Stream: Internet Engineering Task Force (IETF)
RFC: 8848
Category: Experimental
Published: September 2020
ISSN: 2070-1721
Authors: R. Hanton, *Cisco Systems*; P. Kyzivat; L. Xiao, *Beijing Chuangshiyoulian*; C. Groves

RFC 8848
Session Signaling for Controlling Multiple Streams for Telepresence (CLUE)

Abstract

This document specifies how signaling specific to Controlling Multiple Streams for Telepresence (CLUE), such as the CLUE protocol and 2^{31} the CLUE data channel, is used in conjunction with each other and with existing signaling mechanisms, such as SIP and the Session Description Protocol (SDP), to produce a telepresence call.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for examination, experimental implementation, and evaluation.

This document defines an Experimental Protocol for the Internet community. This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Not all documents approved by the IESG are candidates for any level of Internet Standard; see Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at https://www.rfc-editor.org/info/rfc8848.

Copyright Notice

Table of Contents

1. Introduction

To enable devices to participate in a telepresence call, where they select the sources they wish to view, receive those media sources, and display them in an optimal fashion, Controlling Multiple Streams for Telepresence (CLUE) employs two principal and interrelated protocol negotiations. SDP [RFC4566], conveyed via SIP [RFC3261], is used to negotiate the specific media capabilities that can be delivered to specific addresses on a device. Meanwhile, CLUE protocol messages [RFC8847], transported via a CLUE data channel [RFC8850], are used to negotiate the Capture

Sources available, their attributes, and any constraints in their use. They also allow the far-end device to specify which Captures they wish to receive. It is recommended that those documents be read prior to this one as this document assumes familiarity with those protocols and hence uses terminology from each with limited introduction.

Beyond negotiating the CLUE channel, SDP is also used to negotiate the details of supported media streams and the maximum capability of each of those streams. As the CLUE Framework [RFC8845] defines a manner in which the Media Provider expresses their maximum Encoding Group capabilities, SDP is also used to express the encoding limits for each potential Encoding.

Backwards compatibility is an important consideration of the protocol: it is vital that a CLUE-capable device contacting a device that does not support CLUE is able to fall back to a fully functional non-CLUE call. The document also defines how a non-CLUE call may be upgraded to CLUE mid-call and, similarly, how CLUE functionality can be removed mid-call to return to a standard non-CLUE call.

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.

This document uses terminology defined in the CLUE Framework [RFC8845].

A few additional terms specific to this document are defined as follows:

CLUE-controlled media: A media "m=" line that is under CLUE control; the Capture Source that provides the media on this "m=" line is negotiated in CLUE. See Section 4 for details on how this control is signaled in SDP. There is a corresponding "non-CLUE-controlled" media term.

non-CLUE device: A device that supports standard SIP and SDP but either does not support CLUE or does support CLUE but does not currently wish to invoke CLUE capabilities.

RTCP: RTP Control Protocol.

SCTP: Stream Control Transmission Protocol.

STUN: Session Traversal Utilities for NAT.

3. Media Feature Tag Definition

The "sip.clue" media feature tag [RFC3840] indicates support for CLUE in SIP [RFC3261] calls. A CLUE-capable device **SHOULD** include this media feature tag in its REGISTER requests and OPTION responses. It **SHOULD** also include the media feature tag in INVITE and UPDATE [RFC3311] requests and responses.

Presence of the media feature tag in the contact field of a request or response can be used to determine that the far end supports CLUE.

4. SDP Grouping Framework CLUE Extension Semantics

4.1. General

This section defines a new SDP Grouping Framework [RFC5888] extension called 'CLUE'.

The CLUE extension can be indicated using an SDP session-level 'group' attribute. Each SDP media "m=" line that is included in this group, using SDP media-level mid attributes, is CLUE controlled by a CLUE data channel that is also included in this CLUE group.

Currently, only support for a single CLUE group is specified; support for multiple CLUE groups in a single session is outside the scope of this document. A device **MUST NOT** include more than one CLUE group in its SDP message unless it is following a specification that defines how multiple CLUE channels are signaled and is able to either determine that the other side of the SDP exchange supports multiple CLUE channels or fail gracefully in the event it does not.

4.2. The CLUE Data Channel and the CLUE Grouping Semantic

The CLUE data channel [RFC8850] is a bidirectional data channel [RFC8831] used for the transport of CLUE messages, conveyed within an SCTP over DTLS connection. This channel must be established before CLUE protocol messages can be exchanged and CLUE-controlled media can be sent.

The data channel is negotiated over SDP as described in [RFC8864]. A CLUE-capable device wishing to negotiate CLUE **MUST** also include a CLUE group in their SDP Offer or Answer and include the "mid" of the "m=" line for the data channel in that group. The CLUE group **MUST** include the "mid" of the "m=" line for one (and only one) data channel.

Presence of the data channel in the CLUE group in an SDP Offer or Answer also serves, along with the "sip.clue" media feature tag, as an indication that the device supports CLUE and wishes to upgrade the call to include CLUE-controlled media. A CLUE-capable device **SHOULD** include a data channel "m=" line in offers and, when allowed by [RFC3264], answers.

4.3. CLUE-Controlled Media and the CLUE Grouping Semantic

CLUE-controlled media lines in an SDP are "m=" lines in which the content of the media streams to be sent is negotiated via the CLUE protocol [RFC8847]. For an "m=" line to be CLUE controlled, its "mid" value **MUST** be included in the CLUE group. CLUE-controlled media is controlled by the CLUE protocol as negotiated on the CLUE data channel with a "mid" included in the CLUE group.

"m=" lines not specified as being under CLUE control follow normal rules for media streams negotiated in SDP as defined in documents such as [RFC3264].

The restrictions on CLUE-controlled media that are defined below always apply to "m=" lines in an SDP Offer or Answer, even if negotiation of the data channel in SDP failed due to lack of CLUE support by the remote device or for any other reason, or in an offer if the recipient does not include the "mid" of the corresponding "m=" line in their CLUE group.

4.4. SDP Semantics for CLUE-Controlled Media

4.4.1. Signaling CLUE Encodings

The CLUE Framework [RFC8845] defines the concept of "Encodings", which represent the sender's encode ability. Each Encoding the Media Provider wishes to signal is done so via an "m=" line of the appropriate media type, which **MUST** be marked as sendonly with the "a=sendonly" attribute or as inactive with the "a=inactive" attribute.

The encoder limits of active (e.g., "a=sendonly") Encodings can then be expressed using existing SDP syntax. For instance, for H.264, see Table 6 in Section 8.2.2 of [RFC6184] for a list of valid parameters for representing encoder sender stream limits.

These Encodings are CLUE controlled and hence **MUST** include a "mid" in the CLUE group as defined above.

In addition to the normal restrictions defined in [RFC3264], the stream **MUST** be treated as if the "m=" line direction attribute had been set to "a=inactive" until the Media Provider has received a valid CLUE 'configure' message specifying the Capture to be used for this stream. This means that RTP packets **MUST NOT** be sent until configuration is complete, while non-media packets such as STUN, RTCP, and DTLS **MUST** be sent as per their relevant specifications, if negotiated.

Every "m=" line representing a CLUE Encoding **MUST** contain a "label" attribute as defined in [RFC4574]. This label is used to identify the Encoding by the sender in CLUE 'advertisement' messages and by the receiver in CLUE 'configure' messages. Each label used for a CLUE-controlled "m=" line **MUST** be different from the label on all other "m=" lines in the CLUE group, unless an "m=" line represents a dependent stream related to another "m=" line (such as a Forward Error Correction (FEC) stream), in which case it **MUST** have the same label value as the "m=" line on which it depends.

4.4.1.1. Referencing Encodings in the CLUE Protocol

CLUE Encodings are defined in SDP but can be referenced from CLUE protocol messages -- this is how the protocol defines which Encodings are a part of an Encoding Group (in 'advertisement' messages) and which Encoding is used to encode a specific Capture (in 'configure' messages). The labels on the CLUE-controlled "m=" lines are the references that are used in the CLUE protocol.

Each <encID> (in encodingIDList) in a CLUE 'advertisement' message **SHOULD** represent an Encoding defined in SDP; the specific Encoding referenced is a CLUE-controlled "m=" line in the most recent SDP Offer/Answer message sent by the sender of the 'advertisement' message with a label value corresponding to the text content of the <encID>. If the <encID> is not defined in SDP, it **MUST** be one it anticipates sending in a subsequent SDP Offer/Answer exchange.

Each <encodingID> (in captureEncodingType) in a CLUE 'configure' message **MUST** represent an Encoding defined in SDP; the specific Encoding referenced is a CLUE-controlled "m=" line in the most recent SDP Offer/Answer message received by the sender of the 'configure' message with a label value corresponding to the text content of the <encodingID>.

Note that the non-atomic nature of SDP/CLUE protocol interaction may mean that there are temporary periods where an <encID>/<encodingID> in a CLUE message does not reference an SDP "m=" line, or where an Encoding represented in SDP is not referenced in a CLUE protocol message. See Section 5 for specifics.

4.4.2. Negotiating Receipt of CLUE Capture Encodings in SDP

A receiver who wishes to receive a CLUE stream via a specific Encoding requires an "a=recvonly" "m=" line that matches the "a=sendonly" Encoding.

These "m=" lines are CLUE controlled and hence **MUST** include their "mid" in the CLUE group. They **MAY** include a "label" attribute, but this is not required by CLUE, as only label values associated with "a=sendonly" Encodings are referenced by CLUE protocol messages.

4.5. SDP Offer/Answer Procedures

4.5.1. Generating the Initial Offer

A CLUE-capable device sending an initial SDP Offer of a SIP session and wishing to negotiate CLUE will include an "m=" line for the data channel to convey the CLUE protocol, along with a CLUE group containing the "mid" of the data channel "m=" line.

For interoperability with non-CLUE devices, a CLUE-capable device sending an initial SDP Offer **SHOULD NOT** include any "m=" line for CLUE-controlled media beyond the "m=" line for the CLUE data channel, and it **SHOULD** include at least one non-CLUE-controlled media "m=" line.

If the device has evidence that the receiver is also CLUE capable, for instance, due to receiving an initial INVITE with no SDP but including a "sip.clue" media feature tag, the above recommendation is waived, and the initial offer **MAY** contain "m=" lines for CLUE-controlled media.

With the same interoperability recommendations as for Encodings, the sender of the initial SDP Offer **MAY** also include "a=recvonly" media lines to preallocate "m=" lines to receive media. Alternatively, it **MAY** wait until CLUE protocol negotiation has completed before including these lines in a new offer/answer exchange -- see Section 5 for recommendations.

4.5.2. Generating the Answer

4.5.2.1. Negotiating Use of CLUE and the CLUE Data Channel

If the recipient of an initial offer is CLUE capable, and the offer contains both an "m=" line for a data channel and a CLUE group containing the "mid" for that "m=" line, they **SHOULD** negotiate data channel support for an "m=" line and include the "mid" of that "m=" line in a corresponding CLUE group.

A CLUE-capable recipient that receives an "m=" line for a data channel but no corresponding CLUE group containing the "mid" of that "m=" line **MAY** still include a corresponding data channel "m=" line if there are any other non-CLUE protocols it can convey over that channel, but the use of the CLUE protocol **MUST NOT** be negotiated on this channel.

4.5.2.2. Negotiating CLUE-Controlled Media

If the initial offer contained "a=recvonly" CLUE-controlled media lines, the recipient **SHOULD** include corresponding "a=sendonly" CLUE-controlled media lines for accepted Encodings, up to the maximum number of Encodings it wishes to advertise. As CLUE-controlled media, the "mid" of these "m=" lines **MUST** be included in the corresponding CLUE group. The recipient **MUST** set the direction of the corresponding "m=" lines of any remaining "a=recvonly" CLUE-controlled media lines received in the offer to "a=inactive".

If the initial offer contained "a=sendonly" CLUE-controlled media lines, the recipient **MAY** include corresponding "a=recvonly" CLUE-controlled media lines, up to the maximum number of Capture Encodings it wishes to receive. Alternatively, it **MAY** wait until CLUE protocol negotiation has completed before including these lines in a new offer/answer exchange -- see Section 5 for recommendations. The recipient **MUST** set the direction of the corresponding "m=" lines of any remaining "a=sendonly" CLUE-controlled media lines received in the offer to "a=inactive".

4.5.2.3. Negotiating Non-CLUE-controlled Media

A CLUE-controlled device implementation **MAY** prefer to render initial, single-stream audio and/or video for the user as rapidly as possible, transitioning to CLUE-controlled media once that has been negotiated. Alternatively, an implementation **MAY** wish to suppress initial media, only providing media once the final, CLUE-controlled streams have been negotiated.

The receiver of the initial offer, if making the call CLUE-enabled with their SDP Answer, can make their preference clear by their action in accepting or rejecting non-CLUE-controlled media lines. Rejecting these "m=" lines will ensure that no non-CLUE-controlled media flows before the CLUE-controlled media is negotiated. In contrast, accepting one or more non-CLUE-controlled "m=" lines in this initial answer will enable initial media to flow.

If the answerer chooses to send initial non-CLUE-controlled media in a CLUE-enabled call, Section 4.5.4.1 addresses the need to disable it once the CLUE-controlled media is fully negotiated.

4.5.3. Processing the Initial Offer/Answer Negotiation

In the event that both the offer and answer include a data channel "m=" line with a mid value included in corresponding CLUE groups, CLUE has been successfully negotiated, and the call is now CLUE enabled. If not, then the call is not CLUE enabled.

4.5.3.1. Successful CLUE Negotiation

In the event of successful CLUE enablement of the call, devices **MUST** now begin negotiation of the CLUE channel; see [RFC8850] for negotiation details. If negotiation is successful, the sending of CLUE protocol messages [RFC8847] can begin.

A CLUE-capable device **MAY** choose not to send RTP on the non-CLUE-controlled channels during the period in which control of the CLUE-controlled media lines is being negotiated (though RTCP **MUST** still be sent and received as normal). However, a CLUE-capable device **MUST** still be prepared to receive media on non-CLUE-controlled media lines that have been successfully negotiated as defined in [RFC3264].

If either side of the call wishes to add additional CLUE-controlled "m=" lines to send or receive CLUE-controlled media, they **MAY** now send a SIP request with a new SDP Offer following the normal rules of SDP Offer/Answer and any negotiated extensions.

4.5.3.2. CLUE Negotiation Failure

In the event that the negotiation of CLUE fails and the call is not CLUE enabled once the initial offer/answer negotiation completes, then CLUE is not in use in the call. CLUE-capable devices **MUST** either revert to non-CLUE behavior or terminate the call.

4.5.4. Modifying the Session

4.5.4.1. Adding and Removing CLUE-Controlled Media

Subsequent offer/answer exchanges **MAY** add additional "m=" lines for CLUE-controlled media or activate or deactivate existing "m=" lines per the standard SDP mechanisms.

In most cases, at least one additional exchange after the initial offer/answer exchange will be required before both sides have added all the Encodings and the ability to receive Encodings that they desire. Devices **MAY** delay adding "a=recvonly" CLUE-controlled "m=" lines until after CLUE protocol negotiation completes -- see Section 5 for recommendations.

Once CLUE media has been successfully negotiated, devices **SHOULD** ensure that non-CLUE-controlled media is deactivated by setting their ports to 0 in cases where it corresponds to the media type of CLUE-controlled media that has been successfully negotiated. This deactivation may require an additional SDP exchange or may be incorporated into one that is part of the CLUE negotiation.

4.5.4.2. Enabling CLUE Mid-Call

A CLUE-capable device that receives an initial SDP Offer from a non-CLUE device **SHOULD** include a new data channel "m=" line and corresponding CLUE group in any subsequent offers it sends, to indicate that it is CLUE capable.

If, in an ongoing non-CLUE call, an SDP Offer/Answer exchange completes with both sides having included a data channel "m=" line in their SDP and with the "mid" for that channel in a corresponding CLUE group, then the call is now CLUE enabled; negotiation of the data channel and subsequently the CLUE protocol begins.

4.5.4.3. Disabling CLUE Mid-Call

If, during an ongoing CLUE-enabled call, a device wishes to disable CLUE, it can do so by following the procedures for closing a data channel as defined in Section 6.6.1 of [RFC8864]: sending a new SDP Offer/Answer exchange and subsequent SCTP Stream Sequence Number

(SSN) reset for the CLUE channel. It **MUST** also remove the CLUE group. Without the CLUE group, any "m=" lines that were previously CLUE controlled no longer are; implementations **MAY** disable them by setting their ports to 0 or **MAY** continue to use them -- in the latter case, how they are used is outside the scope of this document.

If a device follows the procedure above, or an SDP Offer/Answer negotiation completes in a fashion in which either the "m=" CLUE data channel line was not successfully negotiated and/or one side did not include the data channel in the CLUE group, then CLUE for this call is disabled. In the event that this occurs, CLUE is no longer enabled. Any active "m=" lines still included in the CLUE group are no longer CLUE controlled, and the implementation **MAY** either disable them in a subsequent negotiation or continue to use them in some other fashion. If the data channel is still present but not included in the CLUE group semantic, CLUE protocol messages **MUST** no longer be sent.

4.5.4.4. CLUE Protocol Failure Mid-Call

In contrast to the specific disablement of the use of CLUE described above, the CLUE channel may fail unexpectedly. Two circumstances where this can occur are:

- The CLUE data channel terminates, either gracefully or ungracefully, without any corresponding SDP renegotiation.
- A channel error of the CLUE protocol causes it to return to the IDLE state as defined in Section 6 of [RFC8847].

In this circumstance, implementations **SHOULD** continue to transmit and receive CLUE-controlled media on the basis of the last negotiated CLUE messages, until the CLUE protocol is re-established (in the event of a channel error) or disabled mid-call by an SDP exchange as defined in Section 4.5.4.3. Implementations **MAY** choose to send such an SDP request to disable CLUE immediately or **MAY** continue on in a call-preservation mode.

5. Interaction of the CLUE Protocol and SDP Negotiations

Information about media streams in CLUE is split between two message types: SDP, which defines media addresses and limits, and the CLUE channel, which defines properties of Capture Devices available, scene information, and additional constraints. As a result, certain operations, such as advertising support for a new transmissible Capture with an associated stream, cannot be performed atomically, as they require changes to both SDP and CLUE messaging.

This section defines how the negotiation of the two protocols interact, provides some recommendations on dealing with intermediate stages in non-atomic operations, and mandates additional constraints on when CLUE-configured media can be sent.

5.1. Independence of SDP and CLUE Negotiation

To avoid the need to implement interlocking state machines with the potential to reach invalid states if messages were to be lost, or be rewritten en route by middleboxes, the state machines in SDP and CLUE operate independently. The state of the CLUE channel does not restrict when an

implementation may send a new SDP Offer or Answer; likewise, the implementation's ability to send a new CLUE 'advertisement' or 'configure' message is not restricted by the results of or the state of the most recent SDP negotiation (unless the SDP negotiation has removed the CLUE channel).

The primary implication of this is that a device may receive an SDP Offer/Answer message with a CLUE Encoding for which it does not yet have Capture information or receive a CLUE 'configure' message specifying a Capture Encoding for which the far end has not negotiated a media stream in SDP.

CLUE messages contain an <encID> (in encodingIDList) or <encodingID> (in captureEncodingType), which is used to identify a specific Encoding or captureEncoding in SDP; see [RFC8846] for specifics. The non-atomic nature of CLUE negotiation means that a sender may wish to send a new CLUE 'advertisement' message before the corresponding SDP message. As such, the sender of the CLUE message **MAY** include an <encID> that does not currently match a CLUE-controlled "m=" line label in SDP; a CLUE-capable implementation **MUST NOT** reject a CLUE protocol message solely because it contains <encID> elements that do not match a label in SDP.

The current state of the CLUE Participant or Media Provider/Consumer state machines does not affect compliance with any of the normative language of [RFC3264]. That is, they **MUST NOT** delay an ongoing SDP exchange as part of a SIP server or client transaction; an implementation **MUST NOT** delay an SDP exchange while waiting for CLUE negotiation to complete or for a 'configure' message to arrive.

Similarly, a device in a CLUE-enabled call **MUST NOT** delay any mandatory state transitions in the CLUE Participant or Media Provider/Consumer state machines due to the presence or absence of an ongoing SDP exchange.

A device with the CLUE Participant state machine in the ACTIVE state **MAY** choose to delay moving from ESTABLISHED to ADV (Media Provider state machine) or from ESTABLISHED to WAIT FOR CONF RESPONSE (Media Consumer state machine) based on the SDP state. See [RFC8847] for CLUE state machine specifics. Similarly, a device **MAY** choose to delay initiating a new SDP exchange based on the state of their CLUE state machines.

5.2. Constraints on Sending Media

While SDP and CLUE message states do not impose constraints on each other, both impose constraints on the sending of media -- CLUE-controlled media **MUST NOT** be sent unless it has been negotiated in both CLUE and SDP: an implementation **MUST NOT** send a specific CLUE Capture Encoding unless its most recent SDP exchange contains an active media channel for that Encoding AND it has received a CLUE 'configure' message specifying a valid Capture for that Encoding.

5.3. Recommendations for Operating with Non-atomic Operations

CLUE-capable devices **MUST** be able to handle states in which CLUE messages make reference to EncodingIDs that do not match the most recently received SDP, irrespective of the order in which SDP and CLUE messages are received. While these mismatches will usually be transitory, a device **MUST** be able to cope with such mismatches remaining indefinitely. However, this document makes some recommendations on message ordering for these non-atomic transitions.

CLUE-capable devices **MUST** ensure that any inconsistencies between SDP and CLUE signaling are temporary by sending updated SDP or CLUE messages as soon as the relevant state machines and other constraints permit.

Generally, implementations that receive messages with incomplete information will be most efficient if they wait until they have the corresponding information they lack before sending messages to make changes related to that information. For example, an answerer that receives a new SDP Offer with three new "a=sendonly" CLUE "m=" lines for which it has received no CLUE 'advertisement' message providing the corresponding capture information would typically include corresponding "a=inactive" lines in its answer, and it would only make a new SDP Offer with "a=recvonly" when and if a new 'advertisement' message arrives with Captures relevant to those Encodings.

Because of the constraints of SDP Offer/Answer and because new SDP negotiations are generally more 'costly' than sending a new CLUE message, implementations needing to make changes to both channels **SHOULD** prioritize sending the updated CLUE message over sending the new SDP message. The aim is for the recipient to receive the CLUE changes before the SDP changes, allowing the recipient to send their SDP Answers without incomplete information and reducing the number of new SDP Offers required.

6. Interaction of the CLUE Protocol and RTP/RTCP CaptureID

The CLUE Framework [RFC8845] allows for Multiple Content Captures (MCCs): Captures that contain multiple source Captures, whether composited into a single stream or switched based on some metric.

The Captures that contribute to these MCCs may or may not be defined in the 'advertisement' message. If they are defined and the MCC is providing them in a switched format, the recipient may wish to determine which originating source Capture is currently being provided, so that they can apply geometric corrections based on that Capture's geometry or take some other action based on the original Capture information.

To do this, [RFC8849] allows for the CaptureID of the originating Capture to be conveyed via RTP or RTCP. A Media Provider sending switched media for an MCC with defined originating sources **MUST** send the CaptureID in both RTP and RTCP, as described in the mapping document.

6.1. CaptureID Reception during MCC Redefinition

Because the RTP/RTCP CaptureID is delivered via a different channel to the 'advertisement' message in which in the contents of the MCC are defined, there is an intrinsic race condition in cases where the contents of an MCC are redefined.

When a Media Provider redefines an MCC that involves CaptureIDs, the reception of the relevant CaptureIDs by the recipient will either lead or lag reception and the processing of the new 'advertisement' message by the recipient. As such, a Media Consumer **MUST NOT** be disrupted by any of the following scenarios in any CLUE-controlled media stream it is receiving, whether that stream is for a static Capture or for an MCC (as any static Capture may be redefined to an MCC in a later 'advertisement' message):

- By receiving RTP or RTCP containing a CaptureID when the most recently processed 'advertisement' message means that no media CaptureIDs are expected.
- By receiving RTP or RTCP without CaptureIDs when the most recently processed 'advertisement' message means that media CaptureIDs are expected.
- By receiving a CaptureID in RTP or RTCP for a Capture defined in the most recently processed 'advertisement' message, but which the same 'advertisement' message does not include in the MCC.
- By receiving a CaptureID in RTP or RTCP for a Capture not defined in the most recently processed 'advertisement' message.

7. Multiplexing of CLUE-Controlled Media Using BUNDLE

7.1. Overview

A CLUE call may involve sending and/or receiving significant numbers of media streams. Conventionally, media streams are sent and received on unique ports. However, each separate port used for this purpose may impose costs that a device wishes to avoid, such as the need to open that port on firewalls and NATs, the need to collect Interactive Connectivity Establishment (ICE) candidates [RFC8445], etc.

The BUNDLE extension [RFC8843] can be used to negotiate the multiplexing of multiple media lines onto a single 5-tuple for sending and receiving media, allowing devices in calls to another BUNDLE-supporting device to potentially avoid some of the above costs.

While CLUE-capable devices **MAY** support the BUNDLE extension for this purpose, supporting the extension is not mandatory for a device to be CLUE compliant.

A CLUE-capable device that supports BUNDLE **SHOULD** also support rtcp-mux [RFC5761]. However, a CLUE-capable device that supports rtcp-mux may or may not support BUNDLE.

7.2. Usage of BUNDLE with CLUE

This specification imposes no additional requirements or restrictions on the usage of BUNDLE when used with CLUE. There is no restriction on combining CLUE-controlled media lines and non-CLUE-controlled media lines in the same BUNDLE group or in multiple such groups. However, there are several steps an implementation may wish to take to ameliorate the cost and time requirements of extra SDP Offer/Answer exchanges between CLUE and BUNDLE.

7.2.1. Generating the Initial Offer

BUNDLE mandates that the initial SDP Offer **MUST** use a unique address for each "m=" line with a non-zero port. Because CLUE implementations generally will not include CLUE-controlled media lines, with the exception of the data channel in the initial SDP Offer, CLUE devices that support large numbers of streams can avoid ever having to open large numbers of ports if they successfully negotiate BUNDLE.

An implementation that does include CLUE-controlled media lines in its initial SDP Offer while also using BUNDLE must take care to avoid rendering its CLUE-controlled media lines unusable in the event the far end does not negotiate BUNDLE if it wishes to avoid the risk of additional SDP exchanges to resolve this issue. This is best achieved by not sending any CLUE-controlled media lines in an initial offer with the 'bundle-only' attribute unless it has been established via some other channel that the recipient supports and is able to use BUNDLE.

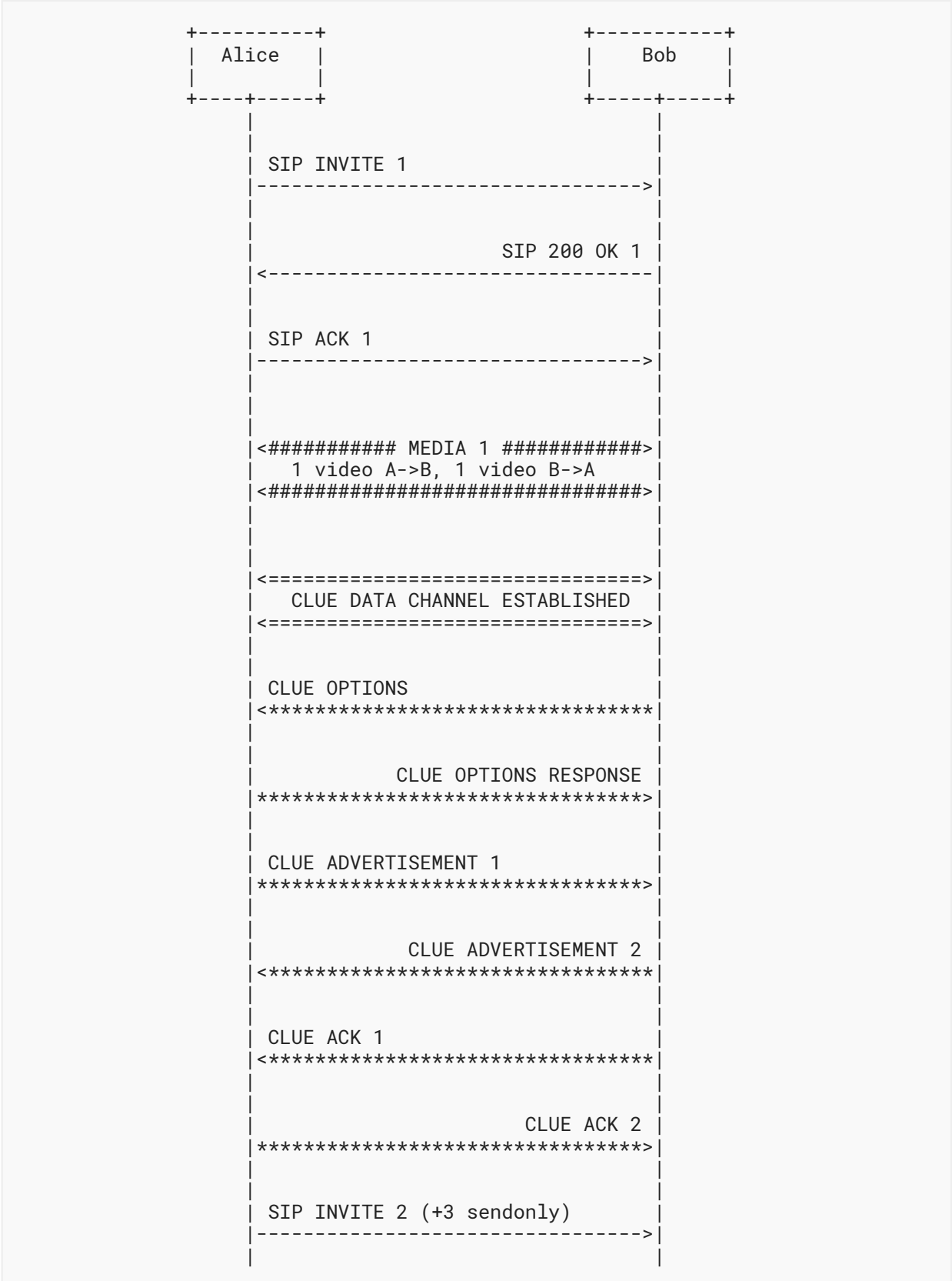
7.2.2. Multiplexing of the Data Channel and RTP Media

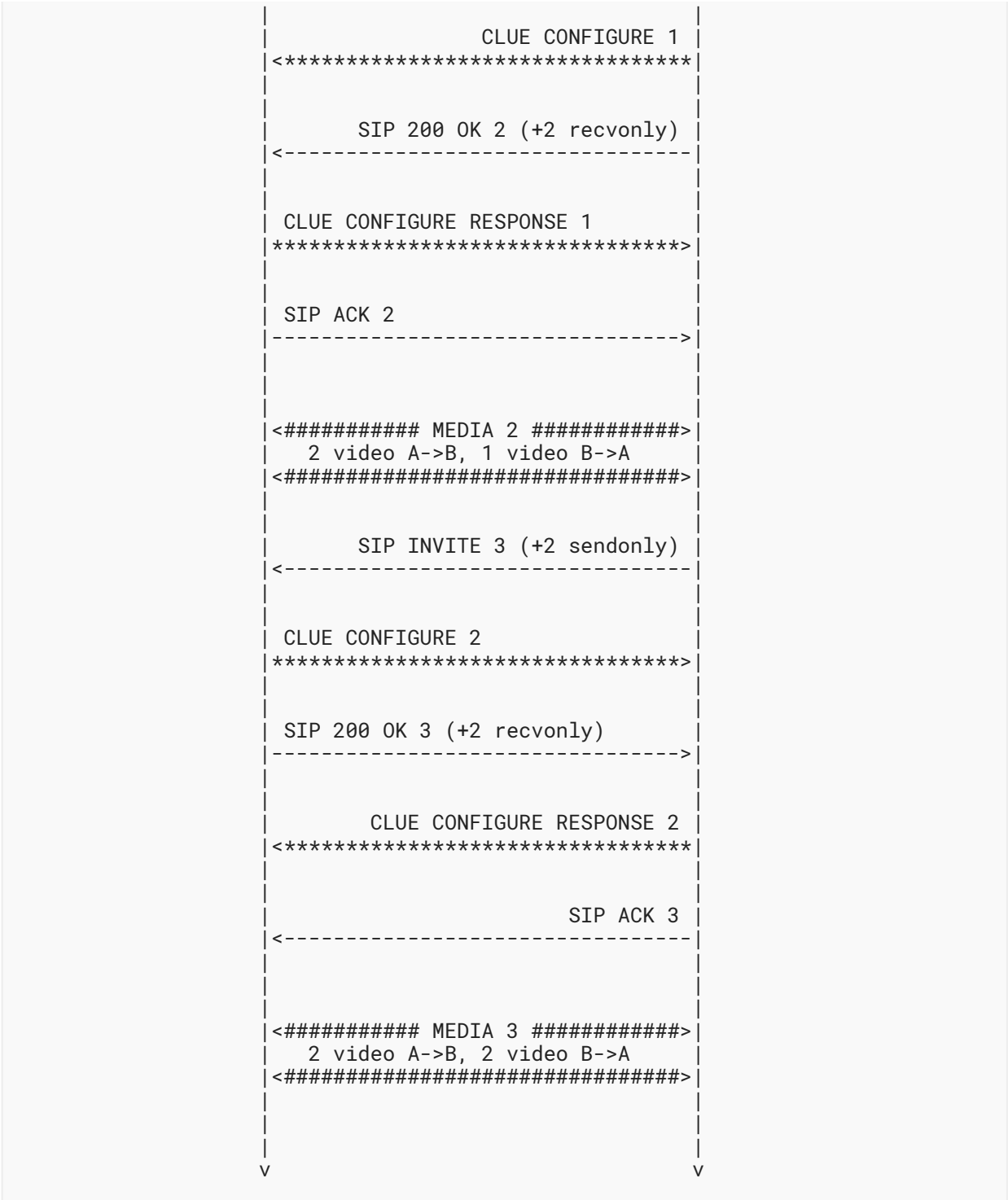
BUNDLE-supporting CLUE-capable devices **MAY** include the data channel in the same BUNDLE group as RTP media. In this case, the device **MUST** be able to demultiplex the various transports -- see Section 9.2 of the BUNDLE specification [RFC8843]. If the BUNDLE group includes protocols other than the data channel transported via DTLS, the device **MUST** also be able to differentiate the various protocols.

8. Example: A Call between Two CLUE-Capable Endpoints

This example illustrates a call between two CLUE-capable Endpoints. Alice, initiating the call, is a system with three cameras and three screens. Bob, receiving the call, is a system with two cameras and two screens. A call-flow diagram is presented, followed by a summary of each message.

To manage the size of this section, the SDP snippets only illustrate video "m=" lines. SIP ACKs are not always discussed. Note that BUNDLE is not in use.


Alice
Bob
SIP INVITE 1
SIP 200 OK 1
SIP ACK 1
MEDIA 1
1 video A->B, 1 video B->A
CLUE DATA CHANNEL ESTABLISHED
CLUE OPTIONS
CLUE OPTIONS RESPONSE
CLUE ADVERTISEMENT 1
CLUE ADVERTISEMENT 2
CLUE ACK 1
CLUE ACK 2
SIP INVITE 2 (+3 sendonly)



In SIP INVITE 1, Alice sends Bob a SIP INVITE with the basic audio and video capabilities and data channel included in the SIP body as per [RFC8841]. Alice also includes the "sip.clue" media feature tag in the INVITE. A snippet of the SDP showing the grouping attribute and the video

"m=" line are shown below. Alice has included a "CLUE" group and the mid corresponding to a data channel in the group (3). Note that Alice has chosen not to include any CLUE-controlled media in the initial offer -- the mid value of the video line is not included in the "CLUE" group.

```
...
a=group:CLUE 3
...
m=video 6002 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=sendrecv
a=mid:2
...
m=application 6100 UDP/DTLS/SCTP webrtc-datachannel
a=setup:actpass
a=sctp-port: 5000
a=dcmap:2 subprotocol="CLUE";ordered=true
a=mid:3
```

Bob responds with a similar SDP in SIP 200 OK 1, which also has a "CLUE" group including the mid value of a data channel; due to their similarity, no SDP snippet is shown here. Bob wishes to receive initial media and thus includes corresponding non-CLUE-controlled audio and video lines. Bob also includes the "sip.clue" media feature tag in the 200 OK. Alice and Bob are each now able to send a single audio and video stream. This is illustrated as MEDIA 1.

With the successful initial SDP Offer/Answer exchange complete, Alice and Bob are also free to negotiate the CLUE data channel. This is illustrated as CLUE DATA CHANNEL ESTABLISHED.

Once the data channel is established, CLUE protocol negotiation begins. In this case, Bob was the DTLS client (sending "a=active" in his SDP Answer) and hence is the CLUE Channel Initiator. He sends a CLUE OPTIONS message describing his version support. On receiving that message, Alice sends her corresponding CLUE OPTIONS RESPONSE.

With the OPTIONS phase complete, Alice now sends her CLUE 'advertisement' message (CLUE ADVERTISEMENT 1). She advertises three static Captures representing her three cameras. She also includes switched Captures suitable for systems with one or two screens. All of these Captures are in a single Capture Scene, with suitable Capture Scene Views that tell Bob he should subscribe to the three static Captures, the two switched Captures, or the one switched Capture. Alice has no simultaneity constraints, so all six Captures are included in one simultaneous set. Finally, Alice includes an Encoding Group with three Encoding IDs: "enc1", "enc2", and "enc3". These Encoding IDs aren't currently valid but will match the next SDP Offer she sends.

Bob received CLUE ADVERTISEMENT 1 but does not yet send a 'configure' message, because he has not yet received Alice's Encoding information; thus, he does not know if she will have sufficient resources in order to send him the two streams he ideally wants at a quality he is happy with. Because Bob is not sending an immediate 'configure' message with the "ack" element set, he must send an explicit 'ack' message (CLUE ACK 1) to signal receipt of CLUE ADVERTISEMENT 1.

Bob also sends his CLUE 'advertisement' message (CLUE ADVERTISEMENT 2) -- though the diagram shows that this occurs after Alice sends CLUE ADVERTISEMENT 1, Bob sends his 'advertisement' message independently and does not wait for CLUE ADVERTISEMENT 1 to arrive. He advertises two static Captures representing his cameras. He also includes a single composed Capture for single-screen systems, in which he will composite the two camera views into a single video stream. All three Captures are in a single Capture Scene, with suitable Capture Scene Views that tell Alice she should subscribe to either the two static Captures or the single composed Capture. Bob also has no simultaneity constraints, so he includes all three Captures in one simultaneous set. Bob also includes a single Encoding Group with two Encoding IDs: "foo" and "bar".

Similarly, Alice receives CLUE ADVERTISEMENT 2 but does not yet send a 'configure' message, because she has not yet received Bob's Encoding information; instead, she sends an 'ack' message (CLUE ACK 2).

Both sides have now sent their CLUE 'advertisement' messages, and an SDP exchange is required to negotiate Encodings. For simplicity, in this case, Alice is shown sending an INVITE with a new offer; in many implementations, both sides might send an INVITE, which would be resolved by use of the 491 Request Pending resolution mechanism from [RFC3261].

Alice now sends SIP INVITE 2. She maintains the sendrecv audio, video, and CLUE "m=" lines, and she adds three new sendonly "m=" lines to represent the three CLUE-controlled Encodings she can send. Each of these "m=" lines has a label corresponding to one of the Encoding IDs from

CLUE ADVERTISEMENT 1. Each also has its mid added to the grouping attribute to show they are controlled by the CLUE data channel. A snippet of the SDP showing the grouping attribute, data channel, and video "m=" lines are shown below:

```
...
a=group:CLUE 3 4 5 6
...
m=video 6002 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=sendrecv
a=mid:2
...
m=application 6100 UDP/DTLS/SCTP webrtc-datachannel
a=sctp-port: 5000
a=dcmap:2 subprotocol="CLUE";ordered=true
a=mid:3
...
m=video 6004 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=mid:4
a=label:enc1
m=video 6006 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=mid:5
a=label:enc2
m=video 6008 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=mid:6
a=label:enc3
```

Bob now has all the information he needs to decide which streams to configure, allowing him to send both a CLUE 'configure' message and his SDP Answer. As such, he now sends CLUE CONFIGURE 1. This requests the pair of switched Captures that represent Alice's scene, and he configures them with encoder ids "enc1" and "enc2".

Bob also sends his SDP Answer as part of SIP 200 OK 2. Alongside his original audio, video, and CLUE "m=" lines, he includes three additional "m=" lines corresponding to the three added by Alice: two active recvonly "m= "lines and an inactive "m=" line for the third. He adds their mid

values to the grouping attribute to show they are controlled by the CLUE data channel. A snippet of the SDP showing the grouping attribute and the video "m=" lines are shown below (mid 100 represents the CLUE data channel, which is not shown):

```
...
a=group:CLUE 11 12 13 100
...
m=video 58722 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=sendrecv
a=mid:10
...
m=video 58724 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:11
m=video 58726 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:12
m=video 58728 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=inactive
a=mid:13
```

Alice receives Bob's CLUE CONFIGURE 1 message and sends CLUE CONFIGURE RESPONSE 1 to acknowledge its reception. She does not yet send the Capture Encodings specified, because at this stage, she hasn't processed Bob's answer SDP and thus hasn't negotiated the ability for Bob to receive these streams.

On receiving SIP 200 OK 2 from Bob, Alice sends her SIP ACK (SIP ACK 2). She is now able to send the two streams of video Bob requested -- this is illustrated as MEDIA 2.

The constraints of offer/answer meant that Bob could not include his Encoding information as new "m=" lines in SIP 200 OK 2. As such, Bob now sends SIP INVITE 3 to generate a new offer. Along with all the streams from SIP 200 OK 2, Bob also includes two new sendonly streams. Each stream has a label corresponding to the Encoding IDs in his CLUE ADVERTISEMENT 2 message.

He also adds their mid values to the grouping attribute to show they are controlled by the CLUE data channel. A snippet of the SDP showing the grouping attribute and the video "m=" lines are shown below (mid 100 represents the CLUE data channel, which is not shown):

```
...
a=group:CLUE 11 12 14 15 100
...
m=video 58722 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=sendrecv
a=mid:10
...
m=video 58724 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:11
m=video 58726 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:12
m=video 0 RTP/AVP 96
a=mid:13
m=video 58728 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=label:foo
a=mid:14
m=video 58730 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=label:bar
a=mid:15
```

Having received this, Alice now has all the information she needs to send her CLUE 'configure' message and her SDP Answer. In CLUE CONFIGURE 2, she requests the two static Captures from Bob to be sent on Encodings "foo" and "bar".

Alice also sends SIP 200 OK 3, matching two recvonly "m=" lines to Bob's new sendonly lines. She includes their mid values in the grouping attribute to show they are controlled by the CLUE data channel. Alice then deactivates the initial non-CLUE-controlled media, as bidirectional CLUE-controlled media is now available. A snippet of the SDP showing the grouping attribute and the video "m=" lines are shown below (mid 3 represents the data channel, not shown):

```
...
a=group:CLUE 3 4 5 7 8
...
m=video 0 RTP/AVP 96
a=mid:2
...
m=video 6004 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=mid:4
a=label:enc1
m=video 6006 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016
a=sendonly
a=mid:5
a=label:enc2
m=video 0 RTP/AVP 96
a=mid:6
m=video 6010 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:7
m=video 6012 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=recvonly
a=mid:8
```

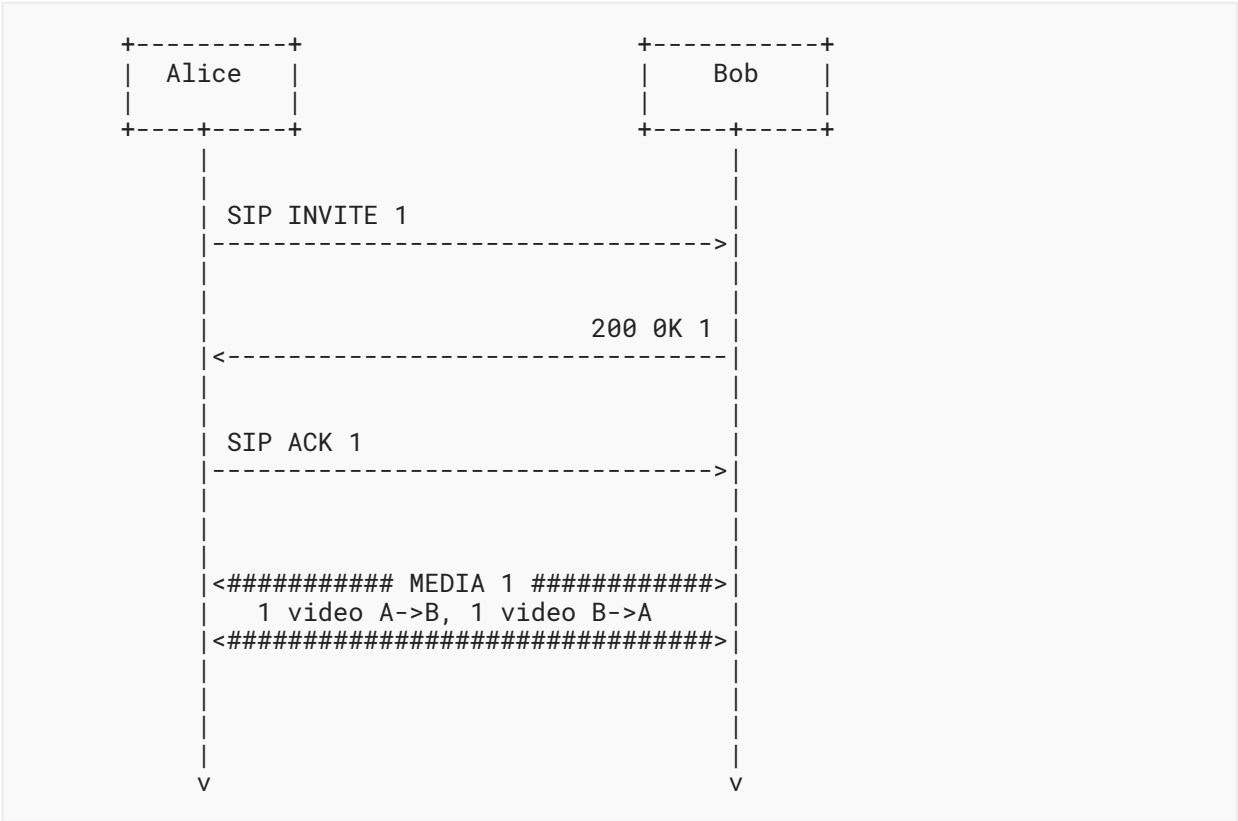
Bob receives Alice's CLUE CONFIGURE 2 message and sends CLUE CONFIGURE RESPONSE 2 to acknowledge its reception. Bob does not yet send the Capture Encodings specified, because he hasn't yet received and processed Alice's SDP Answer and negotiated the ability to send these streams.

Finally, on receiving SIP 200 OK 3, Bob is now able to send the two streams of video Alice requested -- this is illustrated as MEDIA 3.

Both sides of the call are now sending multiple video streams with their sources defined via CLUE negotiation. As the call progresses, either side can send a new 'advertisement' or 'configure' message or the new SDP Offers/Answers to add, remove, or change what they have available or want to receive.

9. Example: A Call between a CLUE-Capable and Non-CLUE Endpoint

In this brief example, Alice is a CLUE-capable Endpoint making a call to Bob, who is not CLUE capable (i.e., is not able to use the CLUE protocol).



In SIP INVITE 1, Alice sends Bob a SIP INVITE including the basic audio and video capabilities and data channel in the SDP body as per [RFC8841]. Alice also includes the "sip.clue" media feature tag in the INVITE. A snippet of the SDP showing the grouping attribute and the video

"m=" line are shown below. Alice has included a "CLUE" group and the mid corresponding to a data channel in the group (3). Note that Alice has chosen not to include any CLUE-controlled media in the initial offer -- the mid value of the video line is not included in the "CLUE" group.

```
...
a=group:CLUE 3
...
m=video 6002 RTP/AVP 96
a=rtpmap:96 H264/90000
a=fmtp:96 profile-level-id=42e016;max-mbps=108000;max-fs=3600
a=sendrecv
a=mid:2
...
m=application 6100 UDP/DTLS/SCTP webrtc-datachannel
a=sctp-port: 5000
a=dcmap:2 subprotocol="CLUE";ordered=true
a=mid:3
```

Bob is not CLUE capable and hence does not recognize the "CLUE" semantic for the grouping attribute, nor does he support the data channel. IN SIP 200 OK 1, he responds with an answer that includes audio and video, but with the data channel zeroed.

From the lack of a CLUE group, Alice understands that Bob does not support CLUE, or does not wish to use it. Both sides are now able to send a single audio and video stream to each other. At this point, Alice begins to send her fallback video: in this case, it's likely a switched view from whichever camera shows the current loudest participant on her side.

10. IANA Considerations

10.1. New SDP Grouping Framework Attribute

This document registers the following semantics with IANA in the "Semantics for the 'group' SDP Attribute" subregistry (under the "Session Description Protocol (SDP) Parameters" registry) per [RFC5888]:

Semantics	Token	Mux Category	Reference
CLUE-controlled "m=" line	CLUE	NORMAL	RFC 8848

Table 1

10.2. New SIP Media Feature Tag

This specification registers a new media feature tag in the SIP [RFC3261] tree per the procedures defined in [RFC2506] and [RFC3840].

Media feature tag name: sip.clue

ASN.1 Identifier: 30

Summary of the media feature indicated by this tag: This feature tag indicates that the device supports CLUE-controlled media.

Values appropriate for use with this feature tag: Boolean.

The feature tag is intended primarily for use in the following applications, protocols, services, or negotiation mechanisms:

> This feature tag is most useful in a communications application for describing the capabilities of a device to use the CLUE control protocol to negotiate the use of multiple media streams.

Related standards or documents: RFC 8848

Security Considerations: Security considerations for this media feature tag are discussed in Section 11 of RFC 8848.

Name(s) & email address(es) of person(s) to contact for further information: Internet Engineering Steering Group <iesg@ietf.org>

Intended usage: COMMON

11. Security Considerations

CLUE makes use of a number of protocols and mechanisms, either defined by CLUE or long-standing. The Security Considerations section of the CLUE Framework document [RFC8845] addresses the need to secure these mechanisms by following the recommendations of the individual protocols.

Beyond the need to secure the constituent protocols, the use of CLUE does impose additional security concerns. One area of increased risk involves the potential for a malicious party to subvert a CLUE-capable device to attack a third party by driving large volumes of media (particularly video) traffic at them by establishing a connection to the CLUE-capable device and directing the media to the victim. While this is a risk for all media devices, a CLUE-capable device may allow the attacker to configure multiple media streams to be sent, significantly increasing the volume of traffic directed at the victim.

This attack can be prevented by ensuring that the media recipient intends to receive the media packets. As such, all CLUE-capable devices **MUST** support key negotiation and receiver intent assurance via DTLS / Secure Real-time Transport Protocol (SRTP) [RFC5763] on CLUE-controlled RTP "m=" lines, and they **MUST** use it or some other mechanism that provides receiver intent assurance. All CLUE-controlled RTP "m" lines must be secured and implemented using mechanisms such as SRTP [RFC3711]. CLUE implementations **MAY** choose not to require the use of SRTP to secure legacy (non-CLUE-controlled) media for backwards compatibility with older SIP clients that are incapable of supporting it.

CLUE also defines a new media feature tag that indicates CLUE support. This tag may be present even in non-CLUE calls, which increases the metadata available about the sending device; this can help an attacker differentiate between multiple devices and identify otherwise anonymized users via the fingerprint of features their device supports. To prevent this, SIP signaling used to set up CLUE sessions **SHOULD** always be encrypted using TLS [RFC5630].

The CLUE protocol also carries additional information that could be used to help fingerprint a particular user or to identify the specific version of software being used. The CLUE Framework [RFC8847] provides details about these issues and how to mitigate them.

12. References

12.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC3711] Baugher, M., McGrew, D., Naslund, M., Carrara, E., and K. Norrman, "The Secure Real-time Transport Protocol (SRTP)", RFC 3711, DOI 10.17487/RFC3711, March 2004, <https://www.rfc-editor.org/info/rfc3711>.

[RFC3840] Rosenberg, J., Schulzrinne, H., and P. Kyzivat, "Indicating User Agent Capabilities in the Session Initiation Protocol (SIP)", RFC 3840, DOI 10.17487/RFC3840, August 2004, <https://www.rfc-editor.org/info/rfc3840>.

[RFC4574] Levin, O. and G. Camarillo, "The Session Description Protocol (SDP) Label Attribute", RFC 4574, DOI 10.17487/RFC4574, August 2006, <https://www.rfc-editor.org/info/rfc4574>.

[RFC5763] Fischl, J., Tschofenig, H., and E. Rescorla, "Framework for Establishing a Secure Real-time Transport Protocol (SRTP) Security Context Using Datagram Transport Layer Security (DTLS)", RFC 5763, DOI 10.17487/RFC5763, May 2010, <https://www.rfc-editor.org/info/rfc5763>.

[RFC5888] Camarillo, G. and H. Schulzrinne, "The Session Description Protocol (SDP) Grouping Framework", RFC 5888, DOI 10.17487/RFC5888, June 2010, <https://www.rfc-editor.org/info/rfc5888>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

[RFC8831] Jesup, R., Loreto, S., and M. Tüxen, "WebRTC Data Channels", RFC 8831, DOI 10.17487/RFC8831, July 2020, <https://www.rfc-editor.org/info/rfc8831>.

[RFC8841] Holmberg, C., Shpount, R., Loreto, S., and G. Camarillo, "Session Description Protocol (SDP) Offer/Answer Procedures for Stream Control Transmission Protocol (SCTP) over Datagram Transport Layer Security (DTLS) Transport", RFC 8841, DOI 10.17487/RFC8841, July 2020, <https://www.rfc-editor.org/info/rfc8841>.

[RFC8843] Holmberg, C., Alvestrand, H., and C. Jennings, "Negotiating Media Multiplexing Using the Session Description Protocol (SDP)", RFC 8843, DOI 10.17487/RFC8843, July 2020, <https://www.rfc-editor.org/info/rfc8843>.

[RFC8845] Duckworth, M., Ed., Pepperell, A., and S. Wenger, "Framework for Telepresence Multi-Streams", RFC 8845, DOI 10.17487/RFC8845, July 2020, <https://www.rfc-editor.org/info/rfc8845>.

[RFC8846] Presta, R. and S P. Romano, "An XML Schema for the Controlling Multiple Streams for Telepresence (CLUE) Data Model", DOI 10.17487/RFC8846, RFC 8846, July 2020, <http://www.rfc-editor.org/info/rfc8846>.

[RFC8847] Presta, R. and S P. Romano, "Protocol for Controlling Multiple Streams for Telepresence (CLUE)", RFC 8847, DOI 10.17487/RFC8847, July 2020, <https://www.rfc-editor.org/info/rfc8847>.

[RFC8849] Even, R. and J. Lennox, "Mapping RTP Streams to Controlling Multiple Streams for Telepresence (CLUE) Media Captures", RFC 8849, DOI 10.17487/RFC8849, July 2020, <https://www.rfc-editor.org/info/rfc8849>.

[RFC8850] Holmberg, C., "Controlling Multiple Streams for Telepresence (CLUE) Protocol Data Channel", RFC 8850, DOI 10.17487/RFC8850, July 2020, <https://www.rfc-editor.org/info/rfc8850>.

[RFC8864] Drage, K., Makaraju, M., Ejzak, R., Marcon, J., and R. Even, Ed., "Data Channel Negotiation Based on the Session Description Protocol (SDP)", RFC 8864, DOI 10.17487/RFC8864, July 2020, <https://www.rfc-editor.org/info/rfc8864>.

12.2. Informative References

[RFC2506] Holtman, K., Mutz, A., and T. Hardie, "Media Feature Tag Registration Procedure", BCP 31, RFC 2506, DOI 10.17487/RFC2506, March 1999, <https://www.rfc-editor.org/info/rfc2506>.

[RFC3261] Rosenberg, J., Schulzrinne, H., Camarillo, G., Johnston, A., Peterson, J., Sparks, R., Handley, M., and E. Schooler, "SIP: Session Initiation Protocol", RFC 3261, DOI 10.17487/RFC3261, June 2002, <https://www.rfc-editor.org/info/rfc3261>.

[RFC3264] Rosenberg, J. and H. Schulzrinne, "An Offer/Answer Model with Session Description Protocol (SDP)", RFC 3264, DOI 10.17487/RFC3264, June 2002, <https://www.rfc-editor.org/info/rfc3264>.

[RFC3311] Rosenberg, J., "The Session Initiation Protocol (SIP) UPDATE Method", RFC 3311, DOI 10.17487/RFC3311, October 2002, <https://www.rfc-editor.org/info/rfc3311>.

[RFC4566] Handley, M., Jacobson, V., and C. Perkins, "SDP: Session Description Protocol", RFC 4566, DOI 10.17487/RFC4566, July 2006, <https://www.rfc-editor.org/info/rfc4566>.

[RFC5630] Audet, F., "The Use of the SIPS URI Scheme in the Session Initiation Protocol (SIP)", RFC 5630, DOI 10.17487/RFC5630, October 2009, <https://www.rfc-editor.org/info/rfc5630>.

[RFC5761] Perkins, C. and M. Westerlund, "Multiplexing RTP Data and Control Packets on a Single Port", RFC 5761, DOI 10.17487/RFC5761, April 2010, <https://www.rfc-editor.org/info/rfc5761>.

[RFC6184] Wang, Y.-K., Even, R., Kristensen, T., and R. Jesup, "RTP Payload Format for H.264 Video", RFC 6184, DOI 10.17487/RFC6184, May 2011, <https://www.rfc-editor.org/info/rfc6184>.

[RFC8445] Keranen, A., Holmberg, C., and J. Rosenberg, "Interactive Connectivity Establishment (ICE): A Protocol for Network Address Translator (NAT) Traversal", RFC 8445, DOI 10.17487/RFC8445, July 2018, <https://www.rfc-editor.org/info/rfc8445>.

Acknowledgements

Besides the authors, the team focusing on this document consists of: Roni Even, Simon Pietro Romano, and Roberta Presta.

Christian Groves, Jonathan Lennox, and Adam Roach have contributed detailed comments and suggestions.

Authors' Addresses

Robert Hanton
Cisco Systems
Email: rohanse2@cisco.com

Paul Kyzivat
Email: pkyzivat@alum.mit.edu

Lennard Xiao
Beijing Chuangshiyoulian
Email: lennard.xiao@outlook.com

Christian Groves
Email: cngroves.std@gmail.com