Video Services Forum (VSF) Technical Recommendation TR-10-1

Internet Protocol Media Experience (IPMX): System Timing and Definitions

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TR-10-1:2022

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Executive Summary

Internet Protocol Media Experience (IPMX) was created to foster the adoption of open standards-based protocols for interoperability over IP in the media and entertainment and professional audio/video industries. IPMX is based on the SMPTE ST 2110 standard and as such the VSF TR-10 suite of technical recommendations is a set of differences between SMPTE ST 2110 and IPMX.

The VSF TR-10-1 document corresponds to the SMPTE ST 2110-10 document and describes the System Timing used in IPMX. It also defines basic terms used in the IPMX TR-10 family of recommendations. Some of the subject covered in this document include how IPMX supports asynchronous media sources, the IPMX traffic shaping model, and how IPMX works in networks where PTP is not present.

Table of Contents

1 Introduction (Informative)

IPMX, which stands for IP Media Experience, is based on two families of specifications. The SMPTE ST 2110 Professional Media Over Managed IP Networks suite of standards for the transport of video, audio, and ancillary/control signals over IP networks, and the NMOS REST APIs from AMWA, which provide discovery, connection management, and control.

IPMX is an accessible, open standard that meets the needs of professional and consumer video and audio users in a wide variety of contexts while giving manufacturers and developers what they need to build low-latency, interoperable, IP based audiovisual products or applications.

This document covers the IPMX system timing requirements across all essence types, and defines a set of common terms. Other parts of the TR-10 Technical Recommendation describe IPMX individual media essence types, along with their requirements, and defines other aspects of the IPMX system.

1.1 Important Differences In Timing Requirements Between IPMX Facilities and SMPTE ST 2110 Facilities

While this Technical Recommendation relies heavily on the SMPTE ST 2110 Standard, this document defines important differences related to timing requirements. Readers of this document may wish to consult Appendix A to gain a better understanding of the implications of these differences in IPMX facilities.

1.2 Contributors

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1.3 About the Video Services Forum

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Normative text describes elements of the design that are indispensable or contain the conformance language keywords: "shall," "should," or "may."

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All text in this document is, by default, normative, except the Introduction and any section explicitly labeled as "Informative" or individual paragraphs that start with "Note:"

The keywords "shall" and "shall not" indicate requirements strictly to be followed to conform to the document and from which no deviation is permitted.

The keywords "should" and "should not" indicate that, among several possibilities, one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required; or that (in the negative form) a certain possibility or course of action is deprecated but not prohibited.

The keywords "may" and "need not" indicate courses of action permissible within the limits of the document.

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Unless otherwise specified, the order of precedence of the types of normative information in this document shall be as follows: Normative prose shall be the authoritative definition; Tables shall be next; followed by formal languages; then figures; and then any other language forms.

3 Normative References

- 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
- SMPTE ST 2110-10:2017 Professional Media over Managed IP Networks: System Timing and Definitions
- SMPTE ST 2110-21:2017 Professional Media over Managed IP Networks: Traffic Shaping and Delivery Timing for Video
- AMWA NMOS IS-04 version 1.3 (Stable) - NMOS Discover and Registration Specification
- AMWA NMOS IS-05 version 1.1 (Stable) - NMOS Device Connection Management Specification
- IEEE 1588-2008 Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- AES67-R16-2016 “AES Standards Report - PTP parameters for AES67 and SMPTE ST 2059-2 interoperability”
- Internet Engineering Task Force (IETF) RFC 3550 RTP: A Transport Protocol for Real-Time Applications [online, viewed 2017-08-10] Available at https://www.ietf.org/rfc/rfc3550.txt
- Internet Engineering Task Force (IETF) RFC 7273 RTP clock Source Signaling [online, viewed 2017-08-10] Available at https://www.ietf.org/rfc/rfc7273.txt
- Video Services Forum (VSF) TR-10-8 Internet Protocol Media Experience (IPMX) NMOS Requirements
- Internet Engineering Task Force (IETF) RFC 8877 Guidelines for Defining Packet Timestamps [online] Available at https://www.ietf.org/rfc/rfc8877.txt

4 Definitions

Async Media	Audio or video baseband media signals that are not frequency or phase aligned to the Common Reference Clock.
Common Reference Clock	Clock that counts time and that all IPMX Devices in the system are able to access.
Internal Clock	Clock internal to a device that can be synchronized to the Common Reference Clock.
IPMX Capture Device	IPMX Sender that digitizes an analog signal and converts it to a IPMX network stream.
IPMX Device	Device that includes one or more IPMX Senders, IPMX Receivers or both.
IMPX Gateway	IPMX Sender that converts the baseband signal from a Source Media Device into an IMPX network stream
IPMX Inline Processor	Combines an IPMX Receiver and Sender in such a way that the signal received by the IPMX Receiver is re-transmitted by the IPMX Sender of the IPMX Device.
IPMX Receiver	A NMOS Receiver that consumes an IPMX network media stream.
IPMX Sender	A NMOS Sender that produces an IPMX network media stream.
Media Clock	Timebase related to the sampling rate (or frame rate in the case of video) of the media within the stream, with a source specified by the **`mediaclk`** attribute in the SDP, used to advance the RTP Clock
Playout Time	The time at which a Sink Media Device will output a given signal.
RTP Clock	Counter advanced by the Media Clock at the rate specified for the media type, and which is sampled to determine the timestamps included in RTP packets
Sink Media Device	Physical device that consumes a baseband media signal, typically by way of HDMI, SDI, AES3 or similar connections. Video displays, DVRs and speakers are examples of such devices.
Source Media Device	Physical device that produces a baseband media signal, typically by way of HDMI, SDI, AES3 or similar connections. Examples of such

devices are cameras, DVD players, computer graphic output signal, Blu-Ray player, audio mixing console, MP3 player etc.

Sync Media	Audio or video baseband media signals that are frequency and phase aligned to the Common Reference Clock.
Synthetic IMPX Sender	IPMX Sender that internally generates a IPMX network stream. Pattern generator and playout servers are examples of Synthetic Sources.

5 IPMX System Timing

IPMX Devices shall be able to operate in both networks that have a Common Reference Clock available and in networks that do not have a Common Reference Clock, as described in this section.

5.1 Networks without a Common Reference Clock

IPMX devices acting as IPMX Senders shall maintain an Internal Clock.

When a Common Reference Clock is not present on the network, IPMX devices shall signal the use of this Internal Clock as a reference clock as described in section 8.2 below.

5.2 Network with a Common Reference Clock

IPMX Devices shall use the Common Reference Clock distributed to all participating IPMX Devices via IEEE Std 1588-2008 (PTPv2) when such a clock is present on the network.

The IPMX Device Internal Clock shall be synchronized to the Common Reference Clock.

IPMX devices acting as IPMX Senders shall signal the use of the Common Reference Clock as a reference clock as described in section 8.2 below.

IPMX Devices shall implement the best master clock algorithm as defined in IEEE Std 1588-2008.

IPMX Devices, including those that are able to become a PTP leader, shall default to follower-only mode (`defaultDS.slaveOnly` set to `TRUE`).

For those IPMX Devices that can become a PTP Leader, a method shall be provided for a user to change the value of `defaultDS.slaveOnly`.

IPMX Devices should implement a PTP Leader that can be elected to serve as a grandmaster via the best master clock algorithm. There is no requirement for the grandmaster to be locked to the SI second. There is no requirement for traceability. The frequency accuracy of the grandmaster shall be better than 100 ppm.

All IPMX Devices that can become the PTP leader shall be constrained by the PTP operating parameters defined in ST 2059-2 and AES-R16-2016 (per Section 5.3.2). The default PTP attribute values shall be set according to ST 2059-2 except for logMinDelayReqInterval that shall default to a value of (logSyncInterval + 5).

`Note: This value reduces the amount of traffic on the network and the workload on the leader.`

IPMX Devices that are followers shall not assume the value of `logMinDelayReqInterval` to be `logSyncInterval + 5`.

IPMX Devices that are followers shall operate properly over the full range of `LogMinDelayReqInterval` specified in ST 2059-2.

6 IPMX Sender Timing

6.1 Transmission Traffic Shape Models

The traffic shaping and delivery timing of IPMX media streams that carry video signals shall be in accordance with the Network Compatibility Model (C_{INST} and C_{MAX}) compliance definitions specified in ST 2110-21.

The value of C_{MAX} for IPMX Video Sender shall be:

$C_{MAX} = MAX (16, INT (N_{PACKETS}/(21600 \times T_{FRAME})))$,

Where $N_{PACKETS}$ is equal to the total number of packets per frame, and T_{FRAME} is the time period between consecutive frames of video.

Note: The C_{MAX} value above was chosen to correspond to the ST 2110-21 Type W sender Network Compatibility Model. The C_{MAX} value above represents the maximum allowed value for an IPMX Sender. An IPMX Sender may choose to support a C_{MAX} that corresponds to ST 2110-21 Type N to provide wider interoperability and support ST 2110-21 Type N receivers.

IPMX Senders shall follow the ST 2110-21 Virtual Receiver Buffer Model compliance definitions, with the following exceptions:

- The VRX_{FULL} bucket starts to drain once $VRX_{FULL}/2$ packets have been received.
- The VRX_{FULL} bucket drains packets at an average rate according to the following equation:
    - Rate = number of packets per frame/((height / vtotal)* T_{FRAME})

Where height is the total number of lines in the active picture portion of the video frame, where vtotal is total number of lines in the video frame, including all active and blanking periods and where T_{FRAME} is as defined for the C_{MAX} equation above.

- VRX_{FULL} bucket has a size of Cmax*2

6.2 Source Media Device Timing

IPMX devices shall support Source Media Devices that produce Async Media signals and Sync Media signals.

6.3 Media Clock Timing

The Media Clock of an IPMX Gateway shall be frequency locked to the sampling rate (or frame rate in the case of video and ancillary) of the baseband media signal from the Source Media Device.

`Note: In the case of an Async Media signal, the Media Clock and RTP Clock will be synchronous with the Media signal. They will not be synchronous with the Internal Clock.`

6.4 RTP Timestamp General Provision

RTP timestamps for IPMX RTP Streams shall be compliant with SMPTE ST 2110-10, subject to the additional provisions in this document.

6.5 Initial Value Of RTP Clock

When the first RTP timestamp of an IPMX network media stream is sampled, the RTP Clock of the IPMX Sender shall be synchronized with the Internal Clock.

`Note: In the case of Async Media signals, although the RTP Clock is asynchronous with respect to the Internal Clock, this initial value will result in an initial RTP Timestamp that is compatible with SMPTE ST 2110-10.`

`Note: In the case of Sync Media signals, this initial value will result in RTP Timestamps that are compatible with SMPTE ST 2110-10.`

6.6 RTCP Sender Report General Provision

IPMX Senders that have a Media Clock that is asynchronous with respect to the Internal Clock, shall send RTCP Sender Report packets as per IETF RFC 3550 section 6.4.1.

RTCP Sender Report packets shall be sent to the same address as their corresponding media payload.

RTCP Sender Report packets shall be sent to the port that corresponds to +1 from the port used by their corresponding media payload.

RTCP Sender Report packets shall be sent according to the schedule outlined in the respective media format sections of this document.

The reception report count (RC) field of the RTCP Sender Report packet should be 0.

The NTP timestamp field of the RTCP Sender Report packets shall be filled using the value of the Internal Clock, reflected in seconds and nanoseconds, that matches the RTP timestamp in the RTCP Sender Report. The PTP Truncated Timestamp Format from RFC 8877 section 4.3 shall be used for filling the NTP field.

IPMX Receivers shall tolerate the presence of other RTCP packets described in IETF RFC 3550 section 6.

```
Note: Only RTCP Sender Reports are required, other parts of the RTCP protocol
are optional.
```

6.7 IPMX Video Sender

6.7.1 Video RTP Clock Sampling

The value of the video RTP Clock shall be sampled at the start of the VSYNC of the baseband video frame or field it is associated with to generate the RTP Timestamp.

Video IPMX Senders that do not derive their video RTP timestamp from a baseband signal shall generate their RTP timestamp as specified in SMPTE ST 2110-10.

6.7.2 Video RTCP Sender Report schedule

When required as per section 6.6, RTCP Sender Reports shall be sent once per frame if the video is progressive, or once per field if the video is interlaced.

The RTP timestamp in the RTCP Sender Report shall match the timestamp used for the corresponding frame or field.

The RTCP Sender Report shall be sent before the first packet of the associated frame or field.

6.8 IPMX Ancillary Sender

6.8.1 Ancillary RTP Clock Sampling

The value of the ancillary RTP Clock shall be sampled at the start of the VSYNC of the baseband video frame or field it is associated with to generate the RTP Timestamp.

6.8.2 Ancillary RTCP Sender Report

When required as per section 6.6, RTCP Sender Reports shall be sent every time a new ancillary RTP timestamp is sampled from the ancillary RTP Clock.

The RTCP Sender Report shall correspond to this RTP timestamp and shall be sent before the first packet containing the associated timestamp.

6.9 IPMX Audio Sender

6.9.1 Audio RTCP Sender Report

When required as per section 6.6, RTCP Sender Reports shall be sent every 10 msec, aligned to correspond with the time a new audio RTP timestamp is sampled from the audio RTP Clock.

The RTCP Sender Report shall correspond to this RTP timestamp and shall be sent before the packet containing the associated RTP timestamp.

7 IPMX Inline Processor Timing

The output stream of the IPMX Inline Processor shall, by default, preserve the original timing of the input stream of the IPMX Inline Processor. In this manner, the output of an IPMX Inline Processor can be re-aligned with other streams that share the same time domain as the original input stream.

If the IPMX Inline Processor also supports generating new timestamps, it may allow the user to override the default behavior.

When the timing of the original input stream is not preserved, the device is considered to be an IPMX Sender, and the timing of the output stream shall follow the guidelines of the IPMX Sender Timing in Section 6 of this document.

8 SDP Signaling General Provision

IPMX Senders shall provide an SDP file for parameter signaling as per the SMPTE ST 2110 standards suite as they apply to each specific media format and subject to the constraints in this document.

IPMX Senders shall make their SDP file available through the method described in TR-10-8.

8.1 IPMX Sender Signaling

IPMX Senders shall include the "`IPMX`" declaration in the `a=fmtp` clause of the SDP file.

```
Note: The following is an example of an SDP file for an audio IPMX Sender
with 8 channels at 48Khz with a packet time of 125 µsec.
```

```
v=0
o=- 1618348182647029200 1618348303876470900 IN IP4 25.25.30.151
s=IP audio OUT 1
t=0 0
m=audio 10000 RTP/AVP 97
c=IN IP4 239.30.0.1/128
a=source-filter: incl IN IP4 239.30.0.1 25.25.30.151
a=rtpmap:97 L24/48000/8
a=fmtp:97 channel-order=SMPTE2110.(U08); IPMX
a=ts-refclk:localmac=00-20-FC-32-2F-40
a=ptime:0.12
a=mediaclk:direct=0
```

8.2 Common Reference Clock Signaling

All IPMX Senders shall signal their reference clock as described in ST 2110-10.

8.3 Media Clock Signaling

All IPMX Senders shall signal the relationship of their Media Clock with respect to their Internal Clock using the `mediaclk` attribute as per IETF RFC 7273 section 5.

If the Media Clock is directly derived from the Internal Clock, the direct reference shall be used and the offset of ‘0’ shall be included. For example:

a=mediaclk:direct=0

If the Media Clock is asynchronous with respect to the Internal Clock, for example if Async Media is present at the input of a Sender, the following form shall be used:

a=mediaclk:sender

8.4 Video Gateway Signaling

A video Gateway IPMX Sender shall report the measured frequency of the pixel clock, total number of horizontal pixels and total number of lines of the Source Media Device signal by setting the parameters as described in this section.

A video Gateway IPMX sender shall include the `measuredpixclk` , `vtotal` and `htotal` parameters in the `a=fmtp` clause of the SDP file that correspond to the signal from the Media Source Device where;

1. `measuredpixclk` reports the pixel clock in Hertz, of the Source Media Device with a max tolerance of 150ppm with respect to the actual pixel clock value
2. `vtotal` specifies the total number of lines in the video frame (2 fields for interlaced), including all active and blanking periods.

3. `htotal` specifies the total number of luminance sample periods per video line, including all active and blanking periods.

Note: These parameters are designed to help the IPMX receiver select an appropriate initial operating point when trying to produce an output signal that matches the IPMX sender signal.

Note: The following is an example of an SDP file for a video Gateway IPMX Sender for a 1080p59.94, YUV 422 10 bits signal and that has a C_{MAX} that corresponds to Type N sender.

```
v=0
o=- 1618351493884125000 1618351539175204201 IN IP4 25.25.30.151
s=IP video OUT 1
t=0 0
m=video 10000 RTP/AVP 96
c=IN IP4 239.20.0.1/128
a=source-filter: incl IN IP4 239.20.0.1 25.25.30.151
a=rtpmap:96 raw/90000
a=fmtp:96 sampling=YCbCr-4:2:2; width=1920; height=1080;
exactframerate=60000/1001; depth=10; TCS=SDR; colorimetry=BT709;
PM=2110GPM; SSN=ST2110-20:2017; TP=2110TPN; IPMX;
measuredpixclk=1485501040; vtotal=1125; htotal=2200
a=ts-refclk:localmac=00-20-FC-32-2F-40
a=mediaclk:direct=0
```

8.5 IPMX Receiver Timing

8.5.1 Recovery of Sender signal timing

All IPMX Receivers should recover the Async signal timing and produce an output signal that is frequency locked to the IPMX Sender.

8.5.2 Link Offset Delay attribute

The Link Offset Delay (D_{LO}) described in ST 2110-10:2021 is an attribute used to synchronize the Playout Time of all components of a stream by IPMX Receivers. For Receivers, a packet j with an RTP timestamp value equivalent to time $T_{RTP(j)}$ is said to be Reconstructed when the media is reconstituted from the received packet and thus available for further use.

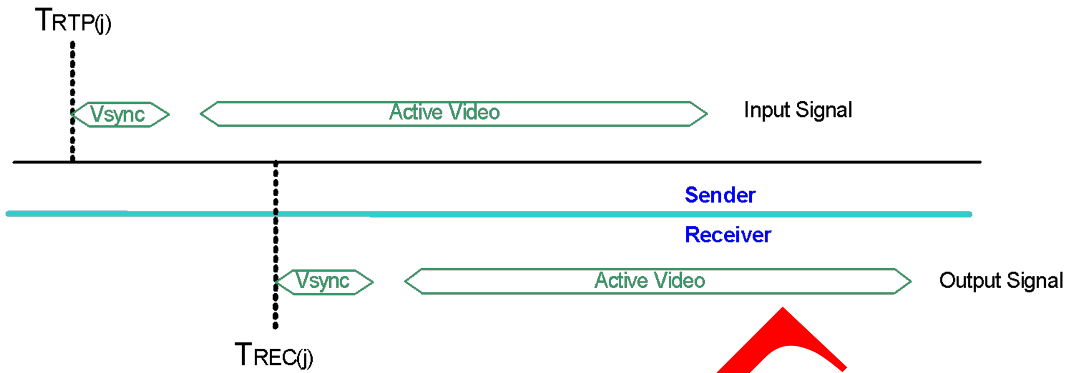

Figure 1 – $T_{REC(j)}$ vs $T_{RTP(j)}$

Figure 1 illustrates the relationship between $T_{REC(j)}$ and $T_{RTP(j)}$ for a Video Sender with a RTP timestamp that corresponds to the start of VSYNC.

Let time $T_{REC(j)}$ indicate the time that packet j is reconstructed. Where multiple packets have the same RTP timestamp e.g. in the case of video, the expressions below apply to the first packet with that RTP timestamp.

D_{LO} shall be set to the offset in time, specified in microseconds (µs), between $T_{RTP(j)}$ and $T_{REC(j)}$ such that $T_{REC(j)} = T_{RTP(j)} + D_{LO}$.

An IMPX Receiver shall support the Link Offset Delay attribute.

An IPMX Receiver shall provide control for the Link Offset Delay attribute through AMWA NMOS IS-05. VSF TR-10-8 documents the relevant implementation details and requirements.

Note: An IPMX Receiver can determine $T_{RTP(j)}$ by examining the RTP timestamp of the incoming stream and the accompanying RTCP Sender Reports.

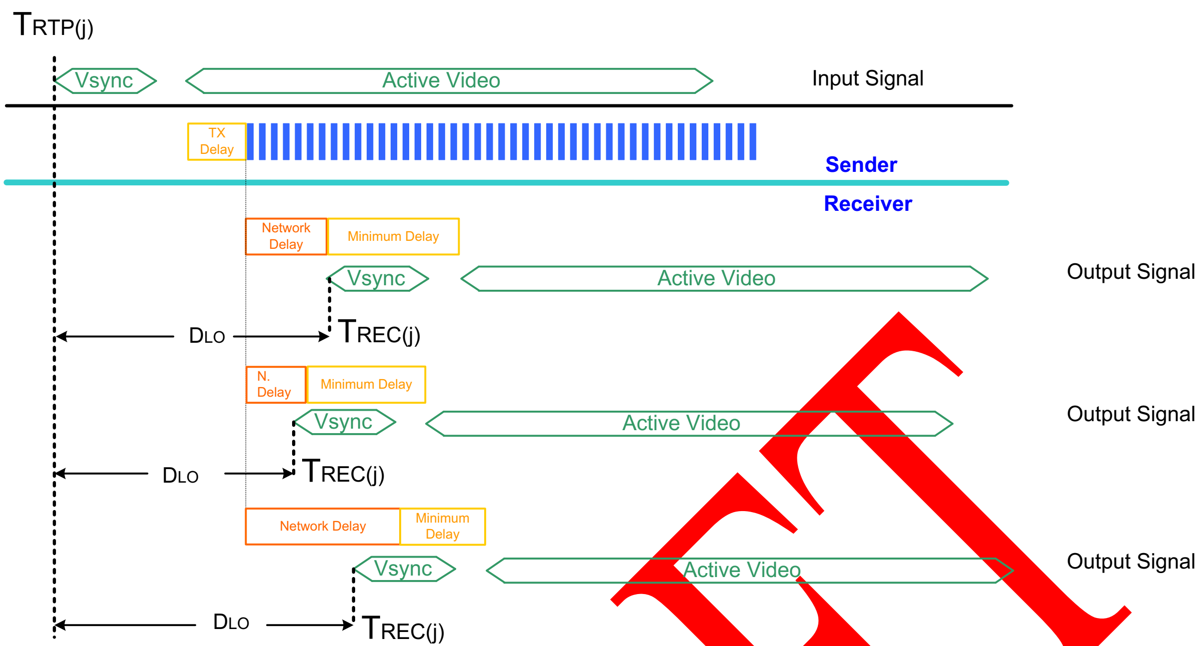

Figure 2 – D_{LO} example

The example of Link Offset Delay illustrated in Figure 2, shows the earliest moment that three video IPMX Receivers, experiencing different network latencies, and having different minimal internal delays, could present a signal on their respective outputs. In the diagram, the TX Delay is the delay between sampling a pixel and transmitting it on the network.

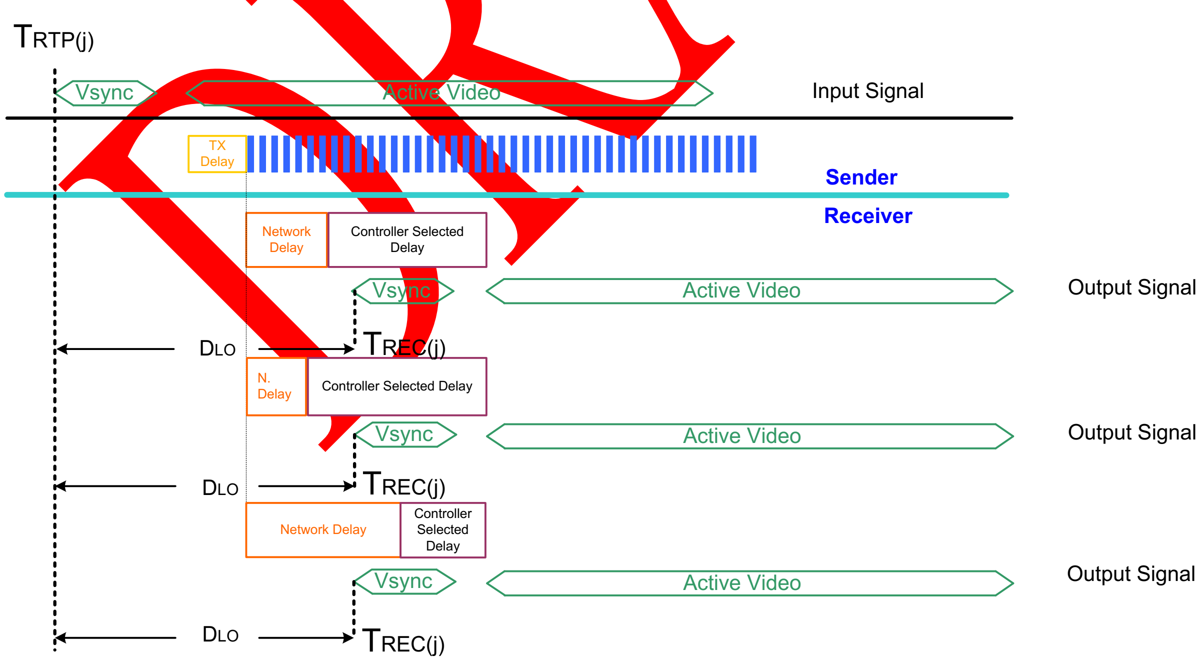

Figure 3 – Alignment of receiver Playout Time using D_{LO}

The example illustrated in Figure 3, shows how Link Delay Offset can be used for coordinating the Playout Time of three different video IPMX Receivers. In this example, the IPMX Receivers are listening to the same Sender but experience different network latencies and have different minimum internal delays. A value for Link Delay Offset that compensates for these variations for each receiver has been programmed into each IPMX Receiver. In the diagram, the TX Delay is the delay between sampling a pixel and transmitting it on the network.

9 Appendix A (Informative)

Based on the broadcast oriented SMPTE ST 2110 suite of standards, the IPMX Specification adds specific extensions targeted at the ProAV industry. The goal is to enable a broader range of infrastructure choices to reduce cost while also providing for simpler installation and lower configuration complexity. Within the scope of IPMX, a system designer may create a range of systems with various complexity. A high-end system might employ a redundant network topology using a broadcast style SMPTE ST 2059 PTP grandmaster which synchronizes uncompressed flows. A simpler system might have no PTP grandmaster using compressed flows on a 1G network infrastructure. There are countless variations in between.

One item that has a large impact on the reduction of system cost is the relaxation of the ST 2110-21 timing specification as it relates to IPMX Sender and Receiver requirements. For instance, the IPMX Sender employs the Wide Network Compatibility Model. The Network Compatibility Model limits the maximum packet burst size (C_{MAX}) in order to avoid overflowing the internal memory of IP switches. The Wide model is more forgiving compared to the narrow model commonly used in ST 2110-21, enabling the sender to be more bursty while still preventing switch overflow.

The IPMX Sender must send packets at a sufficient rate to ensure the receiver buffer will not underflow. The method used in ST 2110 is intended for synchronous sources and does not work well for asynchronous sources. Like SMPTE ST 2110, IPMX uses a virtual receiver buffer model (VRX) to describe when and at what rate a receiver is expected to empty the receiver buffer. The parameters for the VRX model are different in IPMX. An IPMX Receiver will not start emptying its buffer until it is half full. This enables the IPMX Sender to have flexibility in the time when it begins sending its packets.

For the Receiver, the value of VRX_{FULL} (receiver buffer size) in IPMX is specified as a much lower number than is typically required for wide receivers, to enable inexpensive IPMX Receiver implementations. In uncompressed 1.5G HD for example, an ST 2110 VRX_{FULL} would be 720 packets whereas in IPMX, its value is $C_{MAX} * 2$, typically 32 packets.

IPMX Receivers need not support ST 2110-21 linear senders, which reduces the cost of implementation as well as reducing system latency. For the lowest latency possible, generation of the output stream must start as soon as possible, so a gapped read schedule is employed in IPMX. SMPTE ST 2110-21 Linear senders would require additional buffering and result in higher latency.

It is important to note that even though IPMX is based on ST 2110, it is not the goal of IPMX to guarantee that compliance to the IPMX Timing spec will result in interoperability with ST 2110 devices. Keen observers will note that an IPMX Receiver is capable of receiving an ST 2110 narrow flow. An IPMX Receiver with a sufficiently large receiver buffer (at least matching the requirement for VRX_{FULL} from ST 2110) is capable of receiving any ST 2110 compliant flow.

Although it is not the subject of this document, it is important to note that IPMX also supports payload compression. This reduces traffic shaping complexity for software implementations of IPMX Senders by reducing the total amount of data transmitted.

For example, a 2160p60 video in uncompressed exceeds 10Gbits/s with about 15,710 packets per frame (assuming a 1320 byte packet size and the short HDCP RTP header extension). Using compression, the same flow fits on a 1GbE link using a 13:1 compression ratio (assuming an RGB 24 bpp source and a 1320 byte packet size). For the uncompressed case, the normal packet pacing interval is about 1us resulting in a wide sender using C_{MAX} bursts every 16us resulting in about 982 transactions per frame. The compressed version generates about 1414 packets per frame and has a packet pacing interval of about 11.3us resulting in a wide sender using C_{MAX} bursts every 181us. This results in a more reasonable 88 transactions per frame.

IPMX requires that devices synchronize their internal clock to the SMPTE ST 2059 PTP grandmaster when present on the network. This enables compatibility between IPMX and ST 2110 professional broadcast media networks. The clock tracking accuracy that the IPMX timing spec targets is not as stringent as the SMPTE ST 2110 broadcast timing requirement. IPMX does not mandate that the clock of the grandmaster be traceable and the tolerance requirements for the local oscillator are selected to enable less expensive implementations. To reduce the need for PTP aware network switches, the default profile for PTP in IPMX (MinDelayReqInterval) is chosen to help reduce both the traffic on the network and the load on the PTP grandmaster. IPMX also provides a timing mechanism that enables IPMX Senders and Receivers to operate normally in the absence of a PTP grandmaster.

IPMX enables multiple IPMX Receivers that are displaying content from the same IPMX Sender to have similar Playout Time with the use of the Link Offset Delay attribute. A system designer may decide to include a PTP grandmaster to achieve perfect Playout Time synchronization. However, there are workflows that do not require this level of synchronization and a system designer might choose not to include a PTP grandmaster to reduce network complexity and cost.

In ST 2110 and IPMX, timestamps are used to align various flows. When an IPMX Sender generates multiple flows and there is no PTP grandmaster, the relationship of the timestamps to the IPMX Sender' Internal Clock is signaled through RTCP Sender Reports. Using this information an IPMX Receiver does not need a Common Reference Clock to properly align flows from the same Sender. However, a Common Reference Clock is required to accurately re-align flows that come from different IPMX Senders.

It should be noted that IPMX devices default to follower-only mode, and user intervention is required to make them a PTP Leader to prevent multiple PTP grandmasters.

10 Annex B Bibliography (Informative)

NIST Special Publication 330, 2008 Edition, The International System of Units (SI), Barry N. Taylor and Ambler Thompson, Editors