SMPTE EG 2059-10:2016

SMPTE ENGINEERING GUIDELINE

Introduction to the New Synchronization System

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Approved
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Foreword

SMPTE (the Society of Motion Picture and Television Engineers) is an internationally-recognized standards developing organization. Headquartered and incorporated in the United States of America, SMPTE has members in over 80 countries on six continents. SMPTE's Engineering Documents, including Standards, Recommended Practices, and Engineering Guidelines, are prepared by SMPTE's Technology Committees. Participation in these Committees is open to all with a bona fide interest in their work. SMPTE cooperates closely with other standards-developing organizations, including ISO, IEC and ITU.

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Introduction

The current methods of synchronization for television, audio and other moving picture signals rely on standards that have been in place for over 30 years. These standards are becoming increasingly inappropriate for the digital age with, for example, networked content sharing and the higher frame rates appropriate to HDTV, UHDTV and other image formats.

In order to solve these problems, SMPTE has specified a new synchronization system based on alignment to reference time measured from the SMPTE Epoch. SMPTE ST 2059-1 specifies how signals are aligned with respect to the SMPTE Epoch. SMPTE ST 2059-2 specifies a Profile of IEEE Std 1588-2008 Precision Time Protocol for distribution of reference time and synchronization metadata in the professional broadcast environment.

This guideline describes basic ideas, concepts and Use Cases of the new synchronization system, including SMPTE ST 12-1 Time Code generation.

1 Scope

The objective of this document is to introduce the basic concepts behind the use of the new synchronization system and the IEEE-1588 Precision Time Protocol in Professional Broadcast Applications, and to give some use cases. Detailed explanation of the technology is out of scope of this document.

2 Conformance Notation

This Engineering Guideline is purely informative and meant to provide tutorial information to the industry. It does not impose Conformance Requirements and avoids the use of Conformance Notation.

Engineering Guidelines frequently provide tutorial information about a Standard or Recommended Practice and when this is the case, the user should rely on the Standards and Recommended Practices referenced for interoperability information.

3 Concept of the New Synchronization System

Periodic AV signals can be created deterministically if their phase at a particular time is known. In the case of a video synchronization signal, if the start point of the video frame (phase) and the video clock frequency are known, it can be created deterministically at any given point in time.

The new synchronization system takes advantage of this characteristic and shares time information across the system rather than transferring synchronization signals themselves. As time information consists of phase (offset from the certain point in time) and frequency, if the phase relationship between time and an A/V signal has been defined, any A/V synchronization signal can be created deterministically from time information. This concept is illustrated in Figure 1.

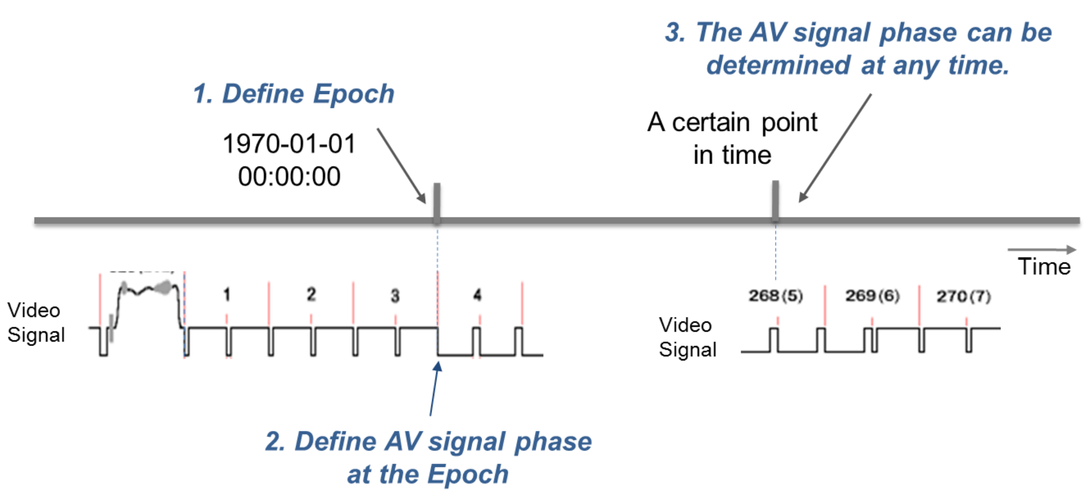

Figure 1 – Concept of the New Synchronization System

SMPTE ST 2059-1 defines a reference point in time (the 'SMPTE Epoch') and the alignment of A/V signals to the Epoch.

The phase of the video signal is given by time since the Epoch modulo video frame period.

4 IEEE 1588 PTP (Precision Time Protocol)

The new synchronization system uses IEEE Std 1588-2008 PTP as a means of sharing precision time across a network. PTP is a time distribution protocol which runs on a network, such as a LAN. It allows for time synchronization with sub-microsecond accuracy.

The PTP defined in IEEE 1588 has many possible parameters and options. A 'Profile' is used to define sets of attributes and their values in order to optimize its application to specific industries or for particular purposes. SMPTE ST 2059-2 specifies the SMPTE PTP profile which is optimized for professional broadcast applications.

The following is a simple explanation of the PTP operation. See IEEE Std 1588 and SMPTE ST 2059-2 for further detail.

4.1 Synchronization Overview

As illustrated in Figure 2, PTP performs time synchronization by exchanging PTP messages periodically between a PTP master and PTP slaves. These messages include timestamps corresponding to time of transmission or reception of the message or a related one. PTP slaves perform time synchronization using the timestamps.

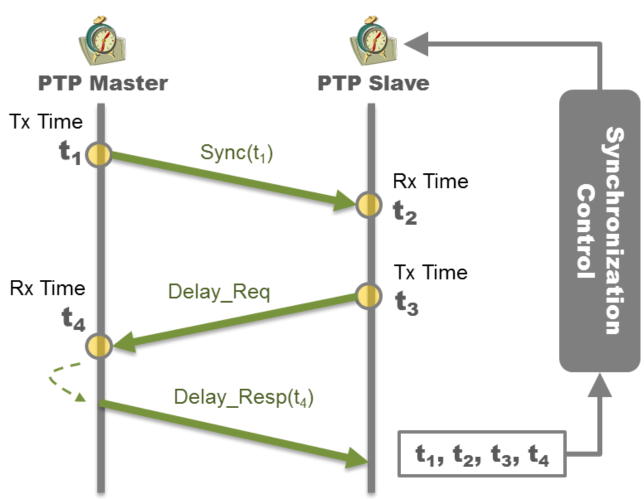

Figure 2 – Concept Diagram of the PTP Synchronization Control

In order to synchronize time at the PTP slave to the PTP master, both the frequency and phase of the time information have to be controlled. The principle is shown in Figure 3.

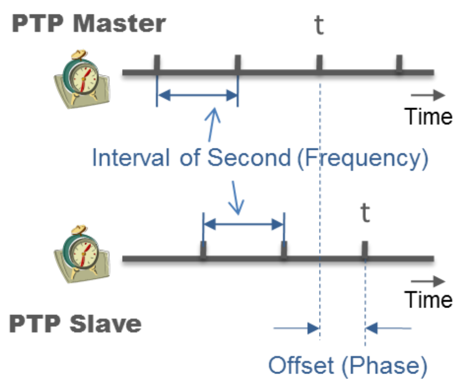

Figure 3 – Time Synchronization: Frequency and Phase

The PTP slave has to extract both frequency and phase information from PTP messages.

Figure 4 shows one example of how frequency information may be extracted and calculated. The Sync message is a PTP message which the PTP master sends to PTP slaves periodically. Assuming that the network delay is always the same between the PTP master and a PTP slave, the difference between Sync message intervals is measured by the PTP master (Δm) and the Sync message intervals measured by PTP slave (Δs) is the frequency difference. Therefore frequency can be synchronized by a control system in the PTP slave to remove the difference (Δm-Δs). In order to achieve precise synchronization it is essential to minimize the impact of variations in the network delay. Also in order to speed up the synchronization time, it is effective to reduce the Sync message intervals.

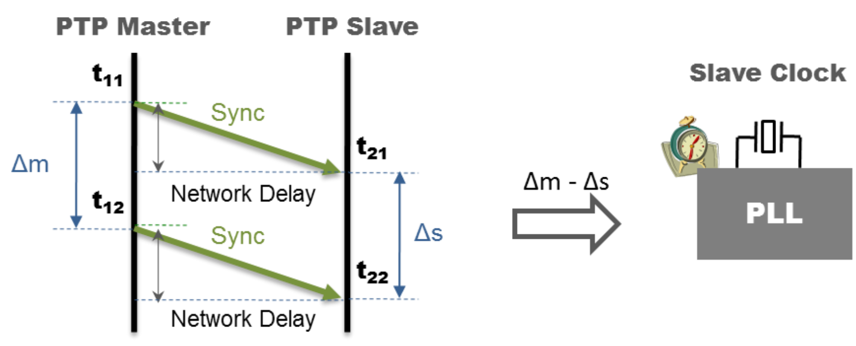

Figure 4 – Example of Frequency Control

Figure 5 shows an example of phase control. The Delay_Req message is a PTP message that a PTP slave sends periodically to the PTP master. Assuming that the network delay between the PTP master and the PTP slave is always same, and is the same in each direction, the time difference between when the Sync message is sent and when the Sync message is received (t_2-t_1) = Network Delay + Time difference (between PTP master clock and PTP slave clock) and time difference between when Delay_Req message is sent and when Delay_Req message is received (t_4-t_3) = Network Delay - Time difference. Therefore time difference (phase) can be calculated as follows:

$$\text{Time Difference} = \frac{(t_2 - t_1) - (t_4 - t_3)}{2}$$

Again as it is assumed the network delay is always same, in order to achieve precise synchronization it is essential to minimize the impact of variations in network delay. Also, in order to speed up the synchronization time, it is effective to reduce the Delay-Req message intervals.

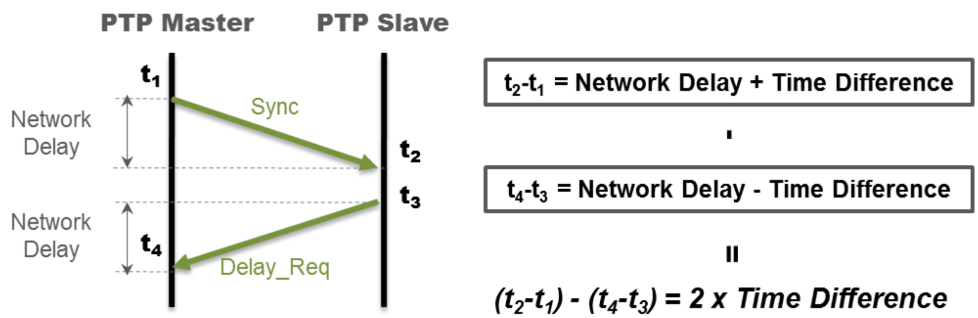

Figure 5 – Example of Time Phase Control

4.2 Device Types

PTP is a distributed protocol that specifies how the real-time clocks in the system synchronize with each other. These clocks are organized into a master-slave synchronization hierarchy.

PTP executes within a logical scope called a ‘domain’. All PTP messages are always associated with a particular domain.

IEEE Std 1588 defines three kinds of clock: an ordinary clock which is an end device with one port on the network described above; a transparent clock, and a boundary clock both of which have more than one port on the network.

Note: More precisely, there are two types of transparent clocks: an end-to-end transparent clock and a peer-to-peer transparent clock. In this document, only the end-to-end transparent clock is described.

1. Ordinary Clock

The ordinary clock can be a grandmaster clock (PTP GM) in a system, or it can be a slave clock (PTP slave). The PTP GM is at the top of the master-slave hierarchy and determines the reference time for the entire system within a domain.

2. Transparent Clock

As described above, reducing the effect of network delay variation is essential in order to perform precision time synchronization. One option to reduce the impact is to use a transparent clock.

The transparent clock, illustrated in Figure 6, is a special switch for PTP and embeds the time taken to pass through the switch (residence time) into PTP event messages. PTP slaves can compensate for varying network delay by subtracting residence time and thereby reduce its impact.

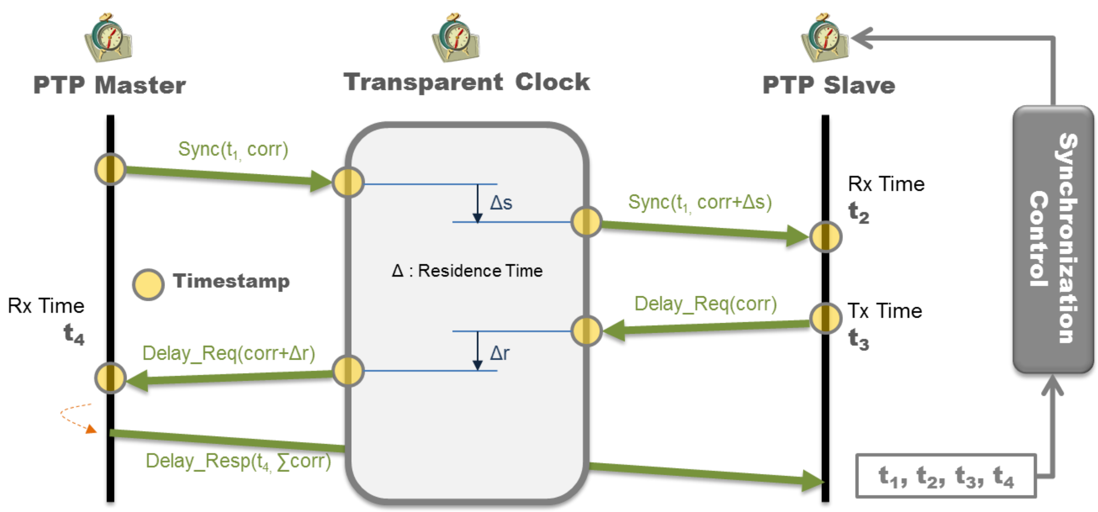

Figure 6 – Concept of Transparent Clock

3. Boundary Clock

The maximum number of PTP slaves that a PTP GM can control is limited by several conditions, including the rate at which it can process and respond to Delay_Req messages. A boundary clock is designed to increase the maximum number of PTP slaves connected to the same PTP GM by establishing hierarchical structure.

Figure 7 illustrates a boundary clock. This includes both a PTP master and a PTP slave, and conveys the time synchronized by the PTP slave to the downstream PTP slaves as a PTP master.

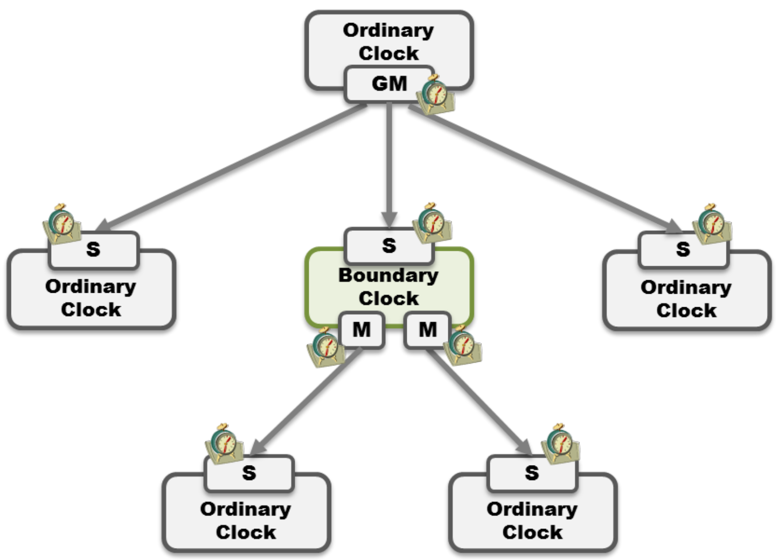

Figure 7 – Concept of Boundary Clock

4.3 Redundancy

IEEE Std 1588 defines the Best Master Clock Algorithm (BMCA) as the default PTP redundancy mechanism.

- *BMCA*

The BMCA is used to determine which of the available clocks is the best clock and which should therefore be used. It is also used to determine whether a newly discovered clock is better than the local clock itself. When the current best PTP master fails, BMCA is initiated to find the best clock to be a new PTP master.

When using a BMCA, SMPTE ST 2059-2 specifies use of the IEEE 1588 default BMCA mechanism.

IEEE Std 1588 also defines several PTP redundancy mechanisms as options. The following alternate master option is permitted in SMPTE ST 2059-2 and could be an appropriate redundancy mechanism for a video system:

- *Alternate Master*

This option allows alternate PTP masters that are not currently the best PTP master to exchange PTP timing information with PTP slaves. This will allow a PTP slave switchover to an alternate PTP master with a small phase excursion when the current best PTP master fails.

5 Time Source

The new synchronization system can be applied to various use cases according to system requirements. The essential point is that in each case PTP slaves create a synchronization signal using exactly the same mechanism.

Aside from use cases related to the network configuration such as inclusion of transparent clocks or boundary clocks, the main distinguishing factor between use cases is the type of time source used by the PTP GM.

There are two types of timescale supported by IEEE Std 1588: ‘PTP’ and ‘ARB’ (arbitrary). With the PTP timescale, the Epoch is the SMPTE Epoch. In the case of timescale ARB, the Epoch is set by an administrative procedure, may be reset during normal operation, and does not necessarily correspond to the SMPTE Epoch.

The type of time source used by the PTP GM is indicated by the attribute timeSource. In the case of the SMPTE ST 2059-2 profile, two additional values for timeSource have been added for cases when the frequency reference is derived from a legacy synchronization signal.

The following four types of time source are assumed, and the features and typical use cases of each are described.

1. Primary reference time

The PTP GM is synchronized to a primary reference time, for example by means of GPS (Global Positioning System) reception. The timescale is PTP.

2. Non-primary reference time

The PTP GM is synchronized to time source that is not referenced to a primary reference time. The timescale is PTP.

3. A/V synchronization signal

A/V synchronization signal such as black burst. Timescale is ARB.

4. A/V synchronization signal + non-primary (or primary) reference time

Combination of A/V synchronization signal such as black burst and non-primary (or primary) reference time. Timescale is ARB or PTP.

5.1 Primary Reference Time

Figure 8 illustrates an example of a use case where GPS is used as a time source.

By sharing a primary reference time, synchronization can be achieved between PTP slaves that are not necessarily connected to the same PTP GM. Synchronization can even be achieved for devices not connected to the PTP GM if the primary reference time can be obtained independently.

Also, as illustrated in Figure 8 as Facility 1, a legacy synchronization signal based facility can also co-exist if the master generator is locked to the primary reference time and as a result the output legacy synchronization signals are Epoch aligned.

Therefore a distributed synchronization environment can be easily established. This could be the optimum solution for new ‘green field’ facilities.

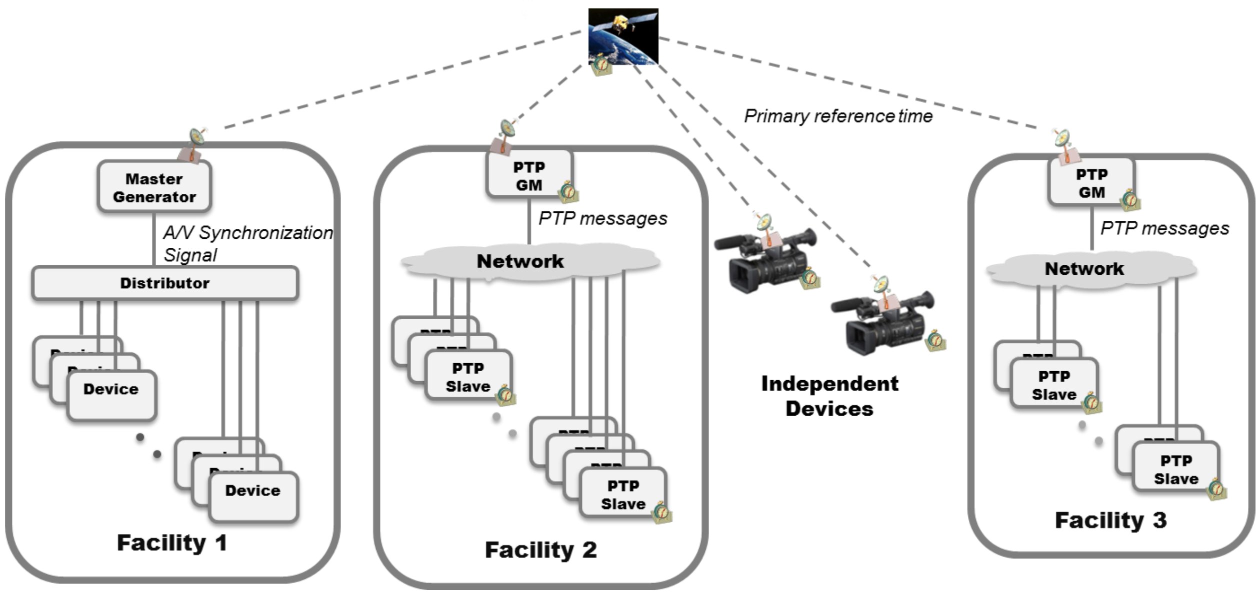

Figure 8 – Use Case where Time Source is a Global Reference Time

5.2 Non-Primary Reference Time

Figure 9 illustrates an example of use case where a non-primary reference time such as a wall clock is used. As with current conventional operation using a master sync generator, synchronization can be achieved between PTP slaves connected to the same PTP GM. The precision of the shared time depends on the precision of the GM time reference. This could be the solution for a closed 'island' system.

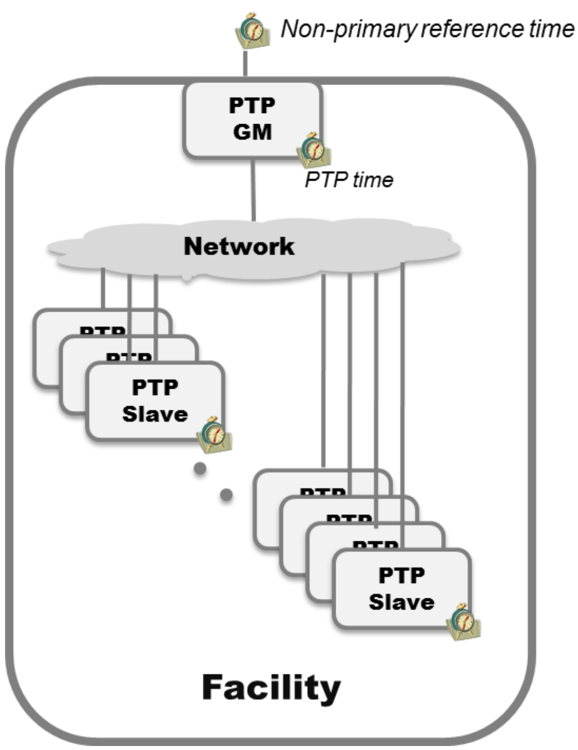

Figure 9 – Use Case where time source is non-primary reference time

5.3 A/V Synchronization Signal

Figure 10 illustrates an example of use case where a free-running legacy A/V synchronization signal such as color black alone is used as a source of PTP time, without any reference to an actual time source. An example of such an application is where it is wished to replace a small part of an established system based on a legacy synchronization signal such as black burst.

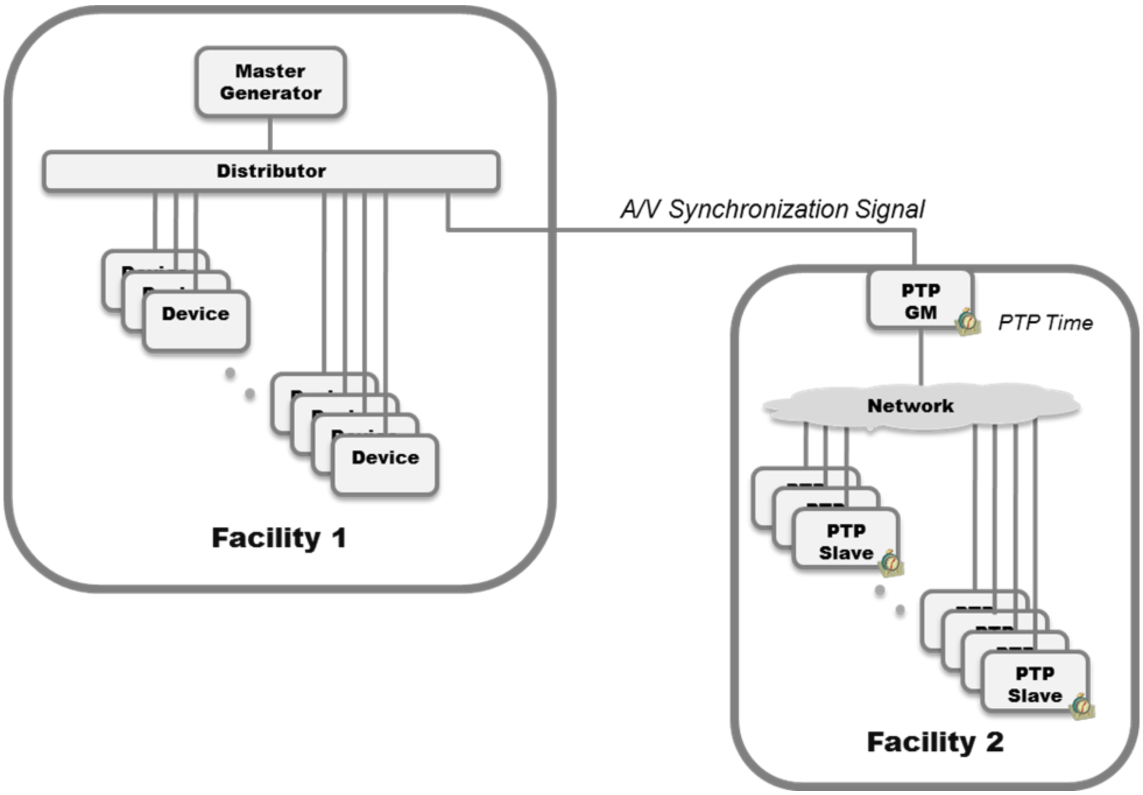

Figure 10 – Use Case where time source is A/V synchronization signal

Figure 11 shows the concept. In this case, the PTP GM extracts frequency and phase information from the A/V synchronization signal and this is used to create a source of time starting from an Epoch that is related to the synchronization signal. As an A/V synchronization signal has only time periodicity, and no absolute relationship with real time, conversion to real time (TOD) is not possible, and so PTP time at initialization always starts from the Epoch.

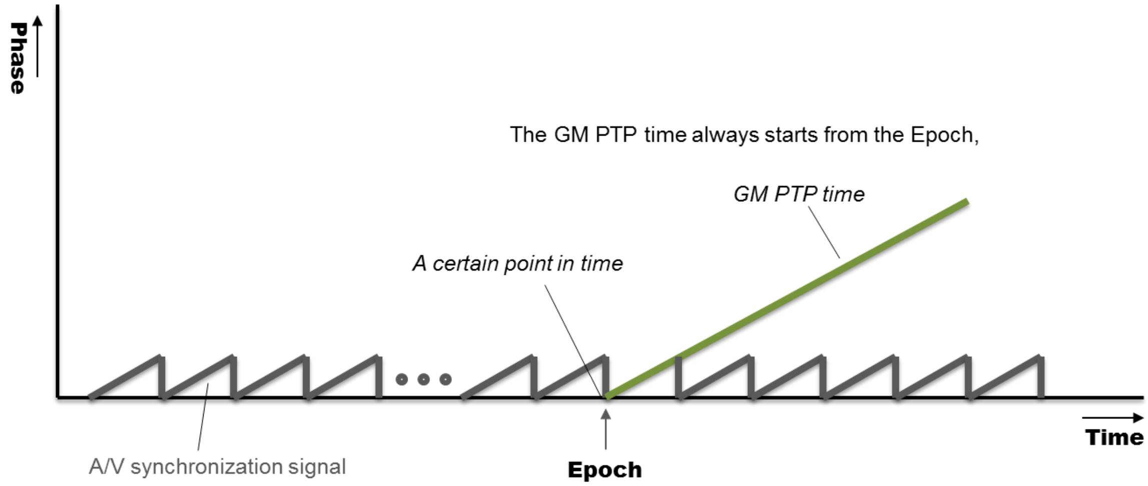

Figure 11 – Example of conversion from A/V synchronization signal to PTP time

If it is required to share real time, the configuration described in Section 5.4 'A/V Synchronization Signal + Non-Primary (or Primary) Reference Time' can be chosen.

5.4 A/V Synchronization Signal + Non-Primary (or Primary) Reference Time

Figure 12 illustrates an example of use case where a free-running legacy A/V synchronization signal and non-primary (or primary) reference time are used as a source of PTP time.

An A/V synchronization signal has its own inherent time period and is not necessarily Epoch aligned. On the other hand, non-primary (or primary) reference time increments monotonically from the Epoch.

The objective is to create the GM PTP time from which the identical AV synchronization signal can be reconstructed at a PTP slave together with approximately the correct time.

Figure 13 ‘Example of conversion from a combination of A/V sync signal and non-primary (or primary) reference time to PTP time’ illustrates the concept. There is an offset between the Epoch of the non-primary reference and Epoch, the phase zero point in time of an A/V synchronization signal which is the closest to the Epoch. The phase of the GM PTP time is set by shifting the non-primary reference by 'Offset' so that the A/V synchronization signal is Epoch aligned. This adjustment affects the PTP time accuracy which would be in error by up to +/- half the inherent time period of the A/V signal.

Non-primary (or primary) time can be replaced with SMPTE ST 12-1 Time Code embedded in the A/V synchronization signal.

Note: Even if primary reference time is used for this use case, the output PTP time from slaves is no longer primary reference time.

The frequency of the GM PTP time is synchronized to the A/V synchronization signal. Because the frequency of the A/V synchronization signal may be slightly different from that of the correct time period, it is possible that the GM PTP time will gradually deviate from the correct real time. For example, if the input video clock frequency is 1ppm different from the nominal frequency, the GM PTP time will deviate by 84ms in a day. Therefore, if the application requires the exact correct real time, it may be necessary to make occasional adjustments to either GM PTP time or slave non-primary reference time.

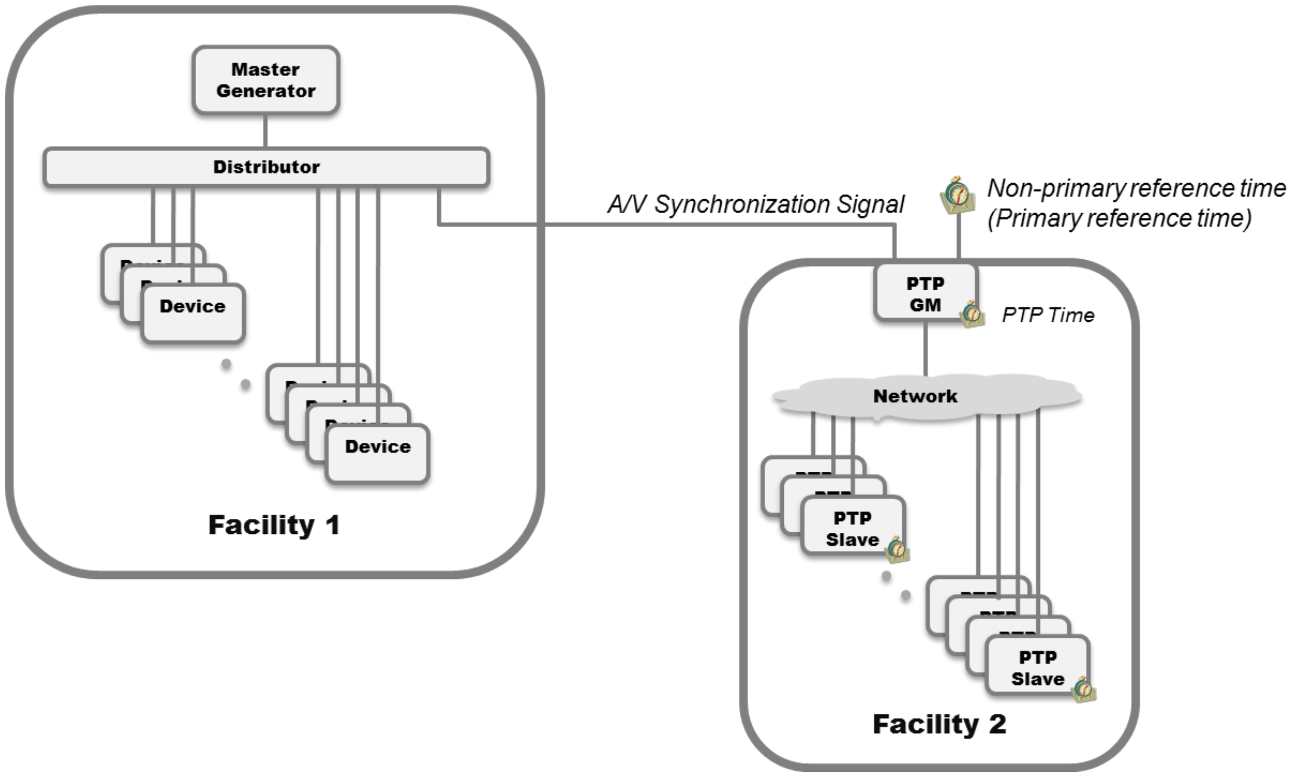

Figure 12 – Use Case where time source is A/V synchronization signal + Non-primary (primary) reference time

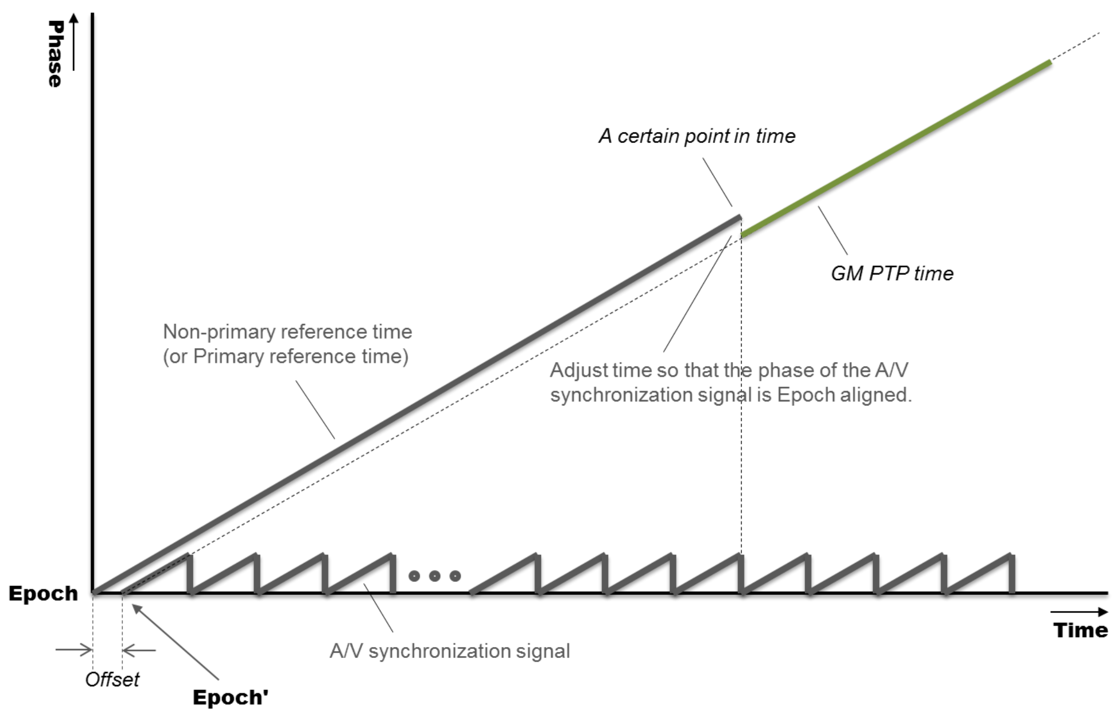

Figure 13 – Example of conversion from a combination of A/V sync signal and non-primary (or primary) reference time to PTP time

6 Synchronization Ecosystem

A simple system using only SMPTE ST 2059-based synchronization is described in Section 5. However, there may be cases where several different synchronization mechanisms are employed in a system.

This section describes use cases with multiple synchronization mechanisms.

1. System with legacy synchronization and ST 2059 PTP-based synchronization

This could be the case where it is wished to replace a small part of an established system based on a legacy synchronization signal such as black burst with SMPTE ST 2059 PTP-based synchronization.

Possible solutions are described in Section 5.3 (illustrated in Figure 10) and Section 5.4 (illustrated in Figure 12).

2. System with multiple PTP profiles

As described in Section 4, SMPTE ST 2059-2 is a PTP profile optimized for professional broadcast applications. However, other PTP profiles exist and the application scope of some might overlap with that of SMPTE ST 2059-2.

In particular, AES 67 is designed for synchronization of audio systems and is closely related to the scope of SMPTE ST 2059-2. For example, if both IP-mapped HD-SDI streams and IP-mapped audio streams are present in a system, there can be the following options in terms of their synchronization:

- Use both the SMPTE ST 2059-2 profile and the AES 67 profile with different PTP domains

PTP has a concept of 'domain' and PTP slaves are able to choose the relevant profile's PTP messages distinguished by PTP domain. If the messages of two PTP profiles are synchronized, two PTP slaves using the different PTP profiles will be synchronized to each other.

- Use a single PTP profile

As SMPTE ST 2059-2 conveys synchronization metadata using PTP Management messages that are not defined in AES 67, most probably SMPTE ST 2059-2 would be chosen.

In this case, audio devices would need to make use of the SMPTE ST 2059-2 profile for their synchronization. In order to make this possible, only PTP attribute values common between SMPTE ST 2059-2 and AES 67 can be used.

7 SMPTE ST 12-1 Time Code Generation

In addition to generating an A/V synchronization signal, SMPTE ST 12-1 Time Code can also be generated from PTP time. The PTP master sends a Management Message periodically which contains Synchronization Metadata. This metadata can be used by PTP slaves when generating time-of-day SMPTE ST 12-1 Time Code.

In current conventional operational practice, SMPTE ST 12-1 Time Code is distributed to each device from a central Time Code generator. The biggest change in the new scheme is that SMPTE ST 12-1 Time Code has to be generated by each individual PTP slave using PTP time provided by the PTP master, and this has to be achieved and maintained deterministically whenever a slave connects to the network. PTP slaves also have to be able to support user configured Daily Jam where this is in use.

Note: The Daily Jam is an optional daily procedure carried out within a facility that uses SMPTE ST 12-1 time code in which the time address value is adjusted to correspond to Local Time at the chosen time of the Daily Jam. It is usually carried out in the early hours of the morning at a non-sensitive time as determined by the operator of the facility.

For details, see SMPTE ST 2059-1 and SMPTE ST 2059-2.

Annex A Bibliography (Informative)

IEEE Std 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

SMPTE ST 2059-1:2015, Generation and Alignment of Interface Signals to the SMPTE Epoch

SMPTE ST 2059-2:2015, SMPTE Profile for use of IEEE-1588 Precision Time Protocol in Professional Broadcast Applications