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

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

April 14, 2023

DRAFT

INTELLECTUAL PROPERTY RIGHTS

RECIPIENTS OF THIS DOCUMENT ARE REQUESTED TO SUBMIT, WITH THEIR COMMENTS, NOTIFICATION OF ANY RELEVANT PATENT CLAIMS OR OTHER INTELLECTUAL PROPERTY RIGHTS OF WHICH THEY MAY BE AWARE THAT MIGHT BE INFRINGED BY ANY IMPLEMENTATION OF THE RECOMMENDATION SET FORTH IN THIS DOCUMENT, AND TO PROVIDE SUPPORTING DOCUMENTATION.

THIS RECOMMENDATION IS BEING OFFERED WITHOUT ANY WARRANTY WHATSOEVER, AND IN PARTICULAR, ANY WARRANTY OF NONINFRINGEMENT IS EXPRESSLY DISCLAIMED. ANY USE OF THIS RECOMMENDATION SHALL BE MADE ENTIRELY AT THE IMPLEMENTER'S OWN RISK, AND NEITHER THE FORUM, NOR ANY OF ITS MEMBERS OR SUBMITTERS, SHALL HAVE ANY LIABILITY WHATSOEVER TO ANY MPLEMENTER OR THIRD PARTY FOR ANY DAMAGES OF ANY NATURE WHATSOEVER, DIRECTLY OR INDIRECTLY, ARISING FROM THE USE OF THIS RECOMMENDATION.

LIMITATION OF LIABILITY

VSF SHALL NOT BE LIABLE FOR ANY AND ALL DAMAGES, DIRECT OR INDIRECT, ARISING FROM OR RELATING TO ANY USE OF THE CONTENTS CONTAINED HEREIN, INCLUDING WITHOUT LIMITATION ANY AND ALL INDIRECT, SPECIAL, INCIDENTAL OR CONSEQUENTIAL DAMAGES (INCLUDING DAMAGES FOR LOSS OF BUSINESS, LOSS OF PROFITS, LITIGATION, OR THE LIKE), WHETHER BASED UPON BREACH OF CONTRACT, BREACH OF WARRANTY, TORT (INCLUDING NEGLIGENCE), PRODUCT LIABILITY OR OTHERWISE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. THE FOREGOING NEGATION OF DAMAGES IS A FUNDAMENTAL ELEMENT OF THE USE OF THE CONTENTS HEREOF, AND THESE CONTENTS WOULD NOT BE PUBLISHED BY VSF WITHOUT SUCH LIMITATIONS.

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 (TR) 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 supports networks where PTP is present and in network 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 family of Technical Recommendation (TRs) 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.

2 Contributors

The following individuals participated in the Video Services Forum IPMX working group that developed this technical recommendation.

Aaron Doughten (Sencore)	Charles Buysschaert (Intopix)	Jean-Baptiste Lorent (IntoPIX)	Phil Nguyen (Nextera)
Alain Bouchard (Matrox)	Chris Lapp (Cisco)	Jed Deame (Nextera Video)	Prinyar Boon (Phabrix)
Albert Faust (Arista)	Clark Williams (Christie Digital)	JJ Eynon (CNN)	Raul Diaz (Intel)
Andre Testa (Matrox)	Daniel BOUQUET (Analogway)	John Belstner (Intel)	Raymond Hermans (Adeas)
Andreas Hildebrand (ALC NetworX)	Danny Pierini (Matrox)	John Dale (Media Links)	Robert Welch (Arista)
Andrew Starks (Macnica)	David Chiappini (Matrox)	John Fletcher (BBC)	Ron Stites (Macnica)
Antoine Hermans (Adeas)	David Mitchinson (Appear TV)	Karl Johnson (Christie Digital)	Tadahiro Watanabe (Macnica)
Arnaud Germain (Intopix)	Gerard Phillips (Arista)	Karl Paulsen (Diversified)	Teiji Kubota (Macnica)
Ben Cope (Intel)	Greg Schlechter (Intel)	Marc Levy (Macnica)	Thomas True (NVIDIA)
Brad Gilmer (VSF)	Greg Stigall (Warner Media)	Mike Boucke (AJA)	Tim Bruylants (intopix)
Bob Ruhl (VSF)	Jack Douglass (PacketStorm)	Paulo Francisco (Evertz)	Wes Simpson (LearnIPvideo)
Cassidy Phillips (Imagine)	Jean Lapierre (Matrox)	Peter Brightwell (BBC)	

3 About the Video Services Forum

The Video Services Forum, Inc. (www.videoservicesforum.org) is an international association dedicated to video transport technologies, interoperability, quality metrics and education. The VSF is composed of service providers, users and manufacturers. The organization's activities include:

- providing forums to identify issues involving the development, engineering, installation, testing and maintenance of audio and video services;
- exchanging non-proprietary information to promote the development of video transport service technology and to foster resolution of issues common to the video services industry;
- identification of video services applications and educational services utilizing video transport services;
- promoting interoperability and encouraging technical standards for national and international standards bodies.

The VSF is an association incorporated under the Not For Profit Corporation Law of the State of New York. Membership is open to businesses, public sector organizations and individuals worldwide. For more information on the Video Services Forum or this document, please call +1 929-279-1995 or e-mail opsmgr@videoservicesforum.org.

4 Conformance Notation

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

Informative text is potentially helpful to the user but not indispensable and can be removed, changed, or added editorially without affecting interoperability. Informative text does not contain any conformance keywords.

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.

The keyword "reserved" indicates a provision that is not defined at this time, shall not be used, and may be defined in the future. The keyword "forbidden" indicates "reserved" and in addition indicates that the provision will never be defined in the future.

A conformant implementation according to this document is one that includes all mandatory provisions ("shall") and, if implemented, all recommended provisions ("should") as described. A conformant implementation need not implement optional provisions ("may") and need not implement them as described.

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.

5 Normative References

- SMPTE ST 2059-2:2021 Profile for Use of IEEE-1588 Precision Time Protocol in Professional Broadcast Applications
- SMPTE ST 2110-10:2022 Professional Media over Managed IP Networks: System Timing and Definitions
- SMPTE ST 2110-21:2022 Professional Media over Managed IP Networks: Traffic Shaping and Delivery Timing for Video

- 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

6 Definitions

Async Media	Audio or video Baseband media signals that are not frequency or phase aligned to the Common Reference Clock.
Baseband	A media signal that is not IP-based, i.e., one that is transported over a physical interface such as analog audio, analog video, HDBaseT, HDMI, SDI, AES3 or similar connections.
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 Device	Device that includes one or more IPMX Senders, IPMX Receivers or both.
IPMX Info Block	A RTCP Sender Report extension that provides a description of the media stream that is associated with a RTCP Sender Report.
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	Element within a IPMX Device which terminates one IPMX RTP stream (or a redundant pair of streams) from the network.
IPMX Sender	Element within a IPMX Device which originates one IPMX RTP stream (or a redundant pair of streams) into the network.
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.

Media Info Block	Section of a IPMX Info Block that contains the attributes that are specific to the media stream that is associated with a RTCP Sender Report.
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.

7 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.

7.1 Networks without a Common Reference Clock

When a Common Reference Clock is not present on the network, IPMX Devices acting as IPMX Senders shall maintain a free running Internal Clock.

7.2 Network with a Common Reference Clock

IPMX Senders 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 Internal Clock of IPMX Senders shall be synchronized to the Common Reference Clock.

IPMX Devices shall implement the best master clock algorithm (BMCA) as specified in ST 2059-2 section 6.2.

IPMX Devices, including those that are able to become a PTP leader, shall default to follower-only mode by setting the value `defaultDS.slaveOnly` as defined in ST 2059-2 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` defined in ST 2059-2.

IPMX Devices should implement a PTP Leader that can be elected to serve as a grandmaster via the best master clock algorithm (BMCA) as specified in ST 2059-2 section 6.2. There is no requirement for the grandmaster to be locked to the International System of Units 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` specified in ST 2059-2 to be `logSyncInterval + 5`.

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

8 IPMX Sender Timing

8.1 Video 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 x 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.

Video 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

8.2 Audio Sender Timing and Receiver Buffering

Audio IPMX Senders and Receivers shall comply with the provisions of AES67 section 7.5.

```
Note: The lowest latency between an audio PCM IPMX Sender and an audio PCM
IPMX Receiver can be achieved when the sender uses a packet time of 125
microseconds.
```

8.3 Source Media Device Timing

When an IPMX Sender's output is based upon the conversion of a Baseband signal, that sender shall support Source Media Devices that produce Async Media signals and Sync Media signals.

8.4 Media Clock Timing

When an IPMX Sender's output is based upon the conversion of a Baseband signal, the Media Clock of that sender 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.
```

8.5 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.

8.6 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: When a common reference clock (PTP) is available, the Internal Clock is
synchronized to the common reference 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.
```

8.7 RTCP Sender Report General Provision

IPMX Senders 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 destination IP address as their corresponding media payload.

RTCP Sender Report packets shall be sent to the UDP destination 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.

IPMX RTCP Sender Report packets shall include a IPMX Info Block extension to provide a description for the media stream they are associated with.

The format of a IPMX RTCP Sender Report including the IPMX Info Block extension shall be as in Figure 1 below.

```
           0                   1                   2                   3
           0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
          +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
header    |V=2|P|    RC   |   PT=SR=200   |             length            |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                         SSRC of sender                        |
          +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
sender    |              NTP timestamp, most significant word             |
info      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |             NTP timestamp, least significant word             |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                         RTP timestamp                         |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                     sender's packet count                     |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                      sender's octet count                     |
          +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
IPMX      |       IPMX tag = 0x5831       |     IPMX Info Block length    |
Info      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
Block     | block version |                   reserved                    |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                        ts-refclk string                       |
          :                              . . .                            :
          |                                                               |
          +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
          |                        mediaclk string                        |
          |                                                               |
          |                                                               |
          +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
          |                           Media Info Block                    |
          +=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+=+
```

Figure 1 – RTCP Sender Report with IPMX Info Block extension

```
Note: A detailed description of fields in the header and sender info can be
found in IETF RFC 3550 section 6.4.1
```

version (V): 2 bits

padding (P): 1 bit

reception report count (RC): 5 bits
For IPMX Sender conforming with this TR, the reception report count (RC) field of the RTCP Sender Report packet should be 0.

packet type (PT): 8 bits

length: 16 bits
Shall be the size in 32-bit words of the packet payload – 1 as defined in as specified in RFC 3550 section 6.4.1. It is obtained by adding the length of RTCP Sender report header (8) plus the length of the sender info (20) plus the length of the IPMX Info Block and then subtracting 1.

SSRC: 32 bits
Shall match the SSRC value of the media payload that the RTCP Sender Report is associated with.

NTP timestamp: 64 bits
For an IPMX Sender conforming with this TR, 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 seconds shall be stored in the NTP timestamp, most significant word field. The nanoseconds shall be stored in the NTP timestamp, least significant word field.

The NTP timestamp fields hold a 64-bit value. The Internal Clock is expected to hold the value of the PTPv2 clock which uses an 80-bit timestamp format. The PTP truncated timestamp format in Figure 1 shall be used for filling the NTP field. This truncated timestamp format is a 64-bit field, which corresponds to the 64 least significant bits of the Internal Clock value.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            Seconds                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                          Nanoseconds                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2 – PTP truncated timestamp format

Seconds: specifies the integer portion of the number of seconds in the Internal Clock value.

Nanoseconds: specifies the fractional portion of the number of seconds in the Internal Clock value in nanoseconds.

RTP timestamp: 32 bits
The RTP timestamp that matches the timestamp in the NTP timestamp field.

sender's packet count: 32 bits

sender's octet count: 32 bits

IPMX tag: 16 bits
Shall contain the constant 0x5831, the string ‘X1’ to identify the RTCP Sender report extension as a IPMX Info Block.

IPMX Info Block length: 16 bits
The length of the IPMX Info Block, including the header, the IPMX Info Block content, all Media Info Block contained in the IPMX Info Block, and any padding required to align the

IPMX Info Block on a 32 bits boundary. The value of the IPMX Info Block length shall be the number of 32-bit words in the IPMX Info Block minus one.

block version: 8 bits
An 8-bit counter that increments whenever the content of the IPMX Info Block changes. The IPMX Sender shall increment the block version counter whenever the associated media stream changes and requires the IPMX Info Block content to be updated.

reserve: 24 bits
Reserved for future use. Should be 0.

ts-refclk string: 64 bytes
A string value that shall contain the string following the a=ts-refclk: media level attribute as specified in section 10.4 of this document. The string shall be padded with 0x0 byte value. For example the ts-refclk string value (minus the 0x0 padding bytes) shall be “ptp=IEEE1588-2008:ec-46-70-ff-fe-10-ff-b0” when “a=ts-refclk:ptp=IEEE1588-2008:ec-46-70-ff-fe-10-ff-b0” is used.

mediaclk string: 12 bytes
A string value that shall contain the string following the a=mediaclk: media level attribute as specified in section 10.5 of this document. The string shall be padded with 0x0 byte value. For example the ts-refclk string value (minus 0x0 padding bytes) shall be “direct=0” when a=mediaclk:direct=0 is used.

Media Info Block: Variable size
A IPMX Info Block can contain 0 or more Media Info Block. Each Media Info Block shall start with a header that contains the Media Info Block type and its size. A Media Info Block should contain the attributes for the media stream. The detailed format of each media info block type is defined in the respective IPMX media transport TR. The Media Info Block shall be aligned on a 32-bit boundary.

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

In networks using Source Specific Multicast (SSM), IPMX senders shall not issue an IGMPv3 Membership report (aka Join) that contains a Group Record that INCLUDES their own source IP address.

```
Note: IPMX only requires RTCP Sender Reports packets. Other parts of RFC 3550
section 6 are not required and do not need to be supported. This includes
RTCP Receiver Reports, which are not required to be compliant with IPMX.
```

8.8 IPMX Video Sender

8.8.1 Video RTP Clock Sampling

When a video IPMX Sender's output is based upon the conversion of a Baseband signal, the value of the video RTP Clock of that sender 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. The value of the Internal clock shall be sampled at the same time and used to fill the NTP Timestamp field of the video RTCP Sender Report described in section 8.7 of this document.

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.

8.8.2 Video RTCP Sender Report schedule

All video IPMX Senders shall create RTCP Sender Reports once per frame if the video is progressive, or once per field if the video is interlaced.

Progressive segmented frame video shall be treated as progressive video. The RTP timestamp in the video RTCP Sender Report shall match the timestamp used in the video media packet for the corresponding frame or field.

The RTCP Sender Report shall be sent before the first video media packet of the associated frame or field but after the first video media packet of the previous frame or field.

8.9 IPMX Ancillary Sender

8.9.1 Ancillary RTP Clock Sampling

When an ancillary IPMX Sender's output is based upon the conversion of a Baseband signal, the value of the ancillary RTP Clock of that sender 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. The value of the Internal clock shall be sampled at the same time and used to fill the NTP Timestamp field of the ancillary RTCP Sender Report described in section 8.7 of this document.

8.9.2 Ancillary RTCP Sender Report

All ancillary IPMX Senders shall create RTCP Sender Reports every time a new ancillary RTP timestamp is sampled from the ancillary RTP Clock.

The RTP timestamp in the ancillary RTCP Sender Report shall match the timestamp used in the ancillary media packet(s) for the corresponding frame or field.

The ancillary RTCP Sender Report shall be sent before the first ancillary media packet containing the associated timestamp but after the first ancillary media packet of the previous frame or field.

8.10 IPMX Audio Sender

8.10.1 Audio RTCP Sender Report

All audio IPMX Senders shall send a RTCP Sender Report corresponding to the first packet of the audio media RTP stream and every N packets after that. Where N is equal to the integer result of dividing 10 milliseconds by the nominal packet time of the audio IPMX RTP stream.

Note: This results in sending RTCP packets approximately every 10 milliseconds. For example, if the audio IPMX Sender is sending a RTP stream with a media packet time of 125 microseconds; N will be equal to 0.01 ÷ 0.000125 = 80.

The NTP field of the RTCP sender report shall be filled with the value of the Internal clock at the moment the Media Clock is sampled to generate the RTP timestamp of the associated audio media RTP packet.

The RTCP Sender Report containing this RTP timestamp shall be sent before the packet containing the associated RTP timestamp but after the previous audio RTCP Sender Report and its associated audio media packet.

Note: The requirement to send the RTCP packet before the first packet of the audio IPMX RTP stream is sent, enables support for use cases where the audio IPMX media stream changes dynamically.

9 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 a new IPMX Sender, and the timing of the output stream shall follow the guidelines of the IPMX Sender Timing in Section 8 of this document.

10 SDP Signaling General Provision

IPMX Senders shall provide an SDP object 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 object available through the management programming interface of the device.

Section 4.1 of IETF RFC 8331 permits the use of Flow Identification (FID) semantics to group streams within the SDP; such use is inconsistent with the "one SDP object per RTP Stream" provision of SMPTE ST 2110-10 and shall not be used under this TR.

10.1 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 microseconds.

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;
measuredsamplerate=47952
a=ts-refclk:localmac=00-20-FC-32-2F-40
a=ptime:0.12
a=mediaclk:sender
```

10.2 Baseband Video IPMX Sender Signaling

When a video IPMX Sender's output is based upon the conversion of a Baseband signal, the 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 below.

When a video IPMX Sender's output is based upon the conversion of a Baseband signal, the 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 Baseband video IPMX
Sender for a 1080p59.94, YUV 422 10 bits signal and that has a CMAX 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:sender
```

10.3 Baseband Audio Sender Signaling

When an audio IPMX Sender's output is based upon the conversion of a Baseband signal, the sender shall report the measured sample rate of the Source Media Device signal by setting the parameters as described below.

An audio IPMX Sender that is converting from a Baseband signal shall include the measuredsamplerate parameters in the a=fmtp clause of the SDP file that correspond to the signal from the Media Source Device where measuredsamplerate reports the audio sample rate in Hertz, of the Source Media Device with a max tolerance of 150ppm with respect to the audio actual sample rate value.

```
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 an audio IPMX Sender
with 8 channels at 48Khz with a packet time of 125 microseconds.
```

```
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;
measuredsamplerate=47952
a=ts-refclk:localmac=00-20-FC-32-2F-40
a=ptime:0.12
a=mediaclk:sender
```

10.4 Common Reference Clock Signaling

All IPMX Senders shall signal their Common Reference Clock using the media-level ts-refclk attribute as specified in ST 2110-10 section 8.2.

When no Common Reference Clock is present on the network, the form ts-refclk:localmac shall be used, indicating that the IPMX Sender is using its Internal Clock as a reference.

10.5 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

11 IPMX Receiver Timing

11.1 Recovery of Sender signal timing

IPMX Receivers that are producing a Baseband signal should recover the Async signal timing and produce an output signal that is frequency locked to the IPMX Sender.

11.2 Link Offset Delay attribute

IPMX Receivers that are producing a Baseband signal should support the Link Offset Delay attribute as described in ST 2110-10.

IPMX Receivers with support for Link Offset Delay shall provide control for the Link Offset Delay attribute through their management programming interface.

Note: An IPMX Receiver can determine $T_{RTP(j)}$ as defined in ST 2110-10 by examining the RTP timestamp of the incoming stream and the accompanying RTCP Sender Reports.

```
Note: Link Offset Delay can be used for coordinating the Playout Time of
multiple IPMX Receivers.
```

12 Appendix A (Informative)

Based on the broadcast oriented SMPTE ST 2110 suite of standards, the IPMX TR 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 1 microsecond resulting in a wide sender using C_{MAX} bursts every 16 microseconds resulting in about 982 transactions per frame. The compressed version generates about 1414 packets per frame and has a packet pacing interval of about 11.3 microseconds 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 SMPTE 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 SMPTE 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's 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.

13 Annex B Bibliography (Informative)

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