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A Solution Framework for Private Media in Privacy Enhanced RTP Conferencing
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Abstract

This document describes a solution framework for ensuring that media confidentiality and integrity are maintained end-to-end within the context of a switched conferencing environment where media distribution devices are not trusted with the end-to-end media encryption keys. The solution aims to build upon existing security mechanisms defined for the real-time transport protocol (RTP).

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1. Introduction

Switched conferencing is an increasingly popular model for multimedia conferences with multiple participants using a combination of audio, video, text, and other media types. With this model, real-time media flows from conference participants are not mixed, transcoded,

transrated, recomposed, or otherwise manipulated by a Media Distributor, as might be the case with a traditional media server or multipoint control unit (MCU). Instead, media flows transmitted by conference participants are simply forwarded by the Media Distributor to each of the other participants, often forwarding only a subset of flows based on voice activity detection or other criteria. In some instances, the Media Distributors may make limited modifications to RTP [RFC3550] headers, for example, but the actual media content (e.g., voice or video data) is unaltered.

An advantage of switched conferencing is that Media Distributors can be more easily deployed on general-purpose computing hardware, including virtualized environments in private and public clouds. Deploying conference resources in a public cloud environment might introduce a higher security risk. Whereas traditional conference resources were usually deployed in private networks that were protected, cloud-based conference resources might be viewed as less secure since they are not always physically controlled by those who use them. Additionally, there are usually several ports open to the public in cloud deployments, such as for remote administration, and so on.

This document defines a solution framework wherein media privacy is ensured by making it impossible for a media distribution device to gain access to keys needed to decrypt or authenticate the actual media content sent between conference participants. At the same time, the framework allows for the Media Distributors to modify certain RTP headers; add, remove, encrypt, or decrypt RTP header extensions; and encrypt and decrypt RTCP packets. The framework also prevents replay attacks by authenticating each packet transmitted between a given participant and the media distribution device using a unique key per endpoint that is independent from the key for media encryption and authentication.

A goal of this document is to define a framework for enhanced privacy in RTP-based conferencing environments while utilizing existing security procedures defined for RTP with minimal enhancements.

2. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119] when they appear in ALL CAPS. These words may also appear in this document in lower case as plain English words, absent their normative meanings.

Additionally, this solution framework uses the following conventions, terms and acronyms:

End-to-End (E2E): Communications from one endpoint through one or more Media Distribution Devices to the endpoint at the other end.

Hop-by-Hop (HBH): Communications between an endpoint and a Media Distribution Device or between Media Distribution Devices.

Endpoint: An RTP flow terminating entity that has possession of E2E media encryption keys and terminates E2E encryption. This may include embedded user conferencing equipment or browsers on computers, media gateways, MCUs, media recording device and more that are in the trusted domain for a given deployment.

Media Distributor (MD): An RTP middlebox that is not allowed to to have access to E2E encryption keys. It operates according to the Selective Forwarding Middlebox RTP topologies [I-D.ietf-avtcore-rtp-topologies-update] per the constraints defined by the PERC system, which includes, but not limited to, having no access to RTP media unencrypted and having limits on what RTP header field it can alter.

Key Distributor: An entity that is a logical function which passes keying material and related information to endpoints and Media Distributor(s) that is appropriate for each. The Key Distributor might be co-resident with another entity trusted with E2E keying material.

Conference: Two or more participants communicating via trusted endpoints to exchange RTP flows through one or more Media Distributor.

Third Party: Any entity that is not an Endpoint, Media Distributor, Key Distributor or Call Processing entity as described in this document.

3. PERC Entities and Trust Model

The following figure depicts the trust relationships, direct or indirect, between entities described in the subsequent sub-sections. Note that these entities may be co-located or further divided into multiple, separate physical devices.

Please note that some entities classified as untrusted in the simple, general deployment scenario used most commonly in this document might be considered trusted in other deployments. This document does not preclude such scenarios, but will keep the definitions and examples focused by only using the the simple, most general deployment scenario.

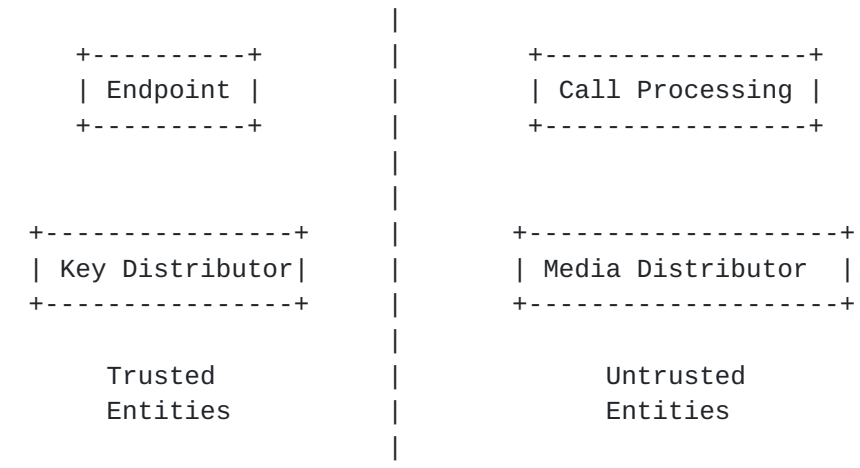


Figure 1: Trusted and Untrusted Entities in PERC

3.1. Untrusted Entities

The architecture described in this framework document enables conferencing infrastructure to be hosted in domains, such as in a cloud conferencing provider's facilities, where the trustworthiness is below the level needed to assume the privacy of participant's media will not be compromised. The conferencing infrastructure in such a domain is still trusted with reliably connecting the participants together in a conference, but not trusted with keying material needed to decrypt any of the participant's media. Entities in such lower trustworthiness domains will simply be referred to as untrusted entities from this point forward. This does not mean that they are completely untrusted as they may be trusted with most non-media related aspects of hosting a conference.

3.1.1. Media Distributor

A Media Distributor forwards RTP flows between endpoints in the conference while performing per-hop authentication of each RTP packet. The Media Distributor may need access to one or more RTP headers or header extensions, potentially adding or modifying a certain subset. The Media Distributor will also relay secured messaging between the endpoints and the Key Distributor and will acquire per-hop key information from the Key Distributor. The actual media content MUST NOT not be decryptable by a Media Distributor, so it is untrusted to have access to the E2E media encryption keys, which this framework's key exchange mechanisms will prevent.

An endpoint's ability to join a conference hosted by a Media Distributor MUST NOT alone be interpreted as being authorized to have access to the E2E media encryption keys, as the Media Distributor

does not have the ability to determine whether an endpoint is authorized.

A Media Distributor MUST perform its role in properly forwarding media packets while taking measures to mitigate the adverse effects of denial of service attacks (refer to Section 6), etc, to a level equal to or better than traditional conferencing (i.e. pre-PERC) deployments.

A Media Distributor or associated conferencing infrastructure may also initiate or terminate various conference control related messaging, which is outside the scope of this framework document.

3.1.2. Call Processing

The call processing function is untrusted in the simple, general deployment scenario. When a physical subset of the call processing function resides in facilities outside the trusted domain, it should not be trusted to have access to E2E key information.

The call processing function may include the processing of call signaling messages, as well as the signing of those messages. It may also authenticate the endpoints for the purpose of call signaling and subsequently joining of a conference hosted through one or more Media Distributors. Call processing may optionally ensure the privacy of call signaling messages between itself, the endpoint, and other entities.

In any deployment scenario where the call processing function is considered trusted, the call processing function MUST ensure the integrity of received messages before forwarding to other entities.

3.2. Trusted Entities

From the PERC model system perspective, entities considered trusted (refer to Figure 1) can be in possession of the E2E media encryption key(s) for one or more conferences.

3.2.1. Endpoint

An endpoint is considered trusted and will have access to E2E key information. While it is possible for an endpoint to be compromised, subsequently performing in undesired ways, defining endpoint resistance to compromise is outside the scope of this document. Endpoints will take measures to mitigate the adverse effects of denial of service attacks (refer to Section 6) from other entities, including from other endpoints, to a level equal to or better than traditional conference (i.e., pre-PERC) deployments.

3.2.2. Key Distributor

The Key Distributor, which may be collocated with an endpoint or exist standalone, is responsible for providing key information to endpoints for both end-to-end and hop-by-hop security and for providing key information to Media Distributors for the hop-by-hop security.

Interaction between the Key Distributor and the call processing function is necessary to for proper conference-to-endpoint mappings. This is described in Section 5.3.

The Key Distributor needs to be secured and managed in a way to prevent exploitation by an adversary, as any kind of compromise of the Key Distributor puts the security of the conference at risk.

4. Framework for PERC

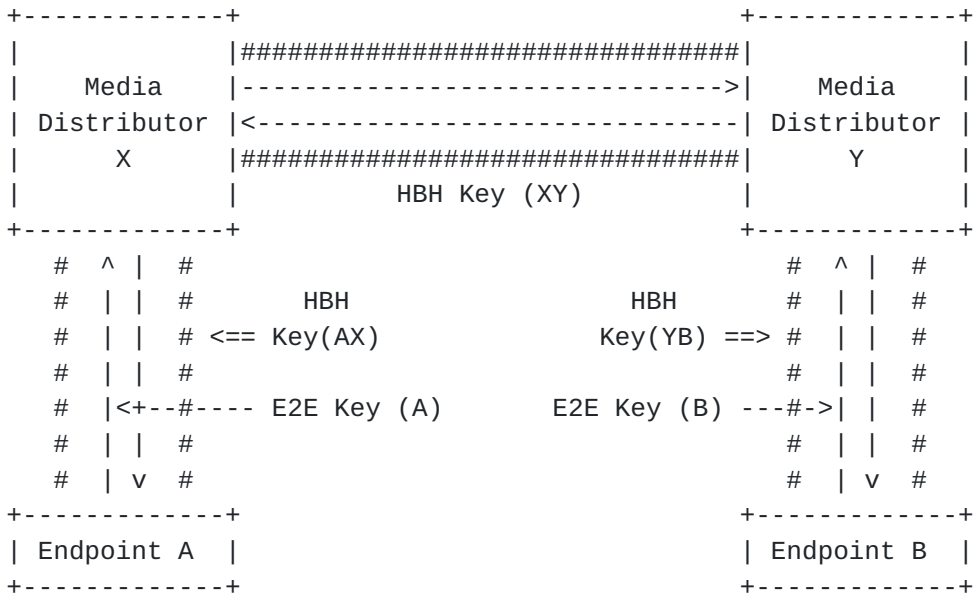
The purpose for this framework is to define a means through which media privacy can be ensured when communicating within a conferencing environment consisting of one or more Media Distributors that only switch, hence not terminate, media. It does not otherwise attempt to hide the fact that a conference between endpoints is taking place.

This framework reuses several specified RTP security technologies, including SRTP [RFC3711], PERC EKT [I-D.ietf-perc-srtp-ekt-diet], and DTLS-SRTP [RFC5764].

4.1. End-to-End and Hop-by-Hop Authenticated Encryption

This solution framework focuses on the end-to-end privacy and integrity of the participant's media by limiting access of the end-to-end key information to trusted entities. However, this framework does give a Media Distributor access to RTP headers and all or most header extensions, as well as the ability to modify a certain subset of those headers and to add header extensions. Packets received by a Media Distributor or an endpoint are authenticated hop-by-hop.

To enable all of the above, this framework defines the use of two security contexts and two associated encryption keys; an "inner" key (E2E Key(i); i={a given endpoint}) for authenticated encryption of RTP media between endpoints and an "outer" key (HBH Key(j); j={a given hop}) for the hop between an endpoint and a Media Distributor or between Media Distributor. Reference the following figure.



E2E and HBH Keys Used for Authenticated Encryption

The PERC Double draft specification [I-D.ietf-perc-double] uses standard SRTP keying material and recommended cryptographic transform(s) to first form the inner, end-to-end SRTP cryptographic context. That end-to-end SRTP cryptographic context MAY be used to encrypt some RTP header extensions along with RTP media content. The output of this is treated like an RTP packet and encrypted again using the outer hop-by-hop cryptographic context. The endpoint executes the entire Double operation while the Media Distributor just performs the outer, hop-by-hop operation.

RTCP can only be encrypted hop-by-hop, not end-to-end. This framework introduces no additional step for RTCP authenticated encryption, so the procedures needed are specified in [RFC3711] and use the same outer, hop-by-hop cryptographic context chosen in the Double operation described above.

4.2. E2E Key Confidentiality

To ensure the confidentiality of E2E keys shared between endpoints, endpoints will make use of a common Key Encryption Key (KEK) that is known only by the trusted entities in a conference. That KEK, defined in the PERC EKT [I-D.ietf-perc-srtp-ekt-diet] as the EKTKey, will be used to subsequently encrypt SRTP master keys used for E2E authenticated encryption (E2E Key(i); i={a given endpoint}) of media sent by a given endpoint.

Key / Entity	Endpoint A	MD X	MD Y	Endpoint B
KEK	Yes	No	No	Yes
E2E Key (i)	Yes	No	No	Yes
HBH Key (A<=>MD X)	Yes	Yes	No	No
HBH Key (B<=>MD Y)	No	No	Yes	Yes

Figure 2: Keys per Entity

4.3. E2E Keys and Endpoint Operations

Any given RTP media flow can be identified by its SSRC, and endpoints might send more than one at a time and change the mix of media flows transmitted during the life of a conference.

Thus, endpoints MUST maintain a list of SSRCs from received RTP flows and each SSRC's associated E2E Key(i) information. Following a change of the KEK (i.e., EKTKey), prior E2E Key(i) information SHOULD be retained for a period long enough to ensure that late-arriving or out-of-order packets from other endpoints can be successfully decrypted. The endpoint MUST discard the E2E Key(i) and KEK information no later than when it leaves the conference.

If there is a need to encrypt one or more RTP header extensions end-to-end, an encryption key is derived from the end-to-end SRTP master key to encrypt header extensions as per [RFC6904]. The Media Distributor will not be able use the information contained in those header extensions encrypted with E2E keys.

4.4. HBH Keys and Hop Operations

To ensure the integrity of transmitted media packets, this framework requires that every packet be authenticated hop-by-hop (HBH) between an endpoint and a Media Distributor, as well between Media Distributors. The authentication key used for hop-by-hop authentication is derived from an SRTP master key shared only on the respective hop (HBH Key(j); j={a given hop}). Each HBH Key(j) is distinct per hop and no two hops ever intentionally use the same SRTP master key.

Using hop-by-hop authentication gives the Media Distributor the ability to change certain RTP header values. Which values the Media Distributor can change in the RTP header are defined in

[I-D.ietf-perc-double]. RTCP can only be encrypted, giving the Media Distributor the flexibility to forward RTCP content unchanged, transmit compound RTCP packets or to initiate RTCP packets for reporting statistics or conveying other information. Performing hop-by-hop authentication for all RTP and RTCP packets also helps provide replay protection (see Section 6).

If there is a need to encrypt one or more RTP header extensions hop-by-hop, an encryption key is derived from the hop-by-hop SRTP master key to encrypt header extensions as per [RFC6904]. This will still give the Media Distributor visibility into header extensions, such as the one used to determine audio level [RFC6464] of conference participants. Note that when RTP header extensions are encrypted, all hops - in the untrusted domain at least - will need to decrypt and re-encrypt these encrypted header extensions.

4.5. Key Exchange

To facilitate key exchange required to establish or generate an E2E key and a HBH key for an endpoint and the same HBH key for the Media Distributor, this framework utilizes a DTLS-SRTP [RFC5764] association between an endpoint and the Key Distributor. To establish this association, an endpoint will send DTLS-SRTP messages to the Media Distributor which will then forward them to the Key Distributor as defined in [I-D.jones-perc-dtls-tunnel]. The Key Encryption Key (KEK) (i.e., EKTKey) is also conveyed by the Key Distributor over the DTLS association to endpoints via procedures defined in PERC EKT [I-D.ietf-perc-srtp-ekt-diet].

Media Distributors use DTLS-SRTP [RFC5764] directly with a peer Media Distributor to establish HBH keys for transmitting RTP and RTCP packets to that peer Media Distributor. The Key Distributor does not facilitate establishing HBH keys for use between Media Distributors.

4.5.1. Initial Key Exchange and Key Distributor

The procedures defined in DTLS Tunnel for PERC [I-D.jones-perc-dtls-tunnel] establish one or more TLS tunnels between the Media Distributor and Key Distributor, making it is possible for the Media Distributor to facilitate the establishment of a secure DTLS association between each endpoint and the Key Distributor as shown the following figure. The DTLS association between endpoints and the Key Distributor will enable each endpoint to receive E2E key information, Key Encryption Key (KEK) information (i.e., EKTKey), and HBH key information. At the same time, the Key Distributor can securely provide the HBH key information to the Media Distributor. The key information summarized here may include the

SRTP master key, SRTP master salt, and the negotiated cryptographic transform.

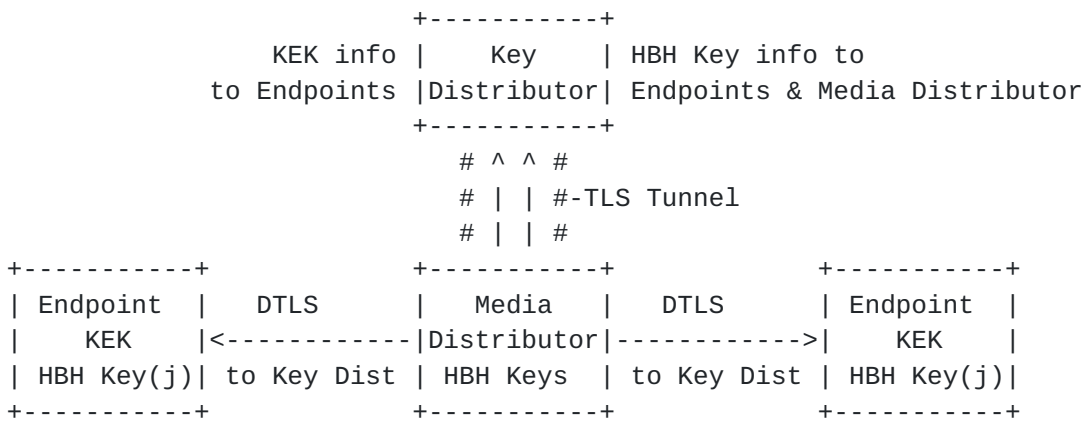


Figure 3: Exchanging Key Information Between Entities

Endpoints will establish a DTLS-SRTP association over the RTP session's media ports for the purposes of key information exchange with the Key Distributor. The Media Distributor will not terminate the DTLS signaling, but will instead forward DTLS packets received from an endpoint on to the Key Distributor (and vice versa) via a tunnel established between Media Distributor and the Key Distributor. This tunnel is used to encapsulate the DTLS-SRTP signaling between the Key Distributor and endpoints will also be used to convey HBH key information from the Key Distributor to the Media Distributor, so no additional protocol or interface is required.

4.5.2. Key Exchange during a Conference

Following the initial key information exchange with the Key Distributor, endpoints will be able to encrypt media end-to-end with their E2E Key(i), sending that E2E Key(i) to other endpoints encrypted with KEK, and will be able to encrypt and authenticate RTP packets using local HBH Key(j). The procedures defined do not allow the Media Distributor to gain access to the KEK information, preventing it from gaining access to any endpoint's E2E key and subsequently decrypting media.

The KEK (i.e., EKTKey) may need to change from time-to-time during the life of a conference, such as when a new participant joins or leaves a conference. Dictating if, when or how often a conference is to be re-keyed is outside the scope of this document, but this framework does accommodate re-keying during the life of a conference.

When a Key Distributor decides to rekey a conference, it transmits a specific message defined in PERC EKT [I-D.ietf-perc-srtp-ekt-diet] to each of the conference participants. The endpoint MUST create a new SRTP master key and prepare to send that key inside a Full EKT Field using the new EKTKey. Since it may take some time for all of the endpoints in conference to finish re-keying, senders MUST delay a short period of time before sending media encrypted with the new master key, but it MUST be prepared to make use of the information from a new inbound EKTKey immediately. See Section 2.2.2 of [I-D.ietf-perc-srtp-ekt-diet].

5. Entity Trust

It is important to this solution framework that the entities can trust and validate the authenticity of other entities, especially the Key Distributor and endpoints. The details of this are outside the scope of specification but a few possibilities are discussed in the following sections. The key requirements is that endpoints can verify they are connected to the correct Key Distributor for the conference and the Key Distributor can verify the endpoints are the correct endpoints for the conference.

Two possible approaches to solve this are Identity Assertions and Certificate Fingerprints.

5.1. Identity Assertions

WebRTC Identity assertion [I-D.ietf-rtcweb-security-arch] can be used to bind the identity of the user of the endpoint to the fingerprint of the DTLS-SRTP certificate used for the call. This certificate is unique for a given call and a conference. This allows the Key Distributor to ensure that only authorized users participate in the conference. Similarly the Key Distributor can create a WebRTC Identity assertion to bind the fingerprint of the unique certificate used by the Key Distributor for this conference so that the endpoint can validate it is talking to the correct Key Distributor. Such a setup requires an Identity Provider (Idp) trusted by the endpoints and the Key Distributor.

5.2. Certificate Fingerprints in Session Signaling

Entities managing session signaling are generally assumed to be untrusted in the PERC framework. However, there are some deployment scenarios where parts of the session signaling may be assumed trustworthy for the purposes of exchanging, in a manner that can be authenticated, the fingerprint of an entity's certificate.

As a concrete example, SIP [RFC3261] and SDP [RFC4566] can be used to convey the fingerprint information per [RFC5763]. An endpoint's SIP User Agent would send an INVITE message containing SDP for the media session along with the endpoint's certificate fingerprint, which can be signed using the procedures described in [RFC4474] for the benefit of forwarding the message to other entities. Other entities can now verify the fingerprints match the certificates found in the DTLS-SRTP connections to find the identity of the far end of the DTLS-SRTP connection and check that is the authorized entity.

Ultimately, if using session signaling, an endpoint's certificate fingerprint would need to be securely mapped to a user and conveyed to the Key Distributor so that it can check that that user is authorized. Similarly, the Key Distributor's certificate fingerprint can be conveyed to endpoint in a manner that can be authenticated as being an authorized Key Distributor for this conference.

5.3. Conferences Identification

The Key Distributor is responsible for knowing what endpoints are allowed in a given conference. Thus, the Key Distributor and the Media Distributor will need to know endpoint-to-conference mappings, which is enabled by exchanging a conference-specific unique identifier as defined in [I-D.jones-perc-dtls-tunnel]. How this unique identifier is assigned is outside the scope of this document.

6. Security Considerations

This framework, and the individual protocols defined to support it, must take care to not increase the exposure to Denial of Service (DoS) attacks by untrusted or third-party entities and should take measures to mitigate, where possible, more serious DoS attacks from on-path and off-path attackers.

The following section enumerates the kind of attacks that will be considered in the development of this framework's solution.

6.1. Third Party Attacks

On-path attacks are mitigated by HBH integrity protection and encryption. The integrity protection mitigates packet modification and encryption makes selective blocking of packets harder, but not impossible.

Off-path attackers may try connecting to different PERC entities and send specifically crafted packets. A successful attacker might be able to get the Media Distributor to forward such packets. If not making use of HBH authentication on the Media Distributor, such an

attack could only be detected in the receiving endpoints where the forged packets would finally be dropped.

Another potential attack is a third party claiming to be a Media Distributor, fooling endpoints in to sending packets to the false Media Distributor instead of the correct one. The deceived sending endpoints could incorrectly assuming their packets have been delivered to endpoints when they in fact have not. Further, the false Media Distributor may cascade to another legitimate Media Distributor creating a false version of the real conference.

This attack can be mitigated by the false Media Distributor not being authenticated by the Key Distributor during PERC Tunnel establishment. Without the tunnel in place, endpoints will not establish secure associations with the Key Distributor and receive the KEK, causing the conference to not proceed.

6.2. Media Distributor Attacks

The Media Distributor can attack the session in a number of possible ways.

6.2.1. Denial of service

Any modification of the end-to-end authenticated data will result in the receiving endpoint getting an integrity failure when performing authentication on the received packet.

The Media Distributor can also attempt to perform resource consumption attacks on the receiving endpoint. One such attack would be to insert random SSRC/CSRC values in any RTP packet with an inband key-distribution message attached (i.e., Full EKT Field). Since such a message would trigger the receiver to form a new cryptographic context, the Media Distributor can attempt to consume the receiving endpoints resources.

Another denial of service attack is where the Media Distributor rewrites the PT field to indicate a different codec. The effect of this attack is that any payload packetized and encoded according to one RTP payload format is then processed using another payload format and codec. Assuming that the implementation is robust to random input, it is unlikely to cause crashes in the receiving software/ hardware. However, it is not unlikely that such rewriting will cause severe media degradation.

For audio formats, this attack is likely to cause highly disturbing audio and/or can be damaging to hearing and playout equipment.

6.2.2. Replay Attack

Replay attack is when an already received packets from a previous point in the RTP stream is replayed as new packet. This could, for example, allow a Media Distributor to transmit a sequence of packets identified as a user saying "yes", instead of the "no" the user actually said.

The mitigation for a replay attack is to prevent old packets beyond a small-to-modest jitter and network re-ordering sized window to be rejected. End-to-end replay protection MUST be provided for the whole duration of the conference.

6.2.3. Delayed Playout Attack

The delayed playout attack is a variant of the replay attack. This attack is possible even if E2E replay protection is in place. However, due to fact that the Media Distributor is allowed to select a sub-set of streams and not forward the rest to a receiver, such as in forwarding only the most active speakers, the receiver has to accept gaps in the E2E packet sequence. The issue with this is that a Media Distributor can select to not deliver a particular stream for a while.

Within the window from last packet forwarded to the receiver and the latest received by the Media Distributor, the Media Distributor can select an arbitrary starting point when resuming forwarding packets. Thus what the media source said can be substantially delayed at the receiver with the receiver believing that it is what was said just now, and only delayed due to transport delay.

6.2.4. Splicing Attack

The splicing attack is an attack where a Media Distributor receiving multiple media sources splices one media stream into the other. If the Media Distributor is able to change the SSRC without the receiver having any method for verifying the original source ID, then the Media Distributor could first deliver stream A and then later forward stream B under the same SSRC as stream A was previously using. Not allowing the Media Distributor to change the SSRC mitigates this attack.

7. IANA Considerations

There are no IANA considerations for this document.

8. Acknowledgments

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