Video Services Forum (VSF)
Technical Recommendation TR-10-13

Internet Protocol Media Experience (IPMX):
Privacy Encryption Protocol (PEP)

January 19, 2024
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Executive Summary

This Technical Recommendation describes a method generating keying material for encrypting, decrypting and authenticating media content over multicast and unicast networks. It is designed to support multiple types of transport protocol adaptations. The default adaptation defined in this document describes privacy encryption of media streams having an RTP payload format. Other adaptations are possible for other transport protocols such as USB over IP, SRTP and SRT.
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3  Introduction (informative)

The privacy encryption protocol (PEP) is based on a set of Pre-Shared Keys (PSK) stored in Sender and Receiver Devices to control access to media content. A Receiver can access content
from various Senders, each possibly having its own PSK. A set of PSKs are programmed in each Sender and Receiver Device in a secure way through a proprietary device configuration interface using a secure communication method.

A privacy attribute and an associated set of parameters in the Sender's SDP transport file and/or in NMOS transport parameters provide a Receiver with all the necessary information for deriving, the encryption key used by a Sender, by using the PSK. A Controller transports keying material information from a Sender to subscribed Receivers through the SDP transport file and/or NMOS transport parameters.

This Technical Recommendation presents the key derivation process and the associated requirements. The key derivation process may be used with various transport protocol adaptations. This Technical Recommendation presents the adaptation for RTP. Companion documents can be used to present adaptations for other transport protocols such as USB over IP, SRTP, SRT, etc.

Figure 2 illustrates the various layers that comprise the Privacy Encryption Protocol. The Key Derivation layer is responsible for deriving a privacy_key from a given PSK and associated keying material. The ECDH layer provides the extra key_pfs keying material for peer-to-peer scenarios. The Key Derivation layer is also responsible for providing the dynamic key_version to transmit in-band to the Protocol Adaptation layer (used for the KDF of the encryption key). The Protocol Adaptation layer is responsible for providing the authentication and encryption/decryption functions and for transmitting/receiving the ciphered content using an associated transport protocol. The Protocol Adaptation layer is also responsible for providing the dynamic key_version, received in-band, to the Key Derivation layer (used for the KDF of the decryption key).
4 Contributors
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5  About the Video Service 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.

6  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.

7 Normative References

- NIST.SP.800-38a: Recommendation for Block Cipher Modes of Operation, Methods and Techniques, December 2001
- NIST.SP.800-38b: Recommendation for Block Cipher Modes of Operation: The CMAC Mode for Authentication May 2005
- NIST.SP.800-56aRev3: Recommendation for Pair-Wise Key-Establishment Schemes Using Discrete Logarithm Cryptography, April 2018
- RFC 8088: How to Write an RTP Payload Format, May 2017
- RFC 8285: A General Mechanism for RTP Header Extensions, October 2017
- JT-NM TR-1001-1:2020: System Environment and Device Behaviors For SMPTE ST 2110 Media Nodes in Engineered Networks, November 11, 2020
- VSF TR-10-8: Internet Protocol Media Experience (IPMX): NMOS Requirements, April 14, 2023
- ST 2022-7:2019: Seamless Protection Switching of RTP Datagrams, December 26, 2018
8 Definitions

|| A concatenation of Octet Strings in big-endian format.

Controller A software component that manages, controls and coordinates the operations of a number of Senders and Receivers in a network, such as an NMOS Controller.

CRLF A carriage return character immediately followed by a line feed character.

Device A physical or virtual entity that is designed to perform a specific function or task within a system.

Octet String An ordered sequence of Octets in big-endian format.

Octet A binary value of eight bits.

Perfect Forward Secrecy A security property in cryptographic protocols where the compromise of long-term secret keys does not compromise the confidentiality of past or future communications.

Pre-Shared Key A cryptographic key that is agreed upon and shared in advance between communicating parties.

Receiver Device A Device having a number of Receivers.

Receiver As per "JT-NM TR-1001-1:2020, v1.1", it is a "Receiver Media Node" that consumes a privacy encrypted stream using ST 2110 or IPMX.

Sender Device A Device having a number of Senders.

Sender As per "JT-NM TR-1001-1:2020, v1.1", it is a "Sender Media Node" that produces a privacy encrypted stream using ST 2110 or IPMX.

9 Abbreviations

AAD Additional Authenticated Data

KDF Key derivation function

MAC Message Authentication Code

PEP Privacy Encryption Protocol
PFS  Perfect Forward Secrecy
PRF  Pseudo Random Function
PSK  Pre-shared key
ECDH  Elliptic Curve Diffie-Hellman

10 Notations

Octet  An Octet is represented in text form as two hexadecimal digits. A hexadecimal digit is one of 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F, a, b, c, d, e, f. Unless otherwise specified both upper and lower case letters are allowed. The leftmost hexadecimal digit corresponds to the most significant 4 bit of the Octet. The rightmost digit corresponds to the least significant 4 bit.

Octet String  An Octet String is represented in text form as a sequence of Octets from left to right. Unless otherwise specified the Octets may be separated by spaces. The leftmost Octet corresponds to the most significant Octet of a numeral value and occupies the lowest address in memory. The rightmost Octet corresponds to the least significant Octet of a numeral value and occupies the highest address in memory. Octet₀ is the leftmost Octet of an Octet String. Octetₙ is the rightmost Octet of an Octet String counting N+1 Octet. For an Octet String named my_var, my_var₀ corresponds to the Octet₀ of such an Octet String.

11 Operations and Functions

CIPHₖ(M)  As per the definition in NIST.SP.800-38a. The variable K may be replaced by the name of a key as in CIPHₖₑ𝐲(M) where the key is named 'key'.

CMAC(K, M)  As per the definition in NIST.SP.800-38b. The variable K may be replaced by the name of a key as in CMAC(key, M) where the key is named 'key'.

HIGH(X)  Return the most significant N bits of X where N corresponds to half the number of bits in X

HMAC-SHA-512/256(K,M)  As per the definition in NIST.FIPS.198-1 and NIST.FIPS.180-4. The variable K may be replaced by the name of a key as in HMAC-SHA-512/256 (key, M) where the key is named 'key'.
LOW(X)  
Return the least significant N bits of X where N corresponds to half the number of bits in X

12 Privacy Key Derivation

Senders and Receivers that produce or consume a privacy encrypted stream shall derive a privacy_key as described in this Technical Recommendation and utilize it to obtain an encryption or decryption key. Such stream may be unidirectional or bidirectional and may comprise a set of sub-streams, each independently privacy encrypted, and having its own direction. Sub-streams that are not independently privacy encrypted, such as FEC sub-streams, are not subject to this recommendation.

Note: By definition a Sender produces one stream and a Receiver consumes one stream. The concept of sub-stream is used to support scenarios where a Sender multiplexes a number of sub-streams and encrypts/decrypts them independently. See the section 14 for more details.

The privacy_key shall be derived from a Pre-Shared Key (PSK), a key generator (key_generator), a key version (key_version) and a Perfect Forward Secrecy shared secret (key_pfs) using a KDF in counter mode as per NIST.SP.800-108Rev1 section 4.1.

The KDF function shall use CMAC as the PRF as defined by NIST.SP.800-108Rev1 for a KDF using a PRF in counter mode for a PSK of 128 and 256 bits.

The KDF function shall use HMAC-SHA-512/256 as the PRF as defined by NIST SP 800-108Rev1 for a KDF using a PRF in counter mode for a PSK of 512 bits. The CMAC algorithm is specified in NIST SP 800-38b and may use an AES-128 (128-bit key) or AES-256 (256-bit key) block cipher. The HMAC and SHA-512/256 algorithms are specified in NIST FIPS 198-1 and NIST FIPS 180-4.

A Perfect Forward Secrecy mode based on ECDH as per NIST.SP.800-56aRev3 section 6.1.2.2 may be used to further restrict access to a privacy encrypted stream to only the two parties on each side of a peer-to-peer connection. The ECDH is performed using domain parameters as per NIST.SP.800-186 for curves “secp256r1” (NIST P-256), “25519” (NIST Curve25519), “448” (NIST Curve448) and “secp521r1” (NIST P-521).

128-bit key derivation (PSK is 128 bits):

\[ \text{privacy_key} = \text{CMAC}(\text{PSK}, \text{AB} \mid\mid \text{key_generator} \mid\mid \text{key_version} \mid\mid \text{key_pfs}) \]

256-bit key derivation (PSK is 128 or 256 bits):

\[ \text{privacy_key} = \text{CMAC}(\text{PSK}, \text{AB} \mid\mid \text{key_generator} \mid\mid \text{key_version} \mid\mid \text{HIGH(key_pfs)}) \mid\mid \]
CMAC(PSK, CD || key_generator || key_version || LOW(key_pfs))

256-bit key derivation (PSK is 512 bits):

privacy_key = HMAC-SHA-512/256(PSK, AB || key_generator || key_version || key_pfs)

- The privacy_key shall be 128 bits for AES-128 and 256 bits for AES-256. It is an Octet String in binary form.

- The PSK shall be 128 bits for AES-128 and may be 128 bits, 256 bits or 512 bits for AES-256. With a 128-bit PSK, CMAC(PSK, M) shall use the AES-128 block cipher. With a 256-bit PSK, CMAC(PSK, M) shall use the AES-256 block cipher. If a 128-bit PSK is used for deriving a 256-bit privacy_key, the CMAC(PSK, M) shall use the AES-128 block cipher. With a 512-bit PSK, HMAC-SHA-512/256(PSK, M) shall use the SHA-512/256 hash function.

The PSK shall be provided to a Sender/Receiver by an administrator and identified by a key_id. The key_id is provided by a Sender and obtained by a Receiver using an SDP transport file and/or NMOS transport parameters. The PSK is an Octet String in binary form.

- The key_generator shall be 128 bits. It shall be provided by a Sender and obtained by a Receiver using an SDP transport file and/or NMOS transport parameters. It is an Octet String in binary form.

- The key_version shall be 32 bits. It shall be provided by a Sender and obtained by a Receiver using an SDP transport file and/or NMOS transport parameters. It may also be transmitted/received along with the ciphered content by a Sender/Receiver configured for in-band dynamic changes of the encryption key. The key_version is an Octet String in binary form.

- The key_pfs shall be a shared secret value calculated by each peer executing an ECDH protocol from the peer public key. For curves “secp256r1” (NIST P-256), “25519” (NIST Curve25519), “448” (NIST Curve448) and “secp521r1” (NIST P-521) the secret value has 255, 256, 448 and 521 bits respectively. The key_pfs value corresponds in size and value to the Z value as specified in NIST.SP.800-56aRev3 section 5.7.1.2. A Controller shall exchange the public keys at the activation of the Sender and Receiver. A peer public key shall be ephemeral and unique to a given activation of a Sender/Receiver. At boot / reset / init time or when a Sender/Receiver becomes inactive, a Sender/Receiver shall generate a new ECDH private/public keys pair. When using redundancy, the legs shall use the same ECDH private/public keys pair. When an ECDH mode of operation is not
used, the `key_pfs` value shall be an empty Octet String. It is an Octet String in binary form.

*Note:* The standard Montgomery X-coordinate encoding used for curves 25519 and 448 uses little-endian ordering of the bytes. To keep consistency among the curves, the bytes of such encoding are reversed in `key_pfs` which is in big-endian format.

**13 SDP transport file parameters / NMOS transport parameters**

Privacy encryption parameters, summarized in Table 1, are communicated/exchanged using an SDP transport file and/or NMOS transport parameters. Additionally, the `key_version` parameter is communicated/exchanged in-band along with the ciphered content when a protocol supporting in-band dynamic key versions is used.

For transport protocols using an SDP transport file:

- A Sender shall communicate privacy encryption parameters using a privacy session attribute or a number of privacy media attributes in the privacy encrypted stream's associated SDP transport file. A Sender in an NMOS environment shall also communicate the privacy encryption parameters using the privacy extended NMOS transport parameters. The privacy encryption parameters `protocol`, `mode`, `iv`, `key_generator`, `key_version` and `key_id` shall all be provided by a Sender when using the SDP or NMOS mechanisms. The privacy encryption parameters `ecdh_sender_public_key`, `ecdh_receiver_public_key` and `ecdh_curve` shall all be provided by a Sender when using the NMOS mechanism. The privacy encryption parameters provided by a Sender simultaneously in the SDP transport file and the NMOS transport parameters shall be identical. The privacy encryption parameters provided by a Sender in an SDP transport file and/or the NMOS transport parameters shall not change while the Sender is active, with the exception of `key_version` that may change in an SDP transport file when a protocol supporting in-band dynamic key versions is used.

- A Receiver in an NMOS environment shall communicate the privacy encryption parameters using the privacy extended NMOS transport parameters. The privacy encryption parameters `protocol`, `mode`, `iv`, `key_generator`, `key_version`, `key_id`, `ecdh_sender_public_key`, `ecdh_receiver_public_key` and `ecdh_curve` shall all be provided by a Receiver using the NMOS mechanism. The privacy encryption parameters provided by a Receiver in the NMOS transport parameters shall not change while the Receiver is active, with the exception of `key_version` that may change in an SDP transport file when a protocol supporting in-band dynamic key versions is used.
• When using redundancy, as in ST 2022-7, the legs shall use the same privacy encryption parameters.

• A Controller in an NMOS environment shall provide the privacy encryption parameters used by a Sender to a number of Receivers using the SDP transport file or NMOS transports parameters mechanisms.

For transport protocols that are not using an SDP transport file:

• A Sender/Receiver shall communicate the privacy encryption parameters using the privacy extended NMOS transport parameters. The privacy encryption parameters protocol, mode, iv, key_generator, key_version, key_id, ecdh_sender_public_key, ecdh_receiver_public_key and ecdh_curve shall all be provided using the NMOS mechanism. The privacy encryption parameters provided by a Sender/Receiver in the NMOS transport parameters shall not change while the Sender/Receiver is active, with the exception of key_version that may change in an SDP transport file when a protocol supporting in-band dynamic key versions is used.

• When using redundancy, as in ST 2022-7, the legs shall use the same privacy encryption parameters.

• A Controller in an NMOS environment shall provide the privacy encryption parameters used by a Sender to a number of Receivers using the NMOS transports parameters mechanism.

The privacy attribute of an SDP transport file shall be formatted as a follow with a semicolon and an optional space separating the parameters and a CRLF to terminate the attribute line. There shall be no semicolon after the last parameter. The placeholders <protocol>, <mode>, <iv>, <key_generator>, <key_version>, and <key_id> shall be replaced with the actual value of the parameter, with Octet String represented in hexadecimal notation without spaces.

```plaintext
a=privacy:protocol=<protocol>; mode=<mode>; iv=<iv>; key_generator=<key_generator>; key_version=<key_version>; key_id=<key_id> CRLF
```

• protocol: this parameter defines the privacy encryption protocol adaptation being used. It represents various aspects of the privacy encrypted stream such as the transport protocol, the encryption behavior (packet layout, encrypted sections, and authenticated sections), the support for in-band dynamic key versions, etc. It shall be a string associated with a protocol as documented in one of the protocol adaptations.
The **protocol** value shall not change while a Sender/Receiver is active. A Sender/Receiver shall become inactive in order to change the **protocol**.

The NULL **protocol** may be used in NMOS transport parameters to indicate that privacy encryption is not available / disabled. It shall not be possible through NMOS transport parameters to disable encryption on a Sender/Receiver that is configured to perform privacy encryption. A Sender/Receiver that does not perform privacy encryption may indicate NULL as the actual protocol adaptation in its NMOS transport parameters.

The NULL **protocol** shall not be used in an SDP transport file. Instead, the privacy attribute shall be omitted.

A Sender/Receiver may support multiple protocols. It may be configured to use one of such protocols through the NMOS transport parameters or through a vendor-specific mechanism. Only a vendor-specific configuration mechanism shall be able to configure a Sender/Receiver to disable privacy encryption.

- **mode**: this parameter defines the encryption, authentication and key derivation functions being used. It represents various aspects of the privacy encrypted stream such as the use of a 128 or 256 bit key, the use of authentication, the use of peer-to-peer ECDH in key derivation, etc. It shall be a string associated with a **mode** as documented in one of the protocol adaptations.

Senders and Receivers shall support operating in AES-128-CTR **mode**. The mode of operation shall not change while a Sender or Receiver is active. A Sender or Receiver shall become inactive in order to change the **mode** of operation.

The NULL **mode** may be used in NMOS transport parameters to indicate that privacy encryption is not available / disabled. It shall not be possible to disable encryption on a Sender/Receiver that is configured to perform privacy encryption. A Sender/Receiver that does not perform privacy encryption may indicate NULL as the actual mode of operation in its NMOS transport parameters.

The NULL **mode** shall not be used in an SDP transport file. Instead, the privacy attribute shall be omitted.

A Sender/Receiver may support multiple modes. It may be configured to use one of such modes through the NMOS transport parameters or a vendor-specific mechanism. Only a vendor-specific configuration mechanism shall be able to configure a Sender/Receiver to disable privacy encryption.

- **iv**: this parameter defines the initial vector being used by the Sender at activation. It shall be a 64-bit Octet String in binary form.
The iv value should be randomly chosen for each stream and should be unique among all the streams encrypted by a Sender Device. Its value shall not change while the Sender is active. A Sender shall become inactive in order to change the iv value.

- **key_generator**: this parameter defines the key generator being used by the Sender at activation. It shall be a 128-bit Octet String in binary form.

  The key_generator value shall be randomly chosen by the Sender Device at boot / reset / init time. It may be shared by a number of streams / sub-streams encrypted by a Sender Device. Its value shall not change until the next boot / reset / init of the Sender Device.

- **key_version**: this parameter defines the key version being used by the Sender at activation. It shall be a 32-bit Octet String in binary form.

  When a Sender becomes active, it selects a key_version value that shall remain constant during the activation of the Sender unless a protocol supporting in-band dynamic key versions is used, in which case the selected key_version value may increment by 1 modulo $2^{32}$ to change the associated privacy_key during the activation.

  The key_version value provided by a Sender in an SDP transport file and/or NMOS transport parameters shall not change while the Sender is active. If a protocol supporting in-band dynamic key versions is used, the key_version value provided in the SDP transport file and/or NMOS transport parameters shall correspond to the value at the activation of the Sender.

  The key_version value transmitted in-band along with the ciphered content may change while a Sender is active.

  The key_version may be shared by a number of streams / sub-streams encrypted by a Sender Device.

- **key_id**: this parameter defines the key identifier being used by the Sender at activation. It shall be a 64-bit Octet String in binary form.

  The key_id value shall be associated with a Pre-Shared Key (PSK). A Sender shall provide the key_id of the PSK from which derives the stream's encryption key. A Receiver shall select a PSK from the key_id to derive the stream's decryption key. Its value shall not change while the Sender is active. A Sender shall become inactive in order to change the key_id.

  The key_id value associated with a Pre-Shared Key (PSK) shall be globally unique among all the Sender/Receiver Devices of a network under a given administrative authority. It is an administrative responsibility to ensure such uniqueness. Administrators
may maintain a central registry of the PSK and their associated key_id or other techniques to comply with the globally unique requirement.

A Receiver may allow the use of multiple key_id values. It may be configured to use one such key_id value through the SDP transport file and/or NMOS transport parameters. The constraints associated with the ext_privacy_key_id parameter of the Receiver should list all the key_id values allowed by the Receiver.

A Sender shall use a single key_id value. The constraints associated with the ext_privacy_key_id NMOS transport parameter of the Sender shall list the one key_id value associated with the Sender.

The NMOS privacy transport parameters shall be named according to the NMOS rules and start with the prefix "ext_". Each transport parameter shall have an associated constraint describing the values supported/allowed for the parameter. A constraint allowing a single value shall describe a read-only parameter that can only be programmed to the constraint value. A Sender/Receiver shall not allow a Controller to set a transport parameter to a value that is not allowed by the associated parameter constraints.

The actual value of the NMOS transport parameters and constraints shall be a string, with Octet String represented in hexadecimal notation without spaces.

<table>
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<th>Transport Parameter Name</th>
<th>Type</th>
<th>SDP Name</th>
<th>Sender</th>
<th>Receiver</th>
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<td>key_id</td>
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<td>r/w</td>
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<tr>
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<td>-</td>
<td>r/w</td>
<td>read-only</td>
</tr>
<tr>
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<td>-</td>
<td>r/w</td>
<td>r/w</td>
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</table>

Table 1 - Transport Parameters

A device supporting the Perfect Forward Secrecy ECDH mode shall implement the ext_privacy_ecdh_curve, ext_privacy_ecdh_sender_public_key and
ext_privacy_ecdh_receiver_public_key NMOS transport parameters. This mode of operations should be used only for peer-to-peer Sender, Receiver configurations. The ECDH parameters are used by the PEP key derivation function when the mode of operation enables ECDH (having an "ECDH_" prefix) as indicated by the ext_privacy_mode NMOS transport parameter and the "a=privacy" mode attribute of the SDP transport file.

- **ext_privacy_ecdh_curve**: this parameter defines the elliptic curve being used by the Sender/Receiver. It shall be a string associated with an ecdh_curve among the following: “secp256r1”, “25519”, “448”, “secp521r1” or "NULL" if the Perfect Forward Secrecy ECDH mode is not available / supported.

The constraint on ext_privacy_ecdh_curve shall indicate which elliptic curves are supported by the Sender. A constraint may indicate that no value is supported (empty enum) or that only the "NULL" value is supported to express that the Perfect Forward Secrecy ECDH mode is not supported by the Sender or Receiver. When Perfect Forward Secrecy is not supported there shall be no mode of operation with an "ECDH_" prefix listed in the constraints on ext_privacy_mode.

The ext_privacy_ecdh_curve parameter shall not change while a Sender or Receiver is active. A Sender or Receiver shall become inactive in order to change the ecdh_curve.

- **ext_privacy_ecdh_sender_public_key**: this parameter defines the ECDH public key of the Sender. It shall be an Octet String in binary form of the corresponding number of bits for the actual elliptic curve. The 00 Octet String should be used when the ecdh_curve is "NULL" or the parameter is not yet defined on a Receiver. A Sender shall generate a new ext_privacy_ecdh_sender_public_key value randomly at initialization, when it becomes inactive either implicitly through some internal process or explicitly through an external deactivation request. The generation of the public key shall depend only on the ecdh_curve being used.

*Note*: A Sender may become inactive automatically without an explicit request from a Controller.

For curves secp256r1 and secp521r1 the public key shall be an Octet String in uncompressed form as per SEC 1, Version 2.0, Section 2.3.3 (prefix byte) while for curves 25519 or 448 the public key shall be a plain Octet String in uncompressed form (no prefix byte).

*Note*: The standard Montgomery X-coordinate encoding used for curves 25519 and 448 uses a little-endian ordering of the bytes. To keep consistency among the curves the bytes of such encoding are reversed in ext_privacy_ecdh_sender_public_key and
ext_privacy_ecdh_receiver_public_key which are in big-endian format.

For a Sender, the constraints on the transport parameter ext_privacy_ecdh_sender_public_key shall allow only one value, indicating that it cannot be changed by a Controller. The value shall correspond to the ECDH public key of the Sender that a Controller shall provide to the peer Receiver. A constraint may indicate that no value is supported (empty enum), or that only the "00" value is supported, to express that the Perfect Forward Secrecy ECDH mode is not supported by the Sender.

For a Receiver, the constraints on the transport parameter ext_privacy_ecdh_sender_public_key should allow any Octet String of the corresponding number of bits for the actual elliptic curve. A constraint may indicate that no value is supported (empty enum) or that only the 00 value is supported to express that the Perfect Forward Secrecy ECDH mode is not supported by the Receiver.

The ext_privacy_ecdh_sender_public_key parameter shall not change while a Sender or Receiver is active. A Sender or Receiver shall become inactive in order to change the ext_privacy_ecdh_sender_public_key.

- ext_privacy_ecdh_receiver_public_key: this parameter defines the ECDH public key of the Receiver. It shall be an Octet String in binary form of the corresponding number of bits for the actual elliptic curve. The 00 Octet String should be used when the ecdh_curve is "NULL", or the parameter is not yet defined on a Sender. A Receiver shall generate a new ext_privacy_ecdh_receiver_public_key value randomly at initialization, when it becomes inactive either implicitly through some internal process, or explicitly through an external deactivation request. The generation of the public key shall depend only on the ecdh_curve being used.

For curves secp256r1 and secp521r1, the public key shall be an Octet String in uncompressed form as per SEC 1, Version 2.0, Section 2.3.3 (prefix byte), while for curves 25519 or 448, the public key shall be a plain Octet String in uncompressed form (no prefix byte).

Note: The standard Montgomery X-coordinate encoding used for curves 25519 and 448 uses a little-endian ordering of the bytes. To keep consistency among the curves, the bytes of such encoding are reversed in ext_privacy_ecdh_sender_public_key and ext_privacy_ecdh_receiver_public_key, which are in big-endian format.

For a Receiver, the constraints on the transport parameter ext_privacy_ecdh_receiver_public_key shall allow only one value, indicating that it
cannot be changed by a Controller. The value shall correspond to the ECDH public key of the Receiver that a Controller shall provide to the peer Sender. A constraint may indicate that no value is supported (empty enum), or that only the 00 value is supported, to express that the Perfect Forward Secrecy ECDH mode is not supported by the Receiver.

For a Sender, the constraints on the transport parameter `ext_privacy_ecdh_receiver_public_key` should allow any Octet String of the corresponding number of bits for the actual elliptic curve. A constraint may indicate that no value is supported (empty enum), or that only the 00 value is supported, to express that the Perfect Forward Secrecy ECDH mode is not supported by the Sender.

The `ext_privacy_ecdh_receiver_public_key` parameter shall not change while a Sender or Receiver is active. A Sender or Receiver shall become inactive in order to change the `ext_privacy_ecdh_sender_public_key`.

A Controller participating in a Privacy Perfect Forward Secrecy ECDH exchange should exchange the `ext_privacy_ecdh_sender_public_key` transport parameter of a Sender and of `ext_privacy_ecdh_receiver_public_key` of a Receiver prior to the activation of the Sender/Receiver. The `ext_privacy_ecdh_curve` value of transport parameters may affect the generation of those values. A controller should read the `ext_privacy_ecdh_sender_public_key` transport parameter of a Sender and of `ext_privacy_ecdh_receiver_public_key` of a Receiver after completing the programming of the `ext_privacy_ecdh_curve` transport parameter and explicitly deactivating the Sender/Receiver.
14 Multiplexed streams and Bidirectional streams

The iv' parameter, which is used by the Privacy Cipher to encrypt/decrypt a stream/sub-stream, derives from iv and shall be equal to the iv value (see Figure 3) unless multiplexed sub-streams (see Figure 4) or bidirectional sub-streams are used (see Figure 5). The iv' value should be unique among all the streams and sub-streams encrypted by a Sender/Receiver Device. Its value shall not change while the Sender/Receiver is active. A Sender/Receiver shall become inactive in order to change the iv' value of a stream or sub-stream.

The actual value of the quartet (iv', key_generator, key_version, key_id) shall be unique among all the streams and sub-streams encrypted by the Sender/Receiver Device. A Sender/Receiver Device may enforce this rule statically by ensuring that the iv' values are unique among all the streams and sub-streams encrypted by the device.

For multiplexed streams where each sub-stream is encrypted independently, the effective iv' value for a given sub-stream shall be obtained by adding modulo $2^{64}$, the sub-stream id in the range $[0, 1023]$, with the base iv value (see Figure 4). The sub-stream id is a concept understood by the Sender and Receiver of such a multiplexed stream and is adaptation specific. This Technical Recommendation requires only that such sub-streams be allocated an identifier in the range $[0, 1023]$ thus restricting such a multiplexed stream to a maximum of 1024 sub-streams.

For bidirectional and optionally multiplexed streams, the sub-streams in each direction shall be encrypted independently, and the effective iv' value for a given sub-stream shall be obtained by adding modulo $2^{64}$, the sub-stream id in the range $[0, 1023]$ with the base iv value (see Figure 5). The sub-stream id shall be an even number for the Sender to Receiver direction and an odd number for the Receiver to Sender direction. The sub-stream id is a concept understood by the Sender and Receiver of such a bidirectional stream and is adaptation specific. This Technical Recommendation requires only that such sub-streams be allocated an identifier in the range $[0, 1023]$ with proper odd/even allocation thus restricting such a bidirectional stream to a maximum of 512 bidirectional sub-streams.
Figure 3 - Single unidirectional stream

Figure 4 - Multiplexed unidirectional streams
15 Privacy Cipher

The privacy cipher shall be based on the AES-128 or AES-256 block cipher operating in CTR or GCM mode (NIST.FIPS.197, NIST.SP.800-38a, NIST.SP.800-38d)

cipher_content\_i = \text{CIPH}_{key}(iv'\_\text{ctr}) \text{ XOR } plain\_content\_i

- The **key** shall be 128 bits for AES-128 and 256 bits for AES-256. It shall be generated from a Pre-Shared Key (PSK) and other values obtained from separate channels. It is an Octet String in binary form.

- The **iv'\_\text{ctr}** shall be a 128-bit Octet String in binary form. It shall be generated from a number of associated values depending on the transport protocol adaptation. Usually, such values comprise an initial vector \(iv'\) and a sequence counter \(ctr\). The \(iv'\_\text{ctr}\) value shall not be used more than once with a given **key**.

- cipher_content\_i is a 128-bit Octet String of binary data from of a stream or sub-stream

- plain_content\_i is a 128-bit Octet String of binary data from of a stream or sub-stream

The effective value of \(iv'\_\text{ctr}\) used by the \text{CIPH}_{key} function may differ according to the transport protocol adaptation.

*Note:* Depending on the transport protocol adaptation, the size and combination of \(iv'\) and \(ctr\) values into \(iv'\_\text{ctr}\) may be slightly different than what is described in this Technical Recommendation for
the RTP transport protocol, while still being compliant with the AES cipher in CTR/GCM mode specification. This Technical Recommendation assumes full control over the encryption process when using the RTP transport protocol, while still allowing a transport protocol specific encryption process based on the privacy_key defined in this document.

The sections of the stream that are encrypted and/or authenticated are protocol and adaptation specific.

Modes of operation using a message authentication code (MAC) of some sections of the stream, excluding GCM, shall operate in a mac-then-encrypt scheme and store the encrypted MAC as the last N bytes of the encrypted payload (the MAC is encrypted along with the payload). The mode of operation shall dictate the size (N), in bytes, of the MAC and the use of AAD. The MAC shall be calculated over the payload data and optionally it may also be calculated over some additional authenticated data (AAD). It then applies to the payload data that is to be encrypted and optionally to some data that is not to be encrypted.

The GCM mode operates in an encrypt-then-mac scheme and stores the MAC in clear as the last N bytes of the encrypted payload (the MAC is not encrypted). The mode of operation shall dictate the size (N), in bytes, of the MAC and the use of AAD. The MAC shall be calculated over the encrypted payload data and optionally it may also be calculated over some additional authenticated data (AAD). It then applies to the encrypted payload data and optionally to some data that is not to be encrypted.

The truncated MAC shall be comprised of the most significant bit of the MAC, as required by NIST SP 800-38b and NIST SP 800-38d.

16 Sender / Receiver Model (Informative)
Figure 6 and Figure 7 describe a model of a Sender and a Receiver implementing the Privacy Encryption Protocol.

Without using dynamic changes of the key_version:

- This is the simplest configuration. The PEP parameters are static for the duration of active state of a Sender Receiver and completely under the control of the Sender Device.
- One or many sub-streams may be encrypted/decrypted in parallel, possibly using the same key. Each sub-stream has a dedicated iv* and ctr parameter.
- There are as many KDFe and KDFd modules as there are distinct keys.
- As the key_version is not allowed to change dynamically there is only one key_version state shared by all the KDFe and KDFd modules.
- The Sender Device possibly shares the same key_id, key_version and key_generator with multiple Senders.
• In this configuration the Sender and Receiver are deactivated to change the PEP parameters. It is not possible to change the encryption key without stopping the Sender and Receiver.

Using dynamic changes of the **key_version**: 

• This is the most flexible configuration. The PEP parameters, except **key_version**, are static for the duration of active state of a Sender/Receiver and completely under the control of the Sender Device. The **key_version** is dynamic, and is communicated in-band along with the ciphered content. It is completely under the control of the device performing the encryption (Sender or Receiver).
• In this configuration the KDFd modules are not connected to the **key_version** but are connected to the dynamic_key_version instead.
• One or many sub-streams may be encrypted/decrypted in parallel, possibly using the same **key**. Each sub-stream has a dedicated **iv** and **ctr** parameter.
• There are as many KDFe modules as there are distinct keys.
• There are as many KDFd modules as there are sub-streams. A number of sub-streams could possibly be using the same **key**, but as the decryption module does not have a priori knowledge of such information, it assumes the worst case of all sub-streams using a different **key**.
• As the **key_version** is allowed to change dynamically there are as many **key_version** states as there are KDFe modules. Note that the number of KDFe modules of a Sender and Receiver will differ and is totally under the control of the Sender and Receiver.
• There are as many dynamic_key_version states transmitted in-band as there are sub-streams encrypted in parallel, each receiving the **key_version** parameter associated with the key used for encryption.
• There are as many dynamic_key_version states received in-band as there are sub-streams decrypted in parallel, each receiving a dynamic **key_version** parameter associated with the key used for decryption.
• The Sender Device possibly shares the same **key_id**, **key_version** and **key_generator** with multiple Senders.
• The Receiver Device possibly shares the same **key_id**, **key_version** and **key_generator** with multiple Receivers.
• In this configuration the Sender and Receiver are deactivated to change all the PEP parameters but **key_version**. It is possible to change the encryption/decryption key without stopping the Sender and Receiver using dynamic **key_version**.
Figure 6 - Sender model

Figure 7 - Receiver model
17 Key distribution

A set of PSK values shall be programmed in both Sender and Receiver Devices by means out of the scope of this Technical Recommendation. Only devices sharing the same secret PSK value and size shall be allowed to successfully exchange privacy encrypted media content when the ECDH mode is not used. Only devices sharing the same secret PSK value and size and ECDH secret value shall be allowed to successfully exchange privacy encrypted media content when the ECDH mode is used.

A Pre-Shared Key has a value (the secret itself) and a size (the number of bits of the associated PSK). This Technical Recommendation describes the requirements for PSK of 128, 256 and 512 bits. The programming of the PSK in the devices shall target one such size. The default target size shall be 128 bits and shall be supported by all devices. The programming interface should clearly indicate the target number of bits for PSK of 256 and 512 bits. If a device does not support PSK of 256 or 512 bits it shall clearly indicate to an administrator using such programming interface that such PSK target sizes are not supported by the device.

Note: When an administrator associates a secret key of value abcd with a Sender it also associates a size, for example 128 bits. When sharing such abcd secret key with some Receivers, the administrator must not only provide the abcd value but also the associated size to the Receivers.

A given PSK is associated with a unique key_id. For security purposes there should be, at most, one PSK value associated with a given key_id. A cryptographically secure random number generator should be used to generate a PSK value and provide a high level of confidence in the uniqueness of the PSK value associated with a given key_id. A deployment with extreme security requirements may further ensure that no one PSK value is associated with more than one key_id.

A number of PSK may be programmed into a Sender Device, each key having an associated key_id and an associated set of streams (Senders). In its simplest configuration a Sender Device uses one PSK for all the streams it transmits over the network. In a complex environment, a Sender Device may have a PSK associated with a specific set of streams (Senders) in order to control the accessibility of such streams by Receivers.

A number of PSK may be programmed into a Receiver Device, each key having an associated key_id. Programming a PSK in a Receiver Device implies allowing such Receiver Device to access the content of the streams encrypted from such PSK.

It shall be assumed that once a PSK associated with a given key_id is given to a Receiver Device, it is able to access a stream associated with this PSK forever. To prevent further access to a stream by such Receiver Device, the Sender Device shall stop using such key_id.
The SDP transport file and/or NMOS transport parameters provide the key_id associated with the stream the Receiver is subscribing, such that the Receiver can look up the proper PSK for accessing the content of the stream.

\[
\text{key_id} \quad \bigg\rvert \quad \text{Stream} \quad \text{---- SDP Transport File ---- Sender} \\
\text{NMOS Transport Parameters}
\]

18.1 Key distribution through HTTPS (informative)

The configuration of the device shall be protected by administrative credentials.

A user is either a the device owner or a program acting on behalf of the device owner.

Sender device

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</tr>
<tr>
<td>2</td>
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<td>************</td>
<td>128</td>
</tr>
<tr>
<td>3</td>
<td>AVSec</td>
<td>************</td>
<td>256</td>
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Receiver device

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<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
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<td>************</td>
<td>128</td>
</tr>
<tr>
<td>3</td>
<td>************</td>
<td>256</td>
</tr>
</tbody>
</table>

Figure 8 - Configuring PSKs using HTTPS Server certificates
The configuration of the device could also be protected with administrative credentials.

A user is either a device owner or a program acting on behalf of the device owner.

<table>
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<th>Size</th>
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</thead>
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<td>3</td>
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<td>256</td>
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</tbody>
</table>

**Figure 9 - Configuring PSKs using HTTPS Client-Server certificates.**

**18 Safety**

The privacy encryption protocol uses various channels for the transport of key material. For instance, the Pre-Shared Key (PSK) is programmed into the device by means out of the scope of this Technical Recommendation. It is expected to be performed in a secure way through a device proprietary configuration interface. For example, such interface may be using a secure connection such as HTTPS as illustrated in Figure 8 and Figure 9, with proper verification of the certificates and using administrator credentials.

The SDP transport file and/or the NMOS transport parameters provide the key id, iv and key_generator values along with the key_version associated with the key_generator. All these values are not secret values but it is expected that a secure deployment of Sender and Receiver Devices would use HTTPS to exchange NMOS messages and SDP transport files, adding an extra layer of security over the privacy attributes of the SDP transport file and NMOS transport parameters. Further security may be achieved using IS-10 to protect the exchange of SDP transport file and NMOS transport parameters. The value of the key_generator attribute of the SDP transport file and/or NMOS transport parameters is subject to an initial random shuffle and will change at every boot / reset / init of the Sender Device.

The in-band dynamic key_version received along with the ciphered content stream, may be protected using a privacy encryption protocol and mode of operation providing authentication of the key_version value.
When an in-band dynamic key_version is received along with the ciphered content stream, a Sender/Receiver should verify that it is making forward progress or has not changed. The incoming key_version value shall be larger or equal to the last key_version value received from the ciphered content stream, taking into account the $2^{32}$ wrap around and the monotonic incremental nature of the value, and that the effective value cannot be farther than $2^{31}$ units from the initial or previous one. After a Receiver is subscribed to a media stream, the first key_version value received along with the ciphered content stream by the subscribed Receiver or by the Sender cannot be verified for making forward progress.

The in-band dynamic key_version protocol (i.e protocol name ending with _KV) should be used with a mode of operation providing authentication.

The ctr received along with the ciphered content stream, may be protected using a privacy encryption protocol and mode of operation providing authentication of the ctr value.

A Sender/Receiver should verify that the ctr value received along with the ciphered content stream is making forward progress. The incoming ctr value shall be larger to the last ctr value received from the ciphered content stream, taking into account the $2^{64}$ wrap around and the monotonic incremental nature of the value. After a Receiver is subscribed to a media stream, the first ctr value received along with the ciphered content stream by the subscribed Receiver or by the Sender cannot be verified for making forward progress. The first ctr value received may not be 0 as the Receiver may be subscribing to a media stream after the initial packet has been transmitted. The mechanism used by a Sender to know that a Receiver subscribed to the content stream is adaptation dependent.

This Technical Recommendation ensures that the AES-CTR mode cipher is used safely, providing requirements and techniques to guarantee the uniqueness of the key and iv'_ctr values of the privacy cipher. See the section 15 for more details.

The use of a 64-bit MAC is within the security guarantees of AES-CMAC as per NIST.SP.800-38b section A.2. “For most applications, a value for Tlen that is at least 64 should provide sufficient protection against guessing attacks.”

The Perfect Forward Secrecy ECDH mode allows further security for peer-to-peer configurations where only the associated Sender and Receiver can decrypt the content as the encryption key derives from both the ECDH, and the privacy encryption protocol schemes. In this mode the knowledge of the PSK is used to ensure that the peers are legitimate devices. Getting the shared ECDH secret key is not enough for decrypting the stream. The key_pfs is one of many pieces of information used for deriving the privacy_key.
## 19 Test vectors for key derivation (informative section)

This section provides test vectors for verifying the implementation of the Privacy Encryption Protocol.

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</tr>
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</tr>
<tr>
<td><strong>ext_privacy_key_generator</strong>: &quot;a7ebcd7bef2b32abc008e1d00c777a0&quot;</td>
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Privacy PFS = 3e1e0e9836bd01b38a9f18fac02da9d5a545f1ca8149f076917d6f3e3a8b94eb
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</table>
20 RTP transport protocol adaptations

The RTP protocol adaptation shall be supported by all implementations of the Privacy Encryption Protocol using the RTP protocol. The RTP_KV protocol adaptation is optional.

For RTP, this Technical Recommendation assumes full control over the encryption process. There is no encryption/authentication of the RTCP messages.

*Note:* This Technical Recommendation does not describe privacy encryption of RTCP messages.

The *protocol* parameter shall be RTP or RTP_KV.

- A Sender / Receiver shall support the RTP *protocol*.
- A Sender using the RTP_KV *protocol* shall transmit the *key_version* along with the ciphered content in the dynamic_key_version field of the Full RTP Extension Header. When using the RTP *protocol*, the dynamic_key_version field of the Full RTP Extension Header shall be set to 0 unless the extension header field is being used for other purposes outside the scope of this Technical Recommendation. A Receiver using the RTP *protocol* shall ignore the dynamic_key_version field of the Full RTP Extension Header. When using the RTP_KV *protocol* the Receiver shall monitor it.

The *mode* parameter shall be one of AES-128-CTR, AES-256-CTR, AES-128-CTR_CMAC-64, AES-256-CTR_CMAC-64, AES-128-CTR_CMAC-64-AAD, AES-256-CTR_CMAC-64-AAD, ECDH_AES-128-CTR, ECDH_AES-256-CTR, ECDH_AES-128-CTR_CMAC-64, ECDH_AES-256-CTR_CMAC-64, ECDH_AES-128-CTR_CMAC-64-AAD, ECDH_AES-256-CTR_CMAC-64-AAD.

- A Sender / Receiver shall support the AES-128-CTR *mode*. Support for all other modes is optional. For modes of operations with authentication, a 64-bit truncated MAC shall be supported. The CMAC function used for authentication shall use the privacy cipher *key*. When the key is 128 bits the CMAC function shall use the AES-128 block cipher. When the key is 256 bits the CMAC function shall use the AES-256 block cipher.

*Note:* The modes AES-128-CTR_CMAC-64 and AES-256-CTR_CMAC-64 are similar in their structure to the CCM mode specified in NIST SP 800-38c with the AES-CBC-MAC function replaced by the more robust AES-CMAC function.

The *key* shall correspond to the *privacy_key* defined in the Privacy Key Derivation section.

The iv'_ctr value shall correspond to iv' || ctr. The iv' value shall be a 64-bit Octet String in binary form. It shall derive from the iv parameter of the stream associated SDP transport file and/or NMOS transport parameters. The iv' value shall correspond to the base iv value for a
stand-alone unidirectional stream or the sum of the base iv and a sub-stream index in the range [0, 1023] for a multiplexed and/or bidirectional stream.

The ctr value shall be a 64-bit Octet String in binary form. It shall be transmitted by the Sender along with the ciphered content. This 64-bit value shall be transmitted in the ctr_high and ctr_low fields of the Full RTP Extension Header. The least significant 24 bits shall be transmitted in the ctr_short field of the Short RTP Extension Header. The ctr value shall start at 0 and increment by 1 modulo 2^{64} every slice being encrypted.

The ctr shall start at 0 for a new key and may continue counting for a given key if it is known that the ctr value cannot wrap-around during the active time of the Sender/Receiver.

A Receiver shall recover the full ctr value from the ctr_low and ctr_high fields of the Full RTP Extension Header as follow:

\[
\text{ctr} = \text{ctr}_{high0} \| \text{ctr}_{high1} \| \text{ctr}_{high2} \| \text{ctr}_{high3} \| \text{ctr}_{low0} \| \text{ctr}_{low1} \| \text{ctr}_{low2} \| \text{ctr}_{low3}
\]

A Receiver shall recover the full ctr value from the ctr_short field of the Short RTP Extension Header as follow:

\[
\begin{align*}
\text{prev24} &= \text{ctr}_5 \| \text{ctr}_6 \| \text{ctr}_7 \\
\text{new24} &= \text{ctr}_short0 \| \text{ctr}_short1 \| \text{ctr}_short2
\end{align*}
\]

If the value corresponding to prev24 is smaller than the value corresponding to new24; then the recovered ctr is \(\text{ctr}_0 \| \text{ctr}_1 \| \text{ctr}_2 \| \text{ctr}_3 \| \text{ctr}_4 \| \text{ctr}_short0 \| \text{ctr}_short1 \| \text{ctr}_short2\); else the recovered ctr is \(\text{ctr}_0 \| \text{ctr}_1 \| \text{ctr}_2 \| \text{ctr}_3 \| \text{ctr}_4 \| \text{ctr}_short0 \| \text{ctr}_short1 \| \text{ctr}_short2 + 00 \| 00 \| 00 \| 00 \| 00 \| 00 \| 00 \| 00\).

**Note:** The else clause is adding 1 to the value corresponding to ctr0 || ctr1 || ctr2 || ctr3 || ctr4 || ctr_short0 || ctr_short1 || ctr_short2.

RTP Header, RTP Header Extensions and RTP Payload Header shall not be encrypted. As per RFC 8088 (How to Write an RTP Payload Format) The RTP Payload Header is defined as follows: "RTP payload formats often need to include metadata relating to the payload data being transported. Such metadata is sent as a payload header, at the start of the payload section of the RTP packet. The RTP packet also includes space for a header extension [RFC5285]; this can be used to transport payload format independent metadata, for example, an SMPTE time code for the packet [RFC5484]. The RTP header extensions are not intended to carry headers that relate to a particular payload format, and must not contain information needed in order to decode the payload."

Depending on the RTP Payload Format, and as specified in the associated RFC specification, the first N bytes of the RTP Payload may contain an RTP Payload Header, as defined in the RFC payload format specification, and as such, shall not be encrypted. Otherwise, if the RFC payload
format specification does not define an RTP Payload Header, the complete RTP Payload shall be encrypted.

The mechanism used by a Sender or Receiver to detect which portion of the RTP Payload is encrypted is outside the scope of this Technical Recommendation. It is expected that an AMWA NMOS message and/or an SDP transport file associated with a Sender media stream would provide the necessary payload format information to a Receiver.

Modes of operation using AAD shall calculate the MAC over the following aad_full Octet String when the Full RTP Extension Header is used, and aad_short Octet String when the Short RTP Extension Header is used, prior to being calculated over the payload data. The Octet String are in binary form.

RTP_KV protocol adaptation:

\[
\text{aad\_full} = 00000000 \| \text{dynamic\_key\_version} \| \text{ctr\_high} \| \text{ctr\_low}
\]

RTP protocol adaptation:

\[
\text{aad\_full} = 00000000 \| 00000000 \| \text{ctr\_high} \| \text{ctr\_low}
\]

RTP and RTP_KV protocol adaptation:

\[
\text{aad\_short} = 0000000000000000 \| 00000000 \| \text{ctr\_short}
\]

Note: Without AAD the MAC applies to the RTP Payload, precisely to the RTP Payload content that is to be encrypted. As described before, RTP Header, RTP Header Extensions and RTP Payload Header are not encrypted and hence are not subject to the MAC. When using AAD additional data is subject to the MAC while still keeping the objective of excluding RTP/UDP/IP specific information.

Note: In order to obtain a fully secure MAC of the encrypted payload a mac-then-encrypt scheme is used with the CMAC function. By using the mac-then-encrypt instead of an encrypt-then-mac, one minimizes the required key material, using the same key for both encryption and authentication. The encrypt-then-mac construction would require using different keys for the encryption and authentication.

21.1 RTP Header Extensions

The following RTP Extension Headers should be declared in the SDP transport file as per RFC 8285.

The following URN shall be used to associate the ID field of the header extensions for the full and short flavors: "urn:ietf:params:rtp-hdrext:PEP-Full-IV-Counter", "urn:ietf:params:rtp-hdrext:PEP-Short-IV-Counter".
The a=extmap attribute shall be used to declare the RTP Extension Headers in the SDP transport file using "sendonly" as the direction parameter.

### 1.1.1 CTR Full RTP Extension Header

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Table 3- CTR Full RTP Extension Header

- All the field are in big-endian unless otherwise specified
- All the Octet String are binary form
- bit 8 of the second 32-bit word shall be set to 0
- RESERVED bits of the second 32-bit word must be set to 0
- ctr_high corresponds to the most significant bits of ctr (first 4 Octet of ctr Octet String)
  - o ctr0 || ctr1 || ctr2 || ctr3
- ctr_low corresponds to the least significant bits of ctr (last 4 Octet of ctr Octet String)
  - o ctr4 || ctr5 || ctr6 || ctr7

### 2.1.1 CTR Short RTP Extension Header

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Table 4 - CTR Short RTP Extension Header

- All the field are in big-endian unless otherwise specified
- All the Octet String are binary form
- ctr_short corresponds to the least significant bits of ctr (last 3 Octet of ctr Octet String)
  - o ctr5 || ctr6 || ctr7

### 2.1.2 RTP Payload format
After the unencrypted RTP Header, RTP Header Extensions and RTP Payload Header the encrypted part of the RTP Payload shall be encoded as a big-endian sequence of bytes subdivided into zero or more complete data slices of 16 bytes, that may be terminated by a partial data slice of less than 16 bytes. Partial data slices shall be assumed to be zero-filled to complete a big-endian data slice of 16 bytes by the AES encryption/decryption internal process. The provided bytes of the partial data slice correspond to the most significant bytes of the big-endian data slice. The zero filled bytes shall be ignored/discarded and not be considered as being part of the RTP Payload.

Note: Any RTP Payload is allowed to terminate with a partial data slice of less than 16 bytes.

A CTR Full RTP Extension Header shall be used in the first RTP packet of a video frame/field, a video frame/field slice, and an audio frame/packet. A CTR Full RTP Extension Header shall also be used in every RTP packet that is not categorized as video or audio. The usage of CTR Full RTP Extension Headers shall ensure that the distance between the associated ctr values of two consecutive Full RTP Extension Headers is less than 2^{24} units. When privacy encrypting an HDCP encrypted RTP stream in-place, and the HDCP encrypted RTP stream uses a Full RTP Extension Header, a CTR Full RTP Extension Header shall be used. A CTR Short RTP Extension Header shall be used when a CTR Full RTP Extension Header is not used.

The RTP packets after the first one, if any, completing a video frame/field, a video frame/field slice or an audio frame/packet should use a CTR Short RTP Extension Header. The concept of “frame” is used for uncompressed and compressed audio and video. The concept of “field” is used for uncompressed and compressed video. The concept of “packet” is used for uncompressed and compressed audio.

Note: A video frame/field may be segmented into slices. Each such slice uses a CTR Full RTP Extension Header in the first RTP packet.

Note: An audio "packet" represents the generic grouping of a number of audio samples into a processing unit.

When a message authentication algorithm is used along with the cipher, the MAC shall be stored as the last N bytes of the RTP Payload. These last N bytes shall be used only by the encryption/decryption process and are not part of the effective RTP payload before/after
encryption/decryption. The RTP payload to encrypt shall be N bytes less than the maximum payload length value possible for a given RTP payload format in order to allow including the N bytes in the length value after encryption.

21.3 Dynamic key_version
A Sender/Receiver configured for in-band dynamic changes of the key_version may change the key_version value dynamically at natural boundaries of the media content (frame, field or GOP boundary for video and ancillary data, packet boundary for audio and generic data) to change the Privacy Cipher encryption key. The current value of the key_version shall be transmitted in clear to the peer through the dynamic_key_version field of the CTR Full RTP Extension Header. The dynamic_key_version value shall correspond to the key_version value used for deriving the encryption key of the associated RTP Payload.

When a Receiver configured for in-band dynamic changes of the key_version becomes active it shall select an initial key_version value. Subsequently it may increment the selected key_version value by 1 modulo $2^{32}$ to change the associated privacy_key during the activation. The key_version may be shared by a number of streams/sub-streams encrypted by a Receiver Device. A Sender/Receiver configured for in-band dynamic changes of the key_version shall use the key_version received in clear from the peer through the dynamic_key_version field of the CTR Full RTP Extension Header to derive the Privacy Cipher decryption key of the associated RTP Payload.

21.4 IPMX integration with HDCP support
The privacy encryption protocol RTP adaptation is compatible with IPMX devices already supporting HDCP in AES-128-CTR mode. An HDCP encrypted content may be privacy encrypted in-place using the same HDCP CTR Full/Short RTP Extension Headers.

- The FRZ control signal of the HDCP CTR Full RTP Extension Header shall be ignored by PEP. It shall be set to 0 in the HDCP CTR Full RTP Extension Header such as to always maintain HDCP encryption and the transmission of HDCP CTR Full/Short RTP Extension Header with appropriate values.

- The StreamCtr value of the HDCP CTR Full RTP Extension Header shall be ignored by PEP.

- The InputCtr value of the HDCP CTR Full/Short RTP Extension Header shall be used by PEP as the ctr_high, ctr_low and ctr_short values.

The privacy cipher described in this document is compatible with the HDCP cipher when $l_{c128}$ and streamCtr at the cipher level are forced to 0. The riv value derives from the iv' value. The ks value is the key derived from PSK, key_generator, key_version and key_pfs values.
21 Other transport protocol adaptations

For transport protocols other than RTP, this Technical Recommendation assumes no control over the encryption process.

The key derives from the privacy_key defined in the Privacy Key Derivation section (key = f(privacy_key)) using a process that is specific to the transport protocol adaptation.

The effective value of iv'_ctr is protocol specific.

The sections of the stream that are encrypted and/or authenticated are protocol specific.