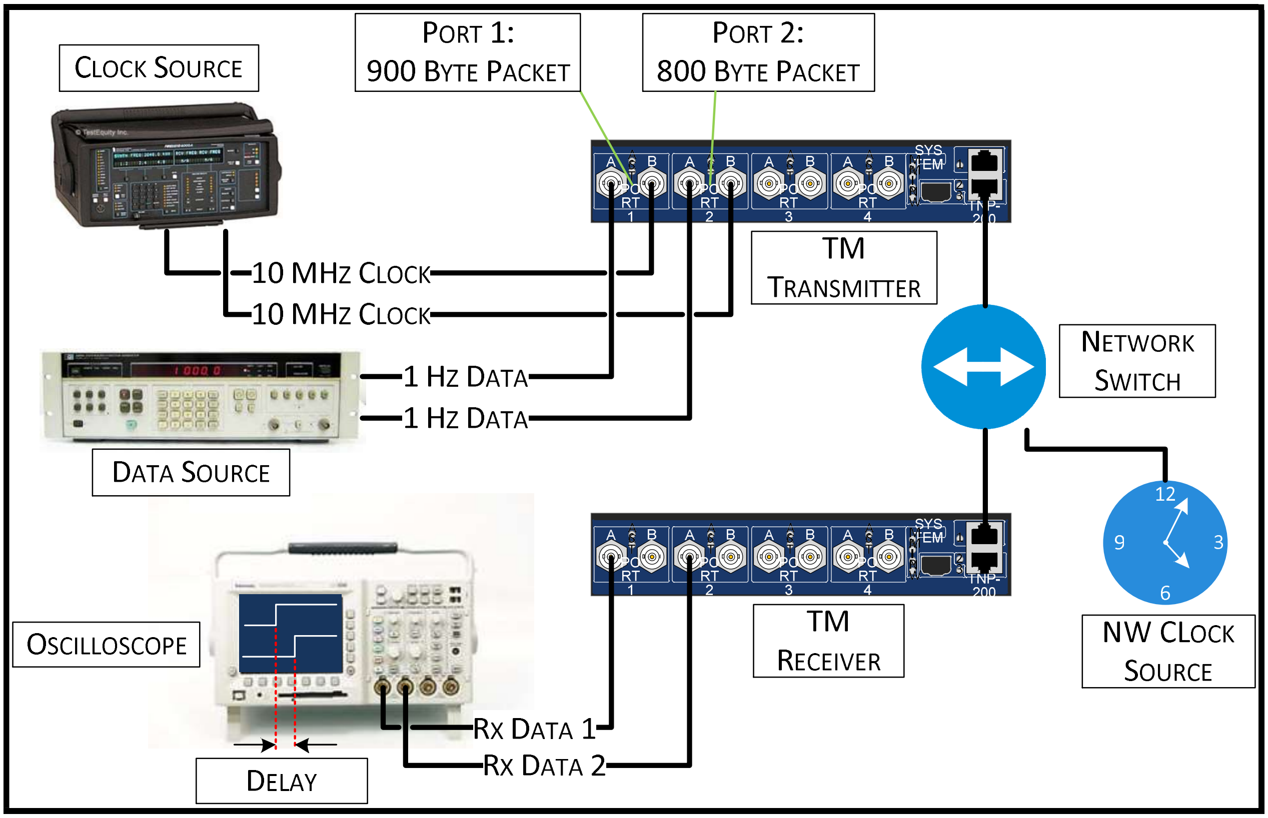

Figure 2 - Test Configuration

The test streams are generated in the following manner. A data stream with a known reference point is produced using a waveform synthesizer. In practice, this can be done by generating a data stream that has a low signaling rate compared to the sampling rate. In this case a 1 Hz data stream is generated by the data source, which will result in the edges of the test stream providing a convenient reference point, as they occur only twice per second (rising + falling edge). The test stream is fed to the data input of 2 ports of a TM Transmitter. The clock is sourced from a high-speed clock generator. In this test the clock source is 10 MHz. This clock rate is chosen to limit the measurement uncertainty of data alignment due to the asynchronous nature of the test setup to a value of 100 ns.

The TM Transmitter will generate IP packets to send to the network interface. Packets of two different sizes are built: a 900-byte and an 800-byte packet. The Telemetry Gateway incurs a delay that is equal to the size of the packet (in bits) divided by the clock rate to allow for the construction of the packet prior to transmission. The packetization time in this configuration is:

900-byte packet: 720 µseconds

800-byte packet: 640 μseconds

The net result is that the data from port 2 will lag the data from port 1 due to the difference in packetization time. The test will verify that the data is correctly aligned by the TM Receiver operation.

The TM Transmitter and TM Receiver are network-connected to a clock source that is used to provide the reference timing for the timestamp function in the transmit path and the clock recovery and alignment function in the receive path. The clock is sourced from an IEEE 1588 grandmaster device.

The TM Receiver recovers the TM packets sourced by the TM Transmitter and re-generates the clock and data for both test streams. The data steam output for both test streams is connected to an oscilloscope to enable measurement of the delay for both streams. As the data rate is 1 Hz, it is certain that either a rising edge of falling edge of the signal is the "same" significant instant for both test streams. Therefore, measuring the delay between the rising (or falling) edges of both test streams provides a measurement of the data alignment.

RESULTS AND DISCUSSION

Preliminary results indicate that stream alignment to an accuracy of $\pm$ 50 μseconds can be achieved from the proposed scheme. The following of areas have been identified for additional exploration, which are anticipated to improve performance:

1. Explore additional filter mechanisms to reduce the impact of packet delay variation on the accuracy of the Network Clock.
2. Compare multiple Network Clock vendors and study the impact of Network Clock performance on stream alignment accuracy. The current implementation uses a Network Clock from a single vendor.
3. Refine internal timestamping schemes in Telemetry Gateway devices.

Further studies and testing will be performed to add more details, with the goal of achieving stream alignment to within $\pm$ 2 μseconds. The methods and results will be shared with the community as they become available.

CONCLUSIONS

As the migration of real time serial streams to transport over IP-based infrastructures accelerates, the need for high accuracy alignment of streams with diverse characteristics and locations is increasing. The availability of high accuracy network-connected timing sources, coupled with hardware processing methods in the Telemetry Gateway makes stream alignment to microsecond accuracy possible.

When implemented in a Telemetry Gateway, the proposed method provided positive evidence of the use of timestamps to support stream alignment, but also provided technical challenges. The solution of these challenges will result in a method that can be used in range environments where stream alignment is required to extended levels of precision.

REFERENCES

[1] Society of Motion Picture and Television Engineers (SMPTE), "32NF-80 DG Report, ST2059 PTP Interoperability Testing and Demonstrations," Jan. 2017.

[2] Calnex Solutions, Ltd, "Implementing IEEE 1588v2 for use in the mobile backhaul," Technical Brief, 2009.

[3] Endace Technology Ltd, "IEEE 1588 clock synchronization over a WAN backbone," Whitepaper, 2016.

[4] Hirschmann, "Precision Clock Synchronization – IEEE 1588", Whitepaper, Rev 1.2.

[5] Symmetricom, Inc., "Best Practices for IEEE 1588/PTP Network Deployment," Application Brief, 2008.

[6] Symmetricom, Inc., "IEEE 1588 Precision Time Protocol – Frequency Synchronization Over Packet Networks," Application Brief, 2008.

[7] TMoIP Standard, RCC-218-10, "Telemetry Transmission Over Internet Protocol (TMoIP) Standard," RCC Telecommunications and Timing Group, 2010.

[8] Society of Motion Picture and Television Engineers (SMPTE), ST 2110 – 10, "System Timing and Definitions," September, 2017.

[9] Society of Motion Picture and Television Engineers (SMPTE), ST 2110 – 20, "Uncompressed Active Video," September, 2017.

[10] IETF, "RTP: A Transport Protocol for Real-Time Applications," The Internet Society, 2003.