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# Secure Frame (SFrame)

## Abstract

This document describes the Secure Frame (SFrame) end-to-end encryption and authentication mechanism for media frames in a multiparty conference call, in which central media servers (SFUs) can access the media metadata needed to make forwarding decisions without having access to the actual media. The proposed mechanism differs from other approaches through its use of media frames as the encryptable unit, instead of individual RTP packets, which makes it more bandwidth efficient and also allows use with non-RTP transports.

## Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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This Internet-Draft will expire on 30 September 2021.

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Authors' Addresses

## 1. Introduction

Modern multi-party video call systems use Selective Forwarding Unit (SFU) servers to efficiently route RTP streams to call endpoints based on factors such as available bandwidth, desired video size, codec support, and other factors. In order for the SFU to work properly though, it needs to be able to access RTP metadata and RTCP feedback messages, which is not possible if all RTP/RTCP traffic is end-to-end encrypted.

As such, two layers of encryptions and authentication are required:

1. Hop-by-hop (HBH) encryption of media, metadata, and feedback messages between the the endpoints and SFU

2. End-to-end (E2E) encryption of media between the endpoints

While DTLS-SRTP can be used as an efficient HBH mechanism, it is inherently point-to-point and therefore not suitable for a SFU context. In addition, given the various scenarios in which video calling occurs, minimizing the bandwidth overhead of end-to-end encryption is also an important goal.

This document proposes a new end-to-end encryption mechanism known as SFrame, specifically designed to work in group conference calls with SFUs.

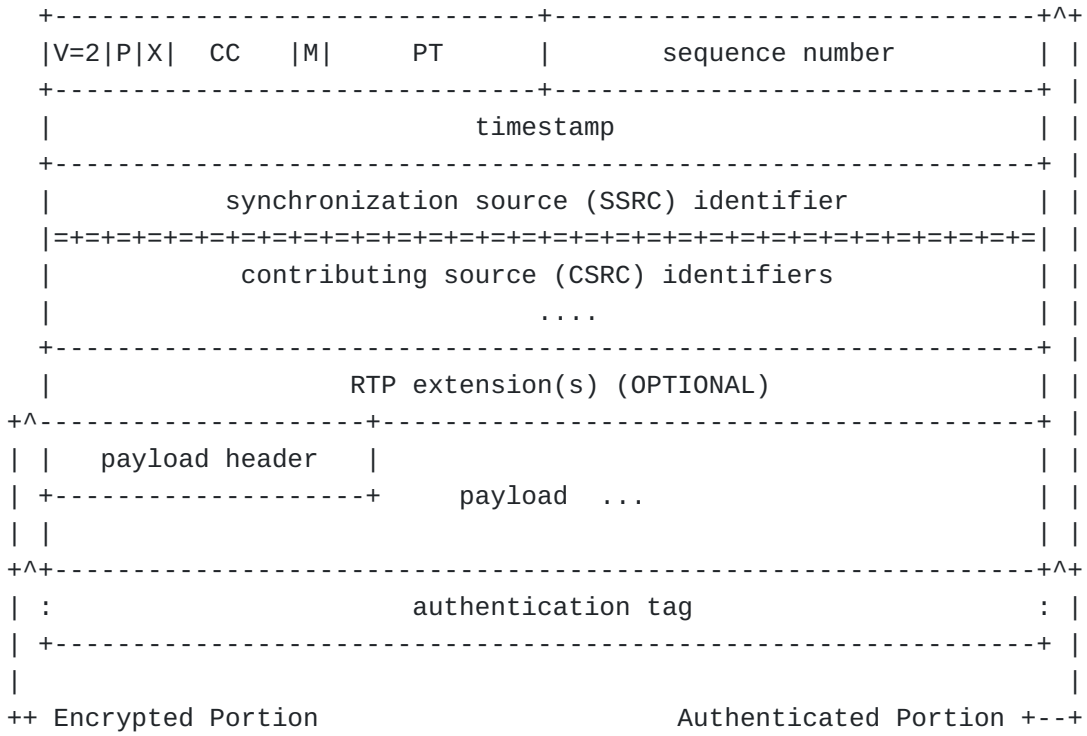



Figure 1: SRTP packet format

## 2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

**SFU:** Selective Forwarding Unit (AKA RTP Switch)

**IV:** Initialization Vector

**MAC:** Message Authentication Code

**E2EE:** End to End Encryption

**HBH:** Hop By Hop

**KMS:** Key Management System

## 3. Goals

SFrame is designed to be a suitable E2EE protection scheme for conference call media in a broad range of scenarios, as outlined by the following goals:

1. Provide an secure E2EE mechanism for audio and video in conference calls that can be used with arbitrary SFU servers.

2. Decouple media encryption from key management to allow SFrame to be used with an arbitrary KMS.

3. Minimize packet expansion to allow successful conferencing in as many network conditions as possible.

4. Independence from the underlying transport, including use in non-RTP transports, e.g., WebTransport.

5. When used with RTP and its associated error resilience mechanisms, i.e., RTX and FEC, require no special handling for RTX and FEC packets.

6. Minimize the changes needed in SFU servers.

7. Minimize the changes needed in endpoints.

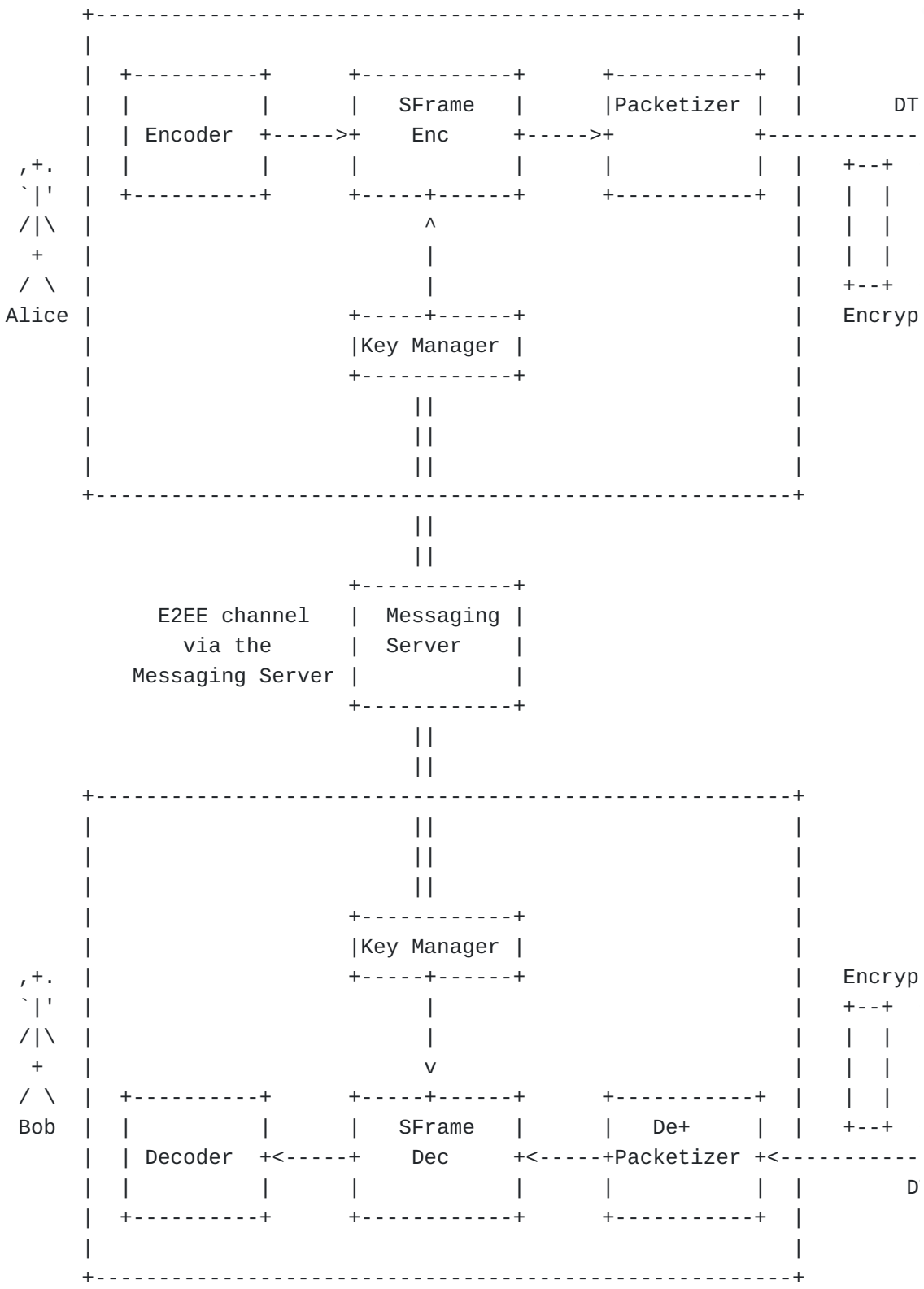
8. Work with the most popular audio and video codecs used in conferencing scenarios.

## 4. SFrame

We propose a frame level encryption mechanism that provides effective end-to-end encryption, is simple to implement, has no dependencies on RTP, and minimizes encryption bandwidth overhead. Because SFrame encrypts the full frame, rather than individual packets, bandwidth overhead is reduced by having a single IV and authentication tag for each media frame.

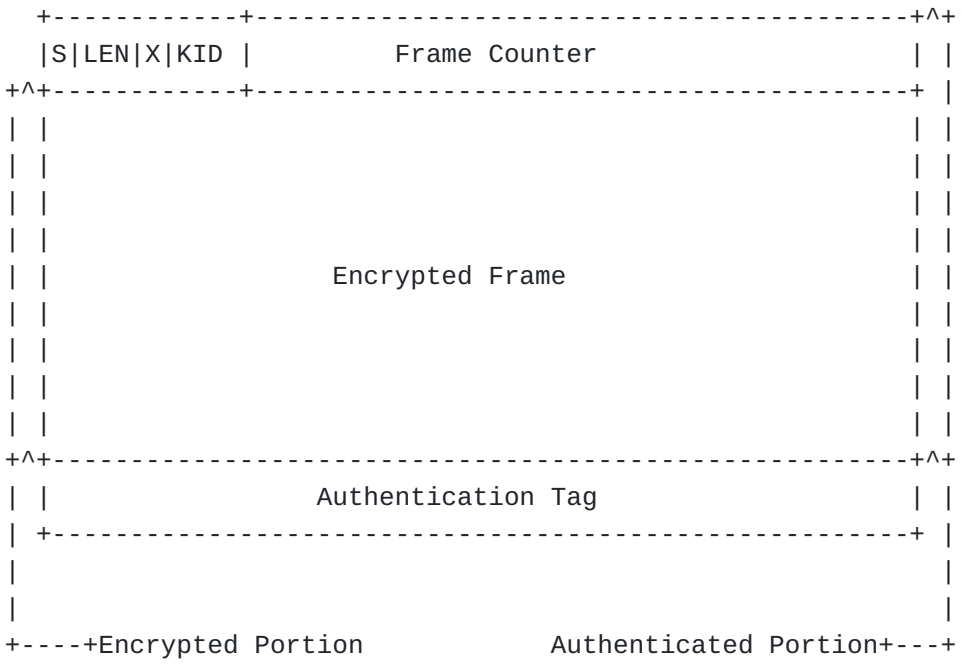
Also, because media is encrypted prior to packetization, the encrypted frame is packetized using a generic RTP packetizer instead of codec-dependent packetization mechanisms. With this move to a generic packetizer, media metadata is moved from codec-specific mechanisms to a generic frame RTP header extension which, while visible to the SFU, is authenticated end-to-end. This extension includes metadata needed for SFU routing such as resolution, frame beginning and end markers, etc.

The generic packetizer splits the E2E encrypted media frame into one or more RTP packets and adds the SFrame header to the beginning of the first packet and an auth tag to the end of the last packet.




The E2EE keys used to encrypt the frame are exchanged out of band using a secure E2EE channel.

### 4.1. SFrame Format

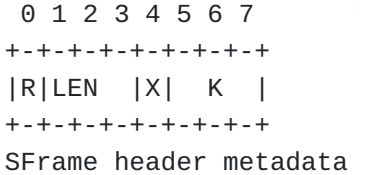



### 4.2. SFrame Header

Since each endpoint can send multiple media layers, each frame will have a unique frame counter that will be used to derive the encryption IV. The frame counter must be unique and monotonically increasing to avoid IV reuse.

As each sender will use their own key for encryption, so the SFrame header will include the key id to allow the receiver to identify the key that needs to be used for decrypting.

Both the frame counter and the key id are encoded in a variable length format to decrease the overhead, so the first byte in the Sframe header is fixed and contains the header metadata with the following format:

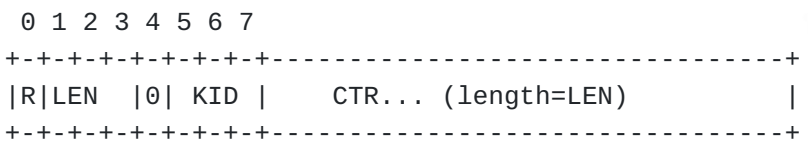



SFrame header metadata

Reserved (R): 1 bit This field MUST be set to zero on sending, and MUST be ignored by receivers. Counter Length (LEN): 3 bits This field indicates the length of the CTR fields in bytes. Extended Key Id Flag (X): 1 bit Indicates if the key field contains the key id or the key length. Key or Key Length: 3 bits This field contains the

key id (KID) if the X flag is set to 0, or the key length (KLEN) if set to 1.

If X flag is 0 then the KID is in the range of 0-7 and the frame counter (CTR) is found in the next LEN bytes:




Key id (KID): 3 bits The key id (0-7). Frame counter (CTR): (Variable length) Frame counter value up to 8 bytes long.

if X flag is 1 then KLEN is the length of the key (KID), that is found after the SFrame header metadata byte. After the key id (KID), the frame counter (CTR) will be found in the next LEN bytes:


Key length (KLEN): 3 bits The key length in bytes. Key id (KID): (Variable length) The key id value up to 8 bytes long. Frame counter (CTR): (Variable length) Frame counter value up to 8 bytes long.

### 4.3. Encryption Schema

SFrame encryption uses an AEAD encryption algorithm and hash function defined by the ciphersuite in use (see Section 4.4). We will refer to the following aspects of the AEAD algorithm below:

- AEAD.Encrypt and AEAD.Decrypt - The encryption and decryption functions for the AEAD. We follow the convention of RFC 5116 [RFC5116] and consider the authentication tag part of the ciphertext produced by AEAD.Encrypt (as opposed to a separate field as in SRTP [RFC3711]).

- AEAD.Nk - The size of a key for the encryption algorithm, in bytes

- AEAD.Nn - The size of a nonce for the encryption algorithm, in bytes

#### 4.3.1. Key Selection

Each SFrame encryption or decryption operation is premised on a single secret base_key, which is labeled with an integer KID value signaled in the SFrame header.

The sender and receivers need to agree on which key should be used for a given KID. The process for provisioning keys and their KID values is beyond the scope of this specification, but its security properties will bound the assurances that SFrame provides. For example, if SFrame is used to provide E2E security against intermediary media nodes, then SFrame keys MUST be negotiated in a way that does not make them accessible to these intermediaries.

For each known KID value, the client stores the corresponding symmetric key base_key. For keys that can be used for encryption, the client also stores the next counter value CTR to be used when encrypting (initially 0).

When encrypting a frame, the application specifies which KID is to be used, and the counter is incremented after successful encryption. When decrypting, the base_key for decryption is selected from the available keys using the KID value in the SFrame Header.

A given key MUST NOT be used for encryption by multiple senders. Such reuse would result in multiple encrypted frames being generated with the same (key, nonce) pair, which harms the protections provided by many AEAD algorithms. Implementations SHOULD mark each key as usable for encryption or decryption, never both.

Note that the set of available keys might change over the lifetime of a real-time session. In such cases, the client will need to manage key usage to avoid media loss due to a key being used to encrypt before all receivers are able to use it to decrypt. For example, an application may make decryption-only keys available immediately, but delay the use of encryption-only keys until (a) all receivers have acknowledged receipt of the new key or (b) a timeout expires.

#### 4.3.2. Key Derivation

SFrame encrytion and decryption use a key and salt derived from the base_key associated to a KID. Given a base_key value, the key and salt are derived using HKDF [RFC5869] as follows:

```
sframe_secret = HKDF-Extract(K, 'SFrame10')
sframe_key = HKDF-Expand(sframe_secret, 'key', AEAD.Nk)
sframe_salt = HKDF-Expand(sframe_secret, 'salt', AEAD.Nn)
```

The hash function used for HKDF is determined by the ciphersuite in use.

#### 4.3.3. Encryption

After encoding the frame and before packetizing it, the necessary media metadata will be moved out of the encoded frame buffer, to be

used later in the RTP generic frame header extension. The encoded frame, the metadata buffer and the frame counter are passed to SFrame encryptor.

SFrame encryption uses the AEAD encryption algorithm for the ciphersuite in use. The key for the encryption is the sframe_key and the nonce is formed by XORing the sframe_salt with the current counter, encoded as a big-endian integer of length AEAD.Nn.

The encryptor forms an SFrame header using the S, CTR, and KID values provided. The encoded header is provided as AAD to the AEAD encryption operation, with any frame metadata appended.

```
def encrypt(S, CTR, KID, frame_metadata, frame):
  sframe_key, sframe_salt = key_store[KID]

  frame_ctr = encode_big_endian(CTR, AEAD.Nn)
  frame_nonce = xor(sframe_salt, frame_ctr)

  header = encode_sframe_header(S, CTR, KID)
  frame_aad = header + frame_metadata

  encrypted_frame = AEAD.Encrypt(sframe_key, frame_nonce, frame_aad, fra
  return header + encrypted_frame
```

The encrypted payload is then passed to a generic RTP packetized to construct the RTP packets and encrypt it using SRTP keys for the HBH encryption to the media server.

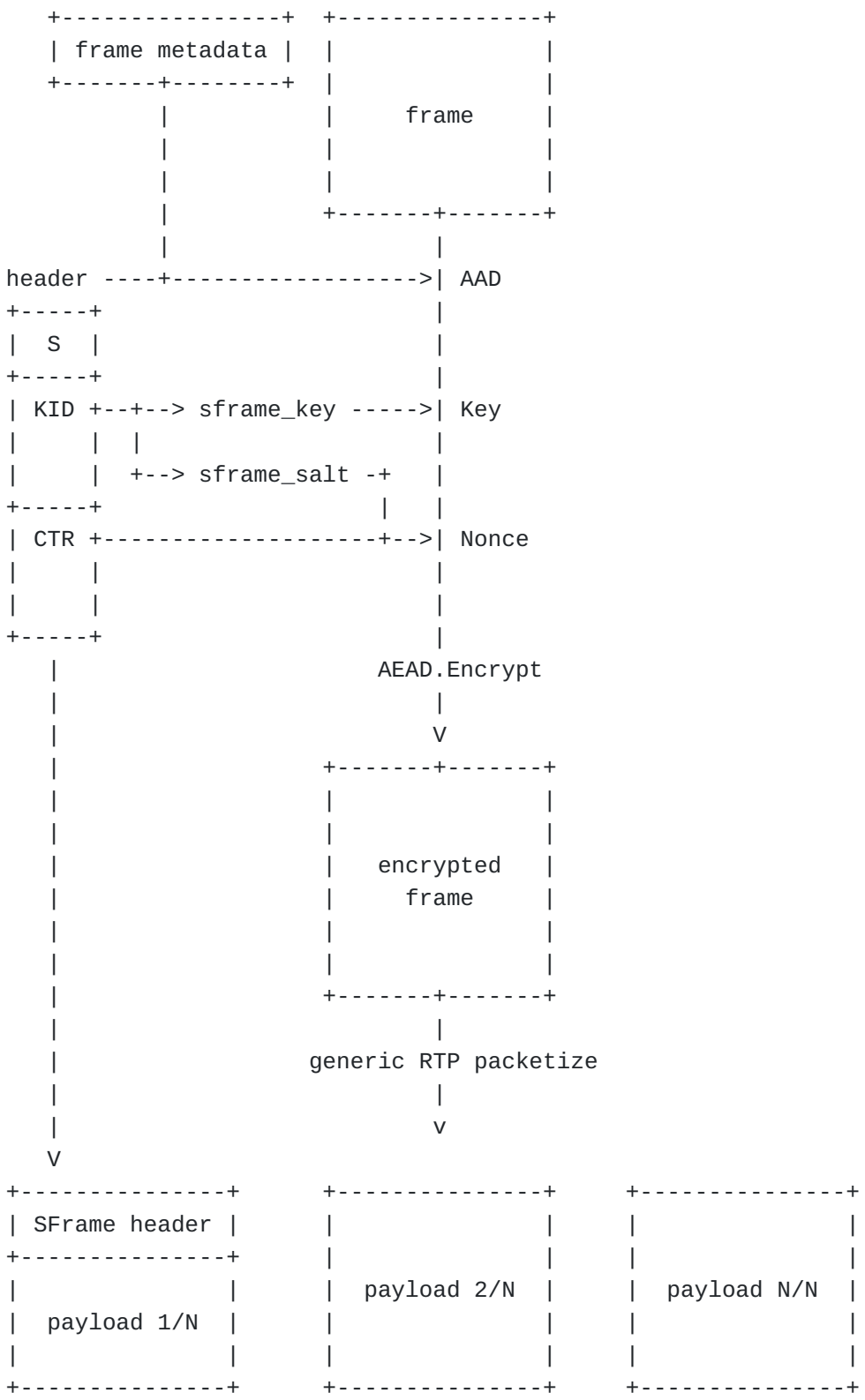



Figure 2: Encryption flow

#### 4.3.4. Decryption

The receiving clients buffer all packets that belongs to the same frame using the frame beginning and ending marks in the generic RTP frame header extension, and once all packets are available, it passes it to SFrame for decryption. The KID field in the SFrame header is used to find the right key for the encrypted frame.

```
def decrypt(frame_metadata, sframe):
  header, encrypted_frame = split_header(sframe)
  S, CTR, KID = parse_header(header)

  sframe_key, sframe_salt = key_store[KID]

  frame_ctr = encode_big_endian(CTR, AEAD.Nn)
  frame_nonce = xor(sframe_salt, frame_ctr)
  frame_aad = header + frame_metadata

  return AEAD.Decrypt(sframe_key, frame_nonce, frame_aad, encrypted_fram
```

For frames that are failed to decrypt because there is key available for the KID in the SFrame header, the client MAY buffer the frame and retry decryption once a key with that KID is received.

#### 4.3.5. Duplicate Frames

Unlike messaging application, in video calls, receiving a duplicate frame doesn't necessary mean the client is under a replay attack, there are other reasons that might cause this, for example the sender might just be sending them in case of packet loss. SFrame decryptors use the highest received frame counter to protect against this. It allows only older frame pithing a short interval to support out of order delivery.

### 4.4. Ciphersuites

Each SFrame session uses a single ciphersuite that specifies the following primitives:

o A hash function used for key derivation and hashing signature inputs

o An AEAD encryption algorithm [RFC5116] used for frame encryption, optionally with a truncated authentication tag

o [Optional] A signature algorithm

This document defines the following ciphersuites:

| Value | Name | Nk | Nn | Reference |
|---|---|---|---|---|
| 0x0001 | AES_CM_128_HMAC_SHA256_8 | 16 | 12 | RFC XXXX |
| 0x0002 | AES_CM_128_HMAC_SHA256_4 | 16 | 12 | RFC XXXX |
| 0x0003 | AES_GCM_128_SHA256 | 16 | 12 | RFC XXXX |
| 0x0004 | AES_GCM_256_SHA512 | 32 | 12 | RFC XXXX |

Table 1

In the "AES_CM" suites, the length of the authentication tag is indicated by the last value: "_8" indicates an eight-byte tag and "_4" indicates a four-byte tag.

In a session that uses multiple media streams, different ciphersuites might be configured for different media streams. For example, in order to conserve bandwidth, a session might use a ciphersuite with 80-bit tags for video frames and another ciphersuite with 32-bit tags for audio frames.

#### 4.4.1. AES-CM with SHA2

In order to allow very short tag sizes, we define a synthetic AEAD function using the authenticated counter mode of AES together with HMAC for authentication. We use an encrypt-then-MAC approach as in SRTP [RFC3711].

Before encryption or decryption, encryption and authentication subkeys are derived from the single AEAD key using HKDF. The subkeys are derived as follows, where Nk represents the key size for the AES block cipher in use and Nh represents the output size of the hash function:

```
def derive_subkeys(key):
  aead_secret = HKDF-Extract(K, 'SFrame10 AES CM AEAD')
  enc_key = HKDF-Expand(aead_secret, 'enc', Nk)
  auth_key = HKDF-Expand(aead_secret, 'auth', Nh)
```

The AEAD encryption and decryption functions are then composed of individual calls to the CM encrypt function and HMAC. The resulting MAC value is truncated to a number of bytes tag_len fixed by the ciphersuite.

```
def compute_tag(nonce, aad, ct):
  aad_len = encode_big_endian(len(aad), 8)
  ct_len = encode_big_endian(len(ct), 8)
  auth_data = aad_len + ct_len + nonce + aad + ct
  tag = HMAC(auth_key, auth_data)
  return truncate(tag, tag_len)

def AEAD.Encrypt(key, nonce, aad, pt):
  ct = AES-CM.Encrypt(key, nonce, pt)
  tag = compute_tag(nonce, aad, ct)
  return ct + tag

def AEAD.Decrypt(key, nonce, aad, ct):
  inner_ct, tag = split_ct(ct, tag_len)

  candidate_tag = compute_tag(nonce, aad, inner_ct)
  if !constant_time_equal(tag, candidate_tag):
    raise Exception("Authentication Failure")

  return AES-CM.Decrypt(key, nonce, inner_ct)
```

## 5. Key Management

SFrame must be integrated with an E2E key management framework to exchange and rotate the keys used for SFrame encryption and/or signing. The key management framework provides the following functions:

- Provisioning KID/base_key mappings to participating clients
- (optional) Provisioning clients with a list of trusted signing keys
- Updating the above data as clients join or leave

It is up to the application to define a rotation schedule for keys. For example, one application might have an ephemeral group for every call and keep rotating key when end points joins or leave the call, while another application could have a persistent group that can be used for multiple calls and simply derives ephemeral symmetric keys for a specific call.

### 5.1. Sender Keys

If the participants in a call have a pre-existing E2E-secure channel, they can use it to distribute SFrame keys. Each client participating in a call generates a fresh encryption key and optionally a signing key pair. The client then uses the E2E-secure channel to send their encryption key and signing public key to the other participants.

In this scheme, it is assumed that receivers have a signal outside of SFrame for which client has sent a given frame, for example the RTP SSRC. SFrame KID values are then used to distinguish generations of the sender's key. At the beginning of a call, each sender encrypts with KID=0. Thereafter, the sender can ratchet their key forward for forward secrecy:

```
sender_key[i+1] = HKDF-Expand(
                    HKDF-Extract(sender_key[i], 'SFrame10 ratchet'),
                      '', AEAD.Nk)
```

The sender signals such an update by incrementing their KID value. A receiver who receives from a sender with a new KID computes the new key as above. The old key may be kept for some time to allow for out-of-order delivery, but should be deleted promptly.

If a new participant joins mid-call, they will need to receive from each sender (a) the current sender key for that sender, (b) the signing key for the sender, if used, and (c) the current KID value for the sender. Evicting a participant requires each sender to send a fresh sender key to all receivers.

### 5.2. MLS

The Messaging Layer Security (MLS) protocol provides group authenticated key exchange [I-D.ietf-mls-architecture] [I-D.ietf-mls-protocol]. In principle, it could be used to instantiate the sender key scheme above, but it can also be used more efficiently directly.

MLS creates a linear sequence of keys, each of which is shared among the members of a group at a given point in time. When a member joins or leaves the group, a new key is produced that is known only to the augmented or reduced group. Each step in the lifetime of the group is know as an "epoch", and each member of the group is assigned an "index" that is constant for the time they are in the group.

In SFrame, we derive per-sender base_key values from the group secret for an epoch, and use the KID field to signal the epoch and sender index. First, we use the MLS exporter to compute a shared SFrame secret for the epoch.

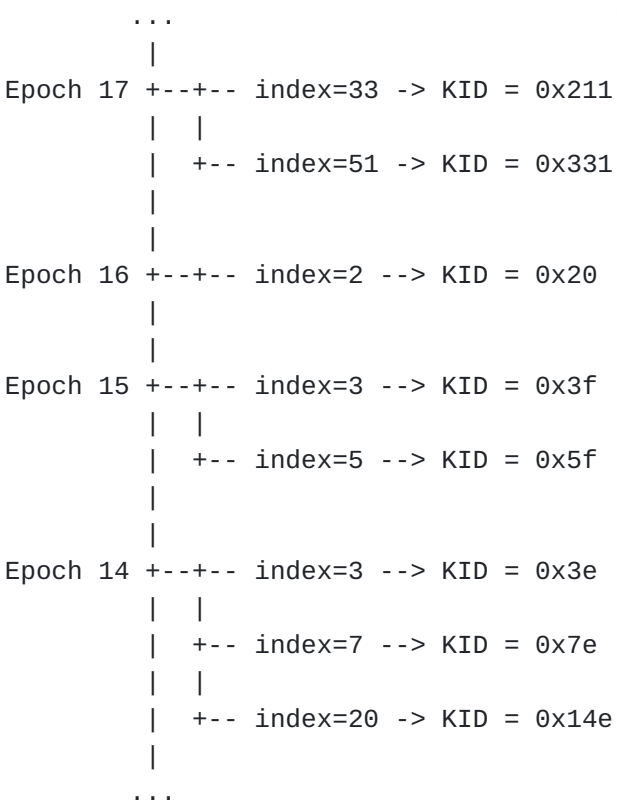
```
sframe_epoch_secret = MLS-Exporter("SFrame 10 MLS", "", AEAD.Nk)

sender_base_key[index] = HKDF-Expand(sframe_epoch_secret,
                           encode_big_endian(index, 4), AEAD.Nk)
```

For compactness, do not send the whole epoch number. Instead, we send only its low-order E bits. Note that E effectively defines a re-ordering window, since no more than 2^E epoch can be active at a

given time. Receivers MUST be prepared for the epoch counter to roll over, removing an old epoch when a new epoch with the same E lower bits is introduced. (Sender indices cannot be similarly compressed.)

```
KID = (sender_index << E) + (epoch % (1 << E))
```

Once an SFrame stack has been provisioned with the sframe_epoch_secret for an epoch, it can compute the required KIDs and sender_base_key values on demand, as it needs to encrypt/decrypt for a given member.




MLS also provides an authenticated signing key pair for each participant. When SFrame uses signatures, these are the keys used to generate SFrame signatures.

## 6. Media Considerations

### 6.1. SFU

Selective Forwarding Units (SFUs) as described in https://tools.ietf.org/html/rfc7667#section-3.7 receives the RTP streams from each participant and selects which ones should be forwarded to each of the other participants. There are several approaches about how to do this stream selection but in general, in order to do so, the SFU needs to access metadata associated to each frame and modify

the RTP information of the incoming packets when they are transmitted to the received participants.

This section describes how this normal SFU modes of operation interacts with the E2EE provided by SFrame

#### 6.1.1. LastN and RTP stream reuse

The SFU may choose to send only a certain number of streams based on the voice activity of the participants. To reduce the number of SDP O/A required to establish a new RTP stream, the SFU may decide to reuse previously existing RTP sessions or even pre-allocate a predefined number of RTP streams and choose in each moment in time which participant media will be sending through it. This means that in the same RTP stream (defined by either SSRC or MID) may carry media from different streams of different participants. As different keys are used by each participant for encoding their media, the receiver will be able to verify which is the sender of the media coming within the RTP stream at any given point if time, preventing the SFU trying to impersonate any of the participants with another participant's media. Note that in order to prevent impersonation by a malicious participant (not the SFU) usage of the signature is required. In case of video, the a new signature should be started each time a key frame is sent to allow the receiver to identify the source faster after a switch.

#### 6.1.2. Simulcast

When using simulcast, the same input image will produce N different encoded frames (one per simulcast layer) which would be processed independently by the frame encryptor and assigned an unique counter for each.

#### 6.1.3. SVC

In both temporal and spatial scalability, the SFU may choose to drop layers in order to match a certain bitrate or forward specific media sizes or frames per second. In order to support it, the sender MUST encode each spatial layer of a given picture in a different frame. That is, an RTP frame may contain more than one SFrame encrypted frame with an incrementing frame counter.

### 6.2. Video Key Frames

Forward and Post-Compromise Security requires that the e2ee keys are updated anytime a participant joins/leave the call.

The key exchange happens async and on a different path than the SFU signaling and media. So it may happen that when a new participant joins the call and the SFU side requests a key frame, the sender

generates the e2ee encrypted frame with a key not known by the receiver, so it will be discarded. When the sender updates his sending key with the new key, it will send it in a non-key frame, so the receiver will be able to decrypt it, but not decode it.

Receiver will re-request an key frame then, but due to sender and sfu policies, that new key frame could take some time to be generated.

If the sender sends a key frame when the new e2ee key is in use, the time required for the new participant to display the video is minimized.

### 6.3. Partial Decoding

Some codes support partial decoding, where it can decrypt individual packets without waiting for the full frame to arrive, with SFrame this won't be possible because the decoder will not access the packets until the entire frame is arrived and decrypted.

## 7. Overhead

The encryption overhead will vary between audio and video streams, because in audio each packet is considered a separate frame, so it will always have extra MAC and IV, however a video frame usually consists of multiple RTP packets. The number of bytes overhead per frame is calculated as the following 1 + FrameCounter length + 4 The constant 1 is the SFrame header byte and 4 bytes for the HBH authentication tag for both audio and video packets.

### 7.1. Audio

Using three different audio frame durations 20ms (50 packets/s) 40ms (25 packets/s) 100ms (10 packets/s) Up to 3 bytes frame counter (3.8 days of data for 20ms frame duration) and 4 bytes fixed MAC length.

| Counter len | Packets | Overhead | Overhead | Overhead |
|---|---|---|---|---|
| | | bps@20ms | bps@40ms | bps@100ms |
| 1 | 0-255 | 2400 | 1200 | 480 |
| 2 | 255 - 65K | 2800 | 1400 | 560 |
| 3 | 65K - 16M | 3200 | 1600 | 640 |

Table 2

### 7.2. Video

The per-stream overhead bits per second as calculated for the following video encodings: 30fps@1000Kbps (4 packets per frame) 30fps@512Kbps (2 packets per frame) 15fps@200Kbps (2 packets per

frame) 7.5fps@30Kbps (1 packet per frame) Overhead bps = (Counter length + 1 + 4 ) * 8 * fps

| Counter len | Frames | Overhead bps@30fps | Overhead bps@15fps | Overhead bps@7.5fps |
|---|---|---|---|---|
| 1 | 0-255 | 1440 | 1440 | 720 |
| 2 | 256 - 65K | 1680 | 1680 | 840 |
| 3 | 56K - 16M | 1920 | 1920 | 960 |
| 4 | 16M - 4B | 2160 | 2160 | 1080 |

Table 3

### 7.3. SFrame vs PERC-lite

[RFC8723] has significant overhead over SFrame because the overhead is per packet, not per frame, and OHB (Original Header Block) which duplicates any RTP header/extension field modified by the SFU. [I-D.murillo-perc-lite] https://mailarchive.ietf.org/arch/msg/perc/SB0qMHWz6EsDtz3yIEX0HWp5IEY/ is slightly better because it doesn't use the OHB anymore, however it still does per packet encryption using SRTP. Below the the overheard in [I-D.murillo-perc-lite] implemented by Cosmos Software which uses extra 11 bytes per packet to preserve the PT, SEQ_NUM, TIME_STAMP and SSRC fields in addition to the extra MAC tag per packet.

OverheadPerPacket = 11 + MAC length Overhead bps = PacketPerSecond * OverHeadPerPacket * 8

Similar to SFrame, we will assume the HBH authentication tag length will always be 4 bytes for audio and video even though it is not the case in this [I-D.murillo-perc-lite] implementation

#### 7.3.1. Audio

| Overhead bps@20ms | Overhead bps@40ms | Overhead bps@100ms |
|---|---|---|
| 6000 | 3000 | 1200 |

Table 4

#### 7.3.2. Video

| Overhead bps@30fps | Overhead bps@15fps | Overhead bps@7.5fps |
|---|---|---|
| (4 packets per frame) | (2 packets per frame) | (1 packet per frame) |
| 14400 | 7200 | 3600 |

Table 5

For a conference with a single incoming audio stream (@ 50 pps) and 4 incoming video streams (@200 Kbps), the savings in overhead is 34800 - 9600 = ~25 Kbps, or ~3%.

## 8. Security Considerations

### 8.1. No Per-Sender Authentication

SFrame does not provide per-sender authentication of media data. Any sender in a session can send media that will be associated with any other sender. This is because SFrame uses symmetric encryption to protect media data, so that any receiver also has the keys required to encrypt packets for the sender.

### 8.2. Key Management

Key exchange mechanism is out of scope of this document, however every client MUST change their keys when new clients joins or leaves the call for "Forward Secrecy" and "Post Compromise Security".

### 8.3. Authentication tag length

The cipher suites defined in this draft use short authentication tags for encryption, however it can easily support other ciphers with full authentication tag if the short ones are proved insecure.

## 9. IANA Considerations

This document makes no requests of IANA.

## 10. References

### 10.1. Normative References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