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# Layered Coding Transport (LCT) Building Block

## Abstract

The Layered Coding Transport (LCT) Building Block provides transport level support for reliable content delivery and stream delivery protocols. LCT is specifically designed to support protocols using IP multicast, but it also provides support to protocols that use unicast. LCT is compatible with congestion control that provides multiple rate delivery to receivers and is also compatible with coding techniques that provide reliable delivery of content. This document obsoletes RFC 3451.

## Status of This Memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

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## 1. Introduction

Layered Coding Transport (LCT) provides transport level support for reliable content delivery and stream delivery protocols. Layered Coding Transport is specifically designed to support protocols using IP multicast, but it also provides support to protocols that use unicast. Layered Coding Transport is compatible with congestion control that provides multiple rate delivery to receivers and is also compatible with coding techniques that provide reliable delivery of content.

This document describes a building block as defined in [RFC3048]. This document is a product of the IETF RMT WG and follows the general guidelines provided in [RFC3269].

[RFC3451], which was published in the "Experimental" category and which is obsoleted by this document, contained a previous version of the protocol.

This Proposed Standard specification is thus based on and backwards compatible with the protocol defined in [RFC3451] updated according to accumulated experience and growing protocol maturity since its original publication. Said experience applies both to this specification itself and to congestion control strategies related to the use of this specification.

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].

## 2. Rationale

LCT provides transport level support for massively scalable protocols using the IP multicast network service. The support that LCT provides is common to a variety of very important applications, including reliable content delivery and streaming applications.

An LCT session comprises multiple channels originating at a single sender that are used for some period of time to carry packets pertaining to the transmission of one or more objects that can be of interest to receivers. The logic behind defining a session as originating from a single sender is that this is the right granularity to regulate packet traffic via congestion control. One rationale for using multiple channels within the same session is that there are massively scalable congestion control protocols that use multiple channels per session. These congestion control protocols are considered to be layered because a receiver joins and leaves channels in a layered order during its participation in the session.

The use of layered channels is also useful for streaming applications.

There are coding techniques that provide massively scalable reliability and asynchronous delivery that are compatible with both layered congestion control and with LCT. When all are combined, the result is a massively scalable reliable asynchronous content delivery protocol that is network friendly. LCT also provides functionality that can be used for other applications as well, e.g., layered streaming applications.

LCT avoids providing functionality that is not massively scalable. For example, LCT does not provide any mechanisms for sending information from receivers to senders, although this does not rule out protocols that both use LCT and do require sending information from receivers to senders.

LCT includes general support for congestion control that must be used. It does not, however, specify which congestion control should be used. The rationale for this is that congestion control must be provided by any protocol that is network friendly, and yet the different applications that can use LCT will not have the same requirements for congestion control. For example, a content delivery protocol may strive to use all available bandwidth between receivers and the sender. It must, therefore, drastically back off its rate when there is competing traffic. On the other hand, a streaming delivery protocol may strive to maintain a constant rate instead of trying to use all available bandwidth, and it may not back off its rate as fast when there is competing traffic.

Beyond support for congestion control, LCT provides a number of fields and supports functionality commonly required by many protocols. For example, LCT provides a Transmission Session ID that can be used to identify to which session each received packet belongs. This is important because a receiver may be joined to many sessions concurrently, and thus it is very useful to be able to demultiplex packets as they arrive according to the session to which they belong. As another example, there are optional fields within the LCT packet header for identifying the object about which information is carried in the packet payload.

## 3. Functionality

An LCT session consists of a set of logically grouped LCT channels associated with a single sender carrying packets with LCT headers for one or more objects. An LCT channel is defined by the combination of a sender and an address associated with the channel by the sender. A

receiver joins a channel to start receiving the data packets sent to the channel by the sender, and a receiver leaves a channel to stop receiving data packets from the channel.

LCT is meant to be combined with other building blocks so that the resulting overall protocol is massively scalable. Scalability refers to the behavior of the protocol in relation to the number of receivers and network paths, their heterogeneity, and the ability to accommodate dynamically variable sets of receivers. Scalability limitations can come from memory or processing requirements, or from the amount of feedback control and redundant data packet traffic generated by the protocol. In turn, such limitations may be a consequence of the features that a complete reliable content delivery or stream delivery protocol is expected to provide.

The LCT header provides a number of fields that are useful for conveying in-band session information to receivers. One of the required fields is the Transmission Session ID (TSI), which allows the receiver of a session to uniquely identify received packets as part of the session. Another required field is the Congestion Control Information (CCI), which allows the receiver to perform the required congestion control on the packets received within the session. Other LCT fields provide optional but often very useful additional information for the session. For example, the Transport Object Identifier (TOI) identifies for which object the packet contains data and flags are included for indicating the close of the session and the close of sending packets for an object. Header extensions can carry additional fields that, for example, can be used for packet authentication or to convey various kinds of timing information: the Sender Current Time (SCT) conveys the time when the packet was sent from the sender to the receiver, the Expected Residual Time (ERT) conveys the amount of time the session or transmission object will be continued for, and Session Last Change (SLC) conveys the time when objects have been added, modified, or removed from the session.

LCT provides support for congestion control. Congestion control MUST be used that conforms to [RFC2357] between receivers and the sender for each LCT session. Congestion control refers to the ability to adapt throughput to the available bandwidth on the path from the sender to a receiver, and to share bandwidth fairly with competing flows such as TCP. Thus, the total flow of packets flowing to each receiver participating in an LCT session MUST NOT compete unfairly with existing flow-adaptive protocols such as TCP.

A multiple rate or a single rate congestion control protocol can be used with LCT. For multiple rate protocols, a session typically consists of more than one channel, and the sender sends packets to

the channels in the session at rates that do not depend on the receivers. Each receiver adjusts its reception rate during its participation in the session by joining and leaving channels dynamically depending on the available bandwidth to the sender independent of all other receivers. Thus, for multiple rate protocols, the reception rate of each receiver may vary dynamically independent of the other receivers.

For single rate protocols, a session typically consists of one channel and the sender sends packets to the channel at variable rates over time depending on feedback from receivers. Each receiver remains joined to the channel during its participation in the session. Thus, for single rate protocols, the reception rate of each receiver may vary dynamically but in coordination with all receivers.

Generally, a multiple rate protocol is preferable to a single rate protocol in a heterogeneous receiver environment, since generally it more easily achieves scalability to many receivers and provides higher throughput to each individual receiver. Use of the multiple rate congestion control scheme defined in [RFC3738] is RECOMMENDED. Alternative multiple rate congestion control protocols are described in [VIC1998] and [BYE2000]. A possible single rate congestion control protocol is described in [RIZ2000].

Layered coding refers to the ability to produce a coded stream of packets that can be partitioned into an ordered set of layers. The coding is meant to provide some form of reliability, and the layering is meant to allow the receiver experience (in terms of quality of playout, or overall transfer speed) to vary in a predictable way depending on how many consecutive layers of packets the receiver is receiving.

The concept of layered coding was first introduced with reference to audio and video streams. For example, the information associated with a TV broadcast could be partitioned into three layers, corresponding to black and white, color, and HDTV quality. Receivers can experience different quality without the need for the sender to replicate information in the different layers.

The concept of layered coding can be naturally extended to reliable content delivery protocols when Forward Error Correction (FEC) techniques are used for coding the data stream. Descriptions of this can be found in [RIZ1997a], [RIZ1997b], [GEM2000], [VIC1998], and [BYE1998]. By using FEC, the data stream is transformed in such a way that reconstruction of a data object does not depend on the reception of specific data packets, but only on the number of different packets received. As a result, by increasing the number of layers from which a receiver is receiving, the receiver can reduce

the transfer time accordingly. Using FEC to provide reliability can increase scalability dramatically in comparison to other methods for providing reliability. More details on the use of FEC for reliable content delivery can be found in [RFC3453].

Reliable protocols aim at giving guarantees on the reliable delivery of data from the sender to the intended recipients. Guarantees vary from simple packet data integrity to reliable delivery of a precise copy of an object to all intended recipients. Several reliable content delivery protocols have been built on top of IP multicast using methods other than FEC, but scalability was not the primary design goal for many of them.

Two of the key difficulties in scaling reliable content delivery using IP multicast are dealing with the amount of data that flows from receivers back to the sender and the associated response (generally data retransmissions) from the sender. Protocols that avoid any such feedback, and minimize the amount of retransmissions, can be massively scalable. LCT can be used in conjunction with FEC codes or a layered codec to achieve reliability with little or no feedback.

Protocol instantiations (PIs) MAY be built by combining the LCT framework with other components. A complete protocol instantiation that uses LCT MUST include a congestion control protocol that is compatible with LCT and that conforms to [RFC2357]. A complete protocol instantiation that uses LCT MAY include a scalable reliability protocol that is compatible with LCT, it MAY include a session control protocol that is compatible with LCT, and it MAY include other protocols such as security protocols.

## 4. Applicability

An LCT session comprises a logically related set of one or more LCT channels originating at a single sender. The channels are used for some period of time to carry packets containing LCT headers, and these headers pertain to the transmission of one or more objects that can be of interest to receivers.

LCT is most applicable for delivery of objects or streams in a session of substantial length, i.e., objects or streams that range in aggregate length from hundreds of kilobytes to many gigabytes, and where the duration of the session is on the order of tens of seconds or more.

As an example, an LCT session could be used to deliver a TV program using three LCT channels. Receiving packets from the first LCT channel could allow black and white reception. Receiving the first

two LCT channels could also permit color reception. Receiving all three channels could allow HDTV quality reception. Objects in this example could correspond to individual TV programs being transmitted.

As another example, a reliable LCT session could be used to reliably deliver hourly updated weather maps (objects) using ten LCT channels at different rates, using FEC coding. A receiver may join and concurrently receive packets from subsets of these channels, until it has enough packets in total to recover the object, then leave the session (or remain connected listening for session description information only) until it is time to receive the next object. In this case, the quality metric is the time required to receive each object.

Before joining a session, the receivers must obtain enough of the session description to start the session. This includes the relevant session parameters needed by a receiver to participate in the session, including all information relevant to congestion control. The session description is determined by the sender, and is typically communicated to the receivers out-of-band. In some cases, as described later, parts of the session description that are not required to initiate a session MAY be included in the LCT header or communicated to a receiver out-of-band after the receiver has joined the session.

An encoder MAY be used to generate the data that is placed in the packet payload in order to provide reliability. A suitable decoder is used to reproduce the original information from the packet payload. There MAY be a reliability header that follows the LCT header if such an encoder and decoder is used. The reliability header helps to describe the encoding data carried in the payload of the packet. The format of the reliability header depends on the coding used, and this is negotiated out-of-band. As an example, one of the FEC headers described in [RFC5052] could be used.

For LCT, when multiple rate congestion control is used, congestion control is achieved by sending packets associated with a given session to several LCT channels. Individual receivers dynamically join one or more of these channels, according to the network congestion as seen by the receiver. LCT headers include an opaque field that MUST be used to convey congestion control information to the receivers. The actual congestion control scheme to use with LCT is negotiated out-of-band. Some examples of congestion control protocols that may be suitable for content delivery are described in [VIC1998], [BYE2000], and [RFC3738]. Other congestion controls may be suitable when LCT is used for a streaming application.

This document does not specify and restrict the type of exchanges between LCT (or any protocol instantiation built on top of LCT) and an upper application. Some upper APIs may use an object-oriented approach, where the only possible unit of data exchanged between LCT (or any protocol instantiation built on top of LCT) and an application, either at a source or at a receiver, is an object. Other APIs may enable a sending or receiving application to exchange a subset of an object with LCT (or any PI built on top of LCT), or may even follow a streaming model. These considerations are outside the scope of this document.

### 4.1. Environmental Requirements and Considerations

LCT is intended for congestion controlled delivery of objects and streams (both reliable content delivery and streaming of multimedia information).

LCT can be used with both multicast and unicast delivery. LCT requires connectivity between a sender and receivers, but it does not require connectivity from receivers to a sender. LCT inherently works with all types of networks, including LANs, WANs, Intranets, the Internet, asymmetric networks, wireless networks, and satellite networks. Thus, the inherent raw scalability of LCT is unlimited. However, when other specific applications are built on top of LCT, then these applications, by their very nature, may limit scalability. For example, if an application requires receivers to retrieve out-of-band information in order to join a session, or an application allows receivers to send requests back to the sender to report reception statistics, then the scalability of the application is limited by the ability to send, receive, and process this additional data.

LCT requires receivers to be able to uniquely identify and demultiplex packets associated with an LCT session. In particular, there MUST be a Transport Session Identifier (TSI) associated with each LCT session. The TSI is scoped by the IP address of the sender, and the IP address of the sender together with the TSI MUST uniquely identify the session. If the underlying transport is UDP, as described in [RFC0768], then the 16-bit UDP source port number MAY serve as the TSI for the session. The TSI value MUST be the same in all places it occurs within a packet. If there is no underlying TSI provided by the network, transport, or any other layer, then the TSI MUST be included in the LCT header.

LCT is presumed to be used with an underlying network or transport service that is a "best effort" service that does not guarantee packet reception or packet reception order, and that does not have any support for flow or congestion control. For example, the Any-Source Multicast (ASM) model of IP multicast as defined in [RFC1112]

is such a "best effort" network service. While the basic service provided by [RFC1112] is largely scalable, providing congestion control or reliability should be done carefully to avoid severe scalability limitations, especially in the presence of heterogeneous sets of receivers.

There are currently two models of multicast delivery, the Any-Source Multicast (ASM) model as defined in [RFC1112] and the Source-Specific Multicast (SSM) model as defined in [RFC4607]. LCT works with both multicast models, but in a slightly different way with somewhat different environmental concerns. When using ASM, a sender S sends packets to a multicast group G, and the LCT channel address consists of the pair (S,G), where S is the IP address of the sender and G is a multicast group address. When using SSM, a sender S sends packets to an SSM channel (S,G), and the LCT channel address coincides with the SSM channel address.

A sender can locally allocate unique SSM channel addresses, and this makes allocation of LCT channel addresses easy with SSM. To allocate LCT channel addresses using ASM, the sender must uniquely chose the ASM multicast group address across the scope of the group, and this makes allocation of LCT channel addresses more difficult with ASM.

LCT channels and SSM channels coincide, and thus the receiver will only receive packets sent to the requested LCT channel. With ASM, the receiver joins an LCT channel by joining a multicast group G, and all packets sent to G, regardless of the sender, may be received by the receiver. Thus, SSM has compelling security advantages over ASM for prevention of denial-of-service (DoS) attacks. In either case, receivers SHOULD use packet authentication mechanisms to mitigate such attacks (see Sections 6.2 and 7).

Some networks are not amenable to some congestion control protocols that could be used with LCT. In particular, for a satellite or wireless network, there may be no mechanism for receivers to effectively reduce their reception rate since there may be a fixed transmission rate allocated to the session.

LCT is compatible with both IPv4 and IPv6 as no part of the packet is IP version specific.

## 4.2. Delivery Service Models

LCT can support several different delivery service models. Two examples are briefly described here.

Push service model

One way a push service model can be used for reliable content delivery is to deliver a series of objects. For example, a receiver could join the session and dynamically adapt the number of LCT channels the receiver is joined to until enough packets have been received to reconstruct an object. After reconstructing the object, the receiver may stay in the session and wait for the transmission of the next object.

The push model is particularly attractive in satellite networks and wireless networks. In these cases, a session may consist of one fixed rate LCT channel.

A push service model can be used, for example, for reliable delivery of a large object such as a 100 GB file. The sender could send a Session Description announcement to a control channel and receivers could monitor this channel and join a session whenever a Session Description of interest arrives. Upon receipt of the Session Description, each receiver could join the session to receive packets until enough packets have arrived to reconstruct the object, at which point the receiver could report back to the sender that its reception was completed successfully. The sender could decide to continue sending packets for the object to the session until all receivers have reported successful reconstruction or until some other condition has been satisfied.

There are several features Asynchronous Layered Coding (ALC) provides to support the push model. For example, the sender can optionally include an Expected Residual Time (ERT) in the packet header extension that indicates the expected remaining time of packet transmission for either the single object carried in the session or for the object identified by the Transmission Object Identifier (TOI) if there are multiple objects carried in the session. This can be used by receivers to determine if there is enough time remaining in the session to successfully receive enough additional packets to recover the object. If, for example, there is not enough time, then the push application may have receivers report back to the sender to extend the transmission of packets for the object for enough time to allow the receivers to obtain enough packets to reconstruct the object. The sender could then include an ERT based on the extended object transmission time in each subsequent packet header for the object. As other examples, the LCT header optionally can contain a Close Session flag that indicates when the sender is about to stop sending packets to the session and a Close Object flag that indicates when the sender is about to stop sending packets to the session for the object identified by the Transmission Object ID. However, these

flags are not a completely reliable mechanism and thus the Close Session flag should only be used as a hint of when the session is about to close, and the Close Object flag should only be used as a hint of when transmission of packets for the object is about to end.

On-demand content delivery model

For an on-demand content delivery service model, senders typically transmit for some given time period selected to be long enough to allow all the intended receivers to join the session and recover the object. For example, a popular software update might be transmitted using LCT for several days, even though a receiver may be able to complete the download in one hour total of connection time, perhaps spread over several intervals of time. In this case, the receivers join the session at any point in time when it is active. Receivers leave the session when they have received enough packets to recover the object. The receivers, for example, obtain a Session Description by contacting a web server.

In this case, the receivers join the session, and dynamically adapt the number of LCT channels to which they subscribe according to the available bandwidth. Receivers then drop from the session when they have received enough packets to recover the object.

As an example, assume that an object is 50 MB. The sender could send 1 KB packets to the first LCT channel at 50 packets per second, so that receivers using just this LCT channel could complete reception of the object in 1,000 seconds in absence of loss, and would be able to complete reception even in presence of some substantial amount of losses with the use of coding for reliability. Furthermore, the sender could use a number of LCT channels such that the aggregate rate of 1 KB packets to all LCT channels is 1,000 packets per second, so that a receiver could be able to complete reception of the object in as little 50 seconds (assuming no loss and that the congestion control mechanism immediately converges to the use of all LCT channels).

Other service models

There are many other delivery service models for which LCT can be used that are not covered above. As examples, a live streaming or an on-demand archival content streaming service model. A description of the many potential applications, the appropriate delivery service model, and the additional mechanisms to support such functionalities when combined with LCT is beyond the scope of

this document. This document only attempts to describe the minimal common scalable elements to these diverse applications using LCT as the delivery transport.

### 4.3. Congestion Control

The specific congestion control protocol to be used for LCT sessions depends on the type of content to be delivered. While the general behavior of the congestion control protocol is to reduce the throughput in presence of congestion and gradually increase it in the absence of congestion, the actual dynamic behavior (e.g., response to single losses) can vary.

It is RECOMMENDED that the congestion control mechanism specified in [RFC3738] be used. Some alternative possible congestion control protocols for reliable content delivery using LCT are described in [VIC1998] and [BYE2000]. Different delivery service models might require different congestion control protocols.

## 5. Packet Header Fields

Packets sent to an LCT session MUST include an "LCT header". The LCT header format is described below.

Other building blocks MAY describe some of the same fields as described for the LCT header. It is RECOMMENDED that protocol instantiations using multiple building blocks include shared fields at most once in each packet. Thus, for example, if another building block is used with LCT that includes the optional Expected Residual Time field, then the Expected Residual Time field SHOULD be carried in each packet at most once.

The position of the LCT header within a packet MUST be specified by any protocol instantiation that uses LCT.

### 5.1. LCT Header Format

The LCT header is of variable size, which is specified by a length field in the third byte of the header. In the LCT header, all integer fields are carried in "big-endian" or "network order" format, that is, most significant byte (octet) first. Bits designated as "padding" or "reserved" (r) MUST by set to 0 by senders and ignored by receivers in this version of the specification. Unless otherwise noted, numeric constants in this specification are in decimal form (base 10).

The format of the default LCT header is depicted in Figure 1.

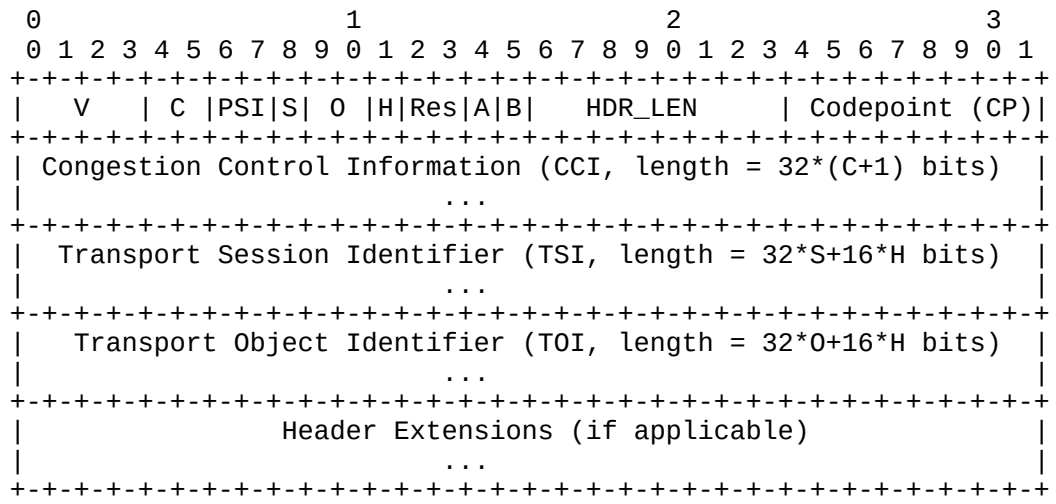


Figure 1: Default LCT Header Format

The function and length of each field in the default LCT header is the following.

LCT version number (V): 4 bits

Indicates the LCT version number. The LCT version number for this specification is 1.

Congestion control flag (C): 2 bits

C=0 indicates the Congestion Control Information (CCI) field is 32 bits in length. C=1 indicates the CCI field is 64 bits in length. C=2 indicates the CCI field is 96 bits in length. C=3 indicates the CCI field is 128 bits in length.

Protocol-Specific Indication (PSI): 2 bits

The usage of these bits, if any, is specific to each protocol instantiation that uses the LCT building block. If no protocol-instantiation-specific usage of these bits is defined, then a sender MUST set them to zero and a receiver MUST ignore these bits.

Transport Session Identifier flag (S): 1 bit

This is the number of full 32-bit words in the TSI field. The TSI field is 32*S + 16*H bits in length, i.e., the length is either 0 bits, 16 bits, 32 bits, or 48 bits.

Transport Object Identifier flag (O): 2 bits

This is the number of full 32-bit words in the TOI field. The TOI field is 32*O + 16*H bits in length, i.e., the length is either 0 bits, 16 bits, 32 bits, 48 bits, 64 bits, 80 bits, 96 bits, or 112 bits.

Half-word flag (H): 1 bit

The TSI and the TOI fields are both multiples of 32 bits plus 16*H bits in length. This allows the TSI and TOI field lengths to be multiples of a half-word (16 bits), while ensuring that the aggregate length of the TSI and TOI fields is a multiple of 32 bits.

Reserved (Res): 2 bits

These bits are reserved. In this version of the specification, they MUST be set to zero by senders and MUST be ignored by receivers.

Close Session flag (A): 1 bit

Normally, A is set to 0. The sender MAY set A to 1 when termination of transmission of packets for the session is imminent. A MAY be set to 1 in just the last packet transmitted for the session, or A MAY be set to 1 in the last few seconds of packets transmitted for the session. Once the sender sets A to 1 in one packet, the sender SHOULD set A to 1 in all subsequent packets until termination of transmission of packets for the session. A received packet with A set to 1 indicates to a receiver that the sender will immediately stop sending packets for the session. When a receiver receives a packet with A set to 1, the receiver SHOULD assume that no more packets will be sent to the session.

Close Object flag (B): 1 bit

Normally, B is set to 0. The sender MAY set B to 1 when termination of transmission of packets for an object is imminent. If the TOI field is in use and B is set to 1, then termination of transmission for the object identified by the TOI field is

imminent. If the TOI field is not in use and B is set to 1, then termination of transmission for the one object in the session identified by out-of-band information is imminent. B MAY be set to 1 in just the last packet transmitted for the object, or B MAY be set to 1 in the last few seconds that packets are transmitted for the object. Once the sender sets B to 1 in one packet for a particular object, the sender SHOULD set B to 1 in all subsequent packets for the object until termination of transmission of packets for the object. A received packet with B set to 1 indicates to a receiver that the sender will immediately stop sending packets for the object. When a receiver receives a packet with B set to 1, then it SHOULD assume that no more packets will be sent for the object to the session.

LCT header length (HDR_LEN): 8 bits

Total length of the LCT header in units of 32-bit words. The length of the LCT header MUST be a multiple of 32 bits. This field can be used to directly access the portion of the packet beyond the LCT header, i.e., to the first other header if it exists, or to the packet payload if it exists and there is no other header, or to the end of the packet if there are no other headers or packet payload.

Codepoint (CP): 8 bits

An opaque identifier that is passed to the packet payload decoder to convey information on the codec being used for the packet payload. The mapping between the codepoint and the actual codec is defined on a per session basis and communicated out-of-band as part of the session description information. The use of the CP field is similar to the Payload Type (PT) field in RTP headers as described in [RFC3550].

Congestion Control Information (CCI): 32, 64, 96, or 128 bits

Used to carry congestion control information. For example, the congestion control information could include layer numbers, logical channel numbers, and sequence numbers. This field is opaque for the purpose of this specification.

This field MUST be 32 bits if C=0.

This field MUST be 64 bits if C=1.

This field MUST be 96 bits if C=2.

This field MUST be 128 bits if C=3.

Transport Session Identifier (TSI): 0, 16, 32, or 48 bits

The TSI uniquely identifies a session among all sessions from a particular sender. The TSI is scoped by the IP address of the sender, and thus the IP address of the sender and the TSI together uniquely identify the session. Although a TSI in conjunction with the IP address of the sender always uniquely identifies a session, whether or not the TSI is included in the LCT header depends on what is used as the TSI value. If the underlying transport is UDP, then the 16-bit UDP source port number MAY serve as the TSI for the session. If the TSI value appears multiple times in a packet, then all occurrences MUST be the same value. If there is no underlying TSI provided by the network, transport or any other layer, then the TSI MUST be included in the LCT header.

The TSI MUST be unique among all sessions served by the sender during the period when the session is active, and for a large period of time preceding and following when the session is active. A primary purpose of the TSI is to prevent receivers from inadvertently accepting packets from a sender that belong to sessions other than the sessions to which receivers are subscribed. For example, suppose a session is deactivated and then another session is activated by a sender and the two sessions use an overlapping set of channels. A receiver that connects and remains connected to the first session during this sender activity could possibly accept packets from the second session as belonging to the first session if the TSI for the two sessions were identical. The mapping of TSI field values to sessions is outside the scope of this document and is to be done out-of-band.

The length of the TSI field is 32*S + 16*H bits. Note that the aggregate lengths of the TSI field plus the TOI field is a multiple of 32 bits.

Transport Object Identifier (TOI): 0, 16, 32, 48, 64, 80, 96, or 112 bits.

This field indicates to which object within the session this packet pertains. For example, a sender might send a number of files in the same session, using TOI=0 for the first file, TOI=1 for the second one, etc. As another example, the TOI may be a unique global identifier of the object that is being transmitted from several senders concurrently, and the TOI value may be the output of a hash function applied to the object. The mapping of TOI field values to objects is outside the scope of this document and is to be done out-of-band. The TOI field MUST be used in all

packets if more than one object is to be transmitted in a session, i.e., the TOI field is either present in all the packets of a session or is never present.

The length of the TOI field is 32*O + 16*H bits. Note that the aggregate length of the TSI field plus the TOI field is a multiple of 32 bits.

## 5.2. Header-Extension Fields

### 5.2.1. General

Header Extensions are used in LCT to accommodate optional header fields that are not always used or have variable size. Examples of the use of Header Extensions include:

- Extended-size versions of already existing header fields.
- Sender and receiver authentication information.
- Transmission of timing information.

The presence of Header Extensions can be inferred by the LCT header length (HDR_LEN). If HDR_LEN is larger than the length of the standard header, then the remaining header space is taken by Header Extension fields.

If present, Header Extensions MUST be processed to ensure that they are recognized before performing any congestion control procedure or otherwise accepting a packet. The default action for unrecognized Header Extensions is to ignore them. This allows the future introduction of backward-compatible enhancements to LCT without changing the LCT version number. Non-backward-compatible Header Extensions CANNOT be introduced without changing the LCT version number.

There are two formats for Header Extension fields, as depicted in Figure 2. The first format is used for variable-length extensions, with Header Extension Type (HET) values between 0 and 127. The second format is used for fixed-length (one 32-bit word) extensions, using HET values from 127 to 255.

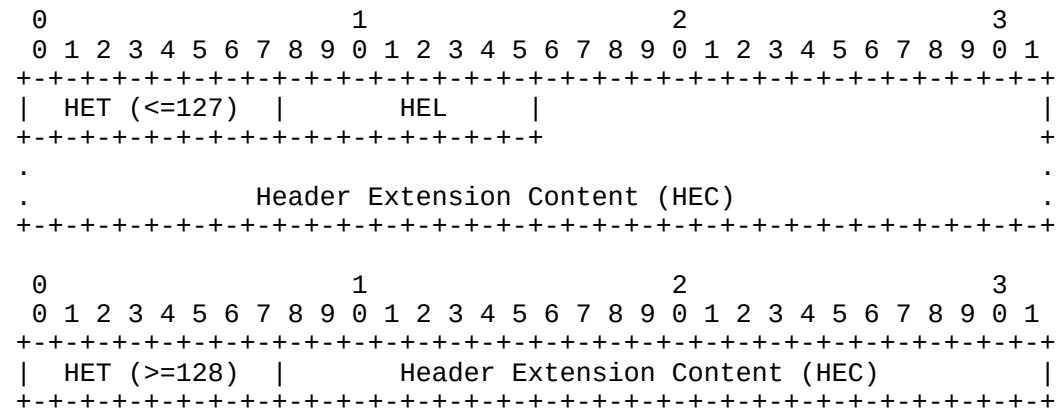


Figure 2: Format of Additional Headers

The explanation of each sub-field is the following:

Header Extension Type (HET): 8 bits

The type of the Header Extension. This document defines a number of possible types. Additional types may be defined in future versions of this specification. HET values from 0 to 127 are used for variable-length Header Extensions. HET values from 128 to 255 are used for fixed-length 32-bit Header Extensions.

Header Extension Length (HEL): 8 bits

The length of the whole Header Extension field, expressed in multiples of 32-bit words. This field MUST be present for variable-length extensions (HETs between 0 and 127) and MUST NOT be present for fixed-length extensions (HETs between 128 and 255).

Header Extension Content (HEC): variable length

The content of the Header Extension. The format of this sub-field depends on the Header Extension Type. For fixed-length Header Extensions, the HEC is 24 bits. For variable-length Header Extensions, the HEC field has variable size, as specified by the HEL field. Note that the length of each Header Extension field MUST be a multiple of 32 bits. Also note that the total size of the LCT header, including all Header Extensions and all optional header fields, cannot exceed 255 32-bit words.

The following LCT Header Extensions are defined by this specification:

EXT_NOP, HET=0 No-Operation extension. The information present in this extension field MUST be ignored by receivers.

EXT_AUTH, HET=1 Packet authentication extension. Information used to authenticate the sender of the packet. The format of this Header Extension and its processing is outside the scope of this document and is to be communicated out-of-band as part of the session description.

It is RECOMMENDED that senders provide some form of packet authentication. If EXT_AUTH is present, whatever packet authentication checks that can be performed immediately upon reception of the packet SHOULD be performed before accepting the packet and performing any congestion-control-related action on it.

Some packet authentication schemes impose a delay of several seconds between when a packet is received and when the packet is fully authenticated. Any congestion control related action that is appropriate SHOULD NOT be postponed by any such full packet authentication.

EXT_TIME, HET=2 Time Extension. This extension is used to carry several types of timing information. It includes general purpose timing information, namely the Sender Current Time (SCT), Expected Residual Time (ERT), and Sender Last Change (SLC) time extensions described in the present document. It can also be used for timing information with narrower applicability (e.g., defined for a single protocol instantiation); in this case, it will be described in a separate document.

All senders and receivers implementing LCT MUST support the EXT_NOP Header Extension and MUST recognize EXT_AUTH and EXT_TIME, but are not required to be able to parse their content.

### 5.2.2. EXT_TIME Header Extension

This section defines the timing Header Extensions with general applicability. The time values carried in this Header Extension are related to the server's wall clock. The server MUST maintain consistent relative time during a session (i.e., insignificant clock drift). For some applications, system or even global synchronization of server wall clock may be desirable, such as using the Network Time

Protocol (NTP) [RFC1305] to ensure actual time relative to 00:00 hours GMT, January 1st 1900. Such session-external synchronization is outside the scope of this document.

The EXT_TIME Header Extension uses the format depicted in Figure 3.

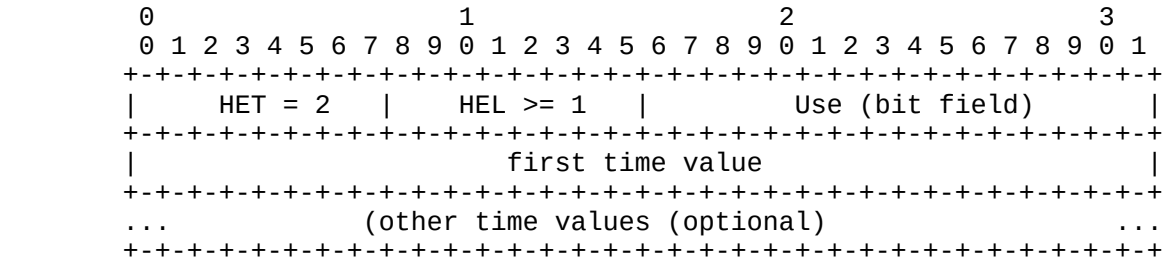


Figure 3: EXT_TIME Header Extension Format

The "Use" bit field indicates the semantic of the following 32-bit time value(s).

It is divided into two parts:

- 8 bits are reserved for general purpose timing information. This information is applicable to any protocol that makes use of LCT.

- 8 bits are reserved for PI-specific timing information. This information is out of the scope of this document.

The format of the "Use" bit field is depicted in Figure 4.

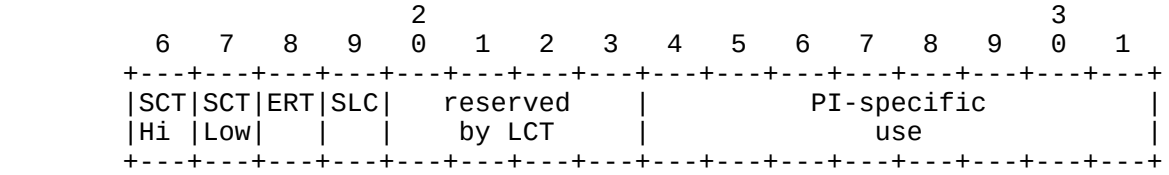


Figure 4: "Use" Bit Field Format

Several "time value" fields MAY be present in a given EXT_TIME Header Extension, as specified in the "Use-field". When several "time value" fields are present, they MUST appear in the order specified by the associated flag position in the "Use-field": first SCT-High (if

present), then SCT-Low (if present), then ERT (if present), then SLC (if present). Receivers SHOULD ignore additional fields within the EXT_TIME Header Extension that they do not support.

The fields for the general purpose EXT_TIME timing information are:

Sender Current Time (SCT): SCT-High flag, SCT-Low flag, corresponding time value (one or two 32-bit words).

This timing information represents the current time at the sender at the time this packet was transmitted.

When the SCT-High flag is set, the associated 32-bit time value provides an unsigned integer representing the time in seconds of the sender's wall clock. In the particular case where NTP is used, these 32 bits provide an unsigned integer representing the time in seconds relative to 00:00 hours GMT, January 1st 1900, (i.e., the most significant 32 bits of a full 64-bit NTP time value). In that case, handling of wraparound of the 32-bit time is outside the scope of NTP and LCT.

When the SCT-Low flag is set, the associated 32-bit time value provides an unsigned integer representing a multiple of 1/2^^32 of a second, in order to allow sub-second precision. When the SCT-Low flag is set, the SCT-High flag MUST be set, too. In the particular case where NTP is used, these 32 bits provide the 32 least significant bits of a 64-bit NTP timestamp.

Expected Residual Time (ERT): ERT flag, corresponding 32-bit time value.

This timing information represents the sender expected residual transmission time for the transmission of the current object. If the packet containing the ERT timing information also contains the TOI field, then ERT refers to the object corresponding to the TOI field; otherwise, it refers to the only object in the session.

When the ERT flag is set, it is expressed as a number of seconds. The 32 bits provide an unsigned integer representing this number of seconds.

Session Last Changed (SLC): SLC flag, corresponding 32-bit time value.

The Session Last Changed time value is the server wall clock time, in seconds, at which the last change to session data occurred. That is, it expresses the time at which the last (most recent)

Transport Object addition, modification, or removal was made for the delivery session. In the case of modifications and additions, it indicates that new data will be transported that was not transported prior to this time. In the case of removals, SLC indicates that some prior data will no longer be transported.

When the SLC flag is set, the associated 32-bit time value provides an unsigned integer representing a time in seconds. In the particular case where NTP is used, these 32 bits provide an unsigned integer representing the time in seconds relative to 00:00 hours GMT, January 1st 1900, (i.e., the most significant 32 bits of a full 64-bit NTP time value). In that case, handling of wraparound of the 32-bit time is outside the scope of NTP and LCT.

In some cases, it may be appropriate that a packet containing an EXT_TIME Header Extension with SLC information also contain an SCT-High information.

Reserved by LCT for future use (4 bits):

In this version of the specification, these bits MUST be set to zero by senders and MUST be ignored by receivers.

PI-specific use (8 bits):

These bits are out of the scope of this document. The bits that are not specified by the PI built on top of LCT SHOULD be set to zero.

The total EXT_TIME length is carried in the HEL, since this Header Extension is of variable length. It also enables clients to skip this Header Extension altogether if not supported (but recognized).

# 6. Operations

## 6.1. Sender Operation

Before joining an LCT session, a receiver MUST obtain a session description. The session description MUST include:

- The sender IP address;
- The number of LCT channels;
- The addresses and port numbers used for each LCT channel;
- The Transport Session ID (TSI) to be used for the session;

- Enough information to determine the congestion control protocol being used;
- Enough information to determine the packet authentication scheme being used (if one is being used).

The session description could also include, but is not limited to:

- The data rates used for each LCT channel;
- The length of the packet payload;
- The mapping of TOI value(s) to objects for the session;
- Any information that is relevant to each object being transported, such as when it will be available within the session, for how long, and the length of the object;

Protocol instantiations using LCT MAY place additional requirements on what must be included in the session description. For example, a protocol instantiation might require that the data rates for each channel, or the mapping of TOI value(s) to objects for the session, or other information related to other headers that might be required be included in the session description.

The session description could be in a form such as SDP as defined in [RFC4566], or another format appropriate to a particular application. It might be carried in a session announcement protocol such as SAP as defined in [RFC2974], obtained using a proprietary session control protocol, located on a Web page with scheduling information, or conveyed via email or other out-of-band methods. Discussion of session description format, and distribution of session descriptions is beyond the scope of this document.

Within an LCT session, a sender using LCT transmits a sequence of packets, each in the format defined above. Packets are sent from a sender using one or more LCT channels, which together constitute a session. Transmission rates may be different in different channels and may vary over time. The specification of the other building block headers and the packet payload used by a complete protocol instantiation using LCT is beyond the scope of this document. This document does not specify the order in which packets are transmitted, nor the organization of a session into multiple channels. Although these issues affect the efficiency of the protocol, they do not affect the correctness nor the inter-operability of LCT between senders and receivers.

Several objects can be carried within the same LCT session. In this case, each object MUST be identified by a unique TOI. Objects MAY be transmitted sequentially, or they MAY be transmitted concurrently. It is good practice to only send objects concurrently in the same session if the receivers that participate in that portion of the session have interest in receiving all the objects. The reason for this is that it wastes bandwidth and networking resources to have receivers receive data for objects in which they have no interest.

Typically, the sender(s) continues to send packets in a session until the transmission is considered complete. The transmission may be considered complete when some time has expired, a certain number of packets have been sent, or some out-of-band signal (possibly from a higher level protocol) has indicated completion by a sufficient number of receivers.

For the reasons mentioned above, this document does not pose any restriction on packet sizes. However, network efficiency considerations recommend that the sender uses an as large as possible packet payload size, but in such a way that packets do not exceed the network's maximum transmission unit size (MTU), or when fragmentation coupled with packet loss might introduce severe inefficiency in the transmission.

It is recommended that all packets have the same or very similar sizes, as this can have a severe impact on the effectiveness of congestion control schemes such as the ones described in [VIC1998], [BYE2000], and [RFC3738]. A sender of packets using LCT MUST implement the sender-side part of one of the congestion control schemes that is in accordance with [RFC2357] using the Congestion Control Information field provided in the LCT header, and the corresponding receiver congestion control scheme is to be communicated out-of-band and MUST be implemented by any receivers participating in the session.

### 6.2. Receiver Operation

Receivers can operate differently depending on the delivery service model. For example, for an on-demand service model, receivers may join a session, obtain the necessary packets to reproduce the object, and then leave the session. As another example, for a streaming service model, a receiver may be continuously joined to a set of LCT channels to download all objects in a session.

To be able to participate in a session, a receiver MUST obtain the relevant session description information as listed in Section 6.1.

If packet authentication information is present in an LCT header, it SHOULD be used as specified in Section 5.2. To be able to be a receiver in a session, the receiver MUST be able to process the LCT header. The receiver MUST be able to discard, forward, store, or process the other headers and the packet payload. If a receiver is not able to process an LCT header, it MUST drop from the session.

To be able to participate in a session, a receiver MUST implement the congestion control protocol specified in the session description using the Congestion Control Information field provided in the LCT header. If a receiver is not able to implement the congestion control protocol used in the session, it MUST NOT join the session. When the session is transmitted on multiple LCT channels, receivers MUST initially join channels according to the specified startup behavior of the congestion control protocol. For a multiple rate congestion control protocol that uses multiple channels, this typically means that a receiver will initially join only a minimal set of LCT channels, possibly a single one, that in aggregate are carrying packets at a low rate. This rule has the purpose of preventing receivers from starting at high data rates.

Several objects can be carried either sequentially or concurrently within the same LCT session. In this case, each object is identified by a unique TOI. Note that even if a server stops sending packets for an old object before starting to transmit packets for a new object, both the network and the underlying protocol layers can cause some reordering of packets, especially when sent over different LCT channels, and thus receivers SHOULD NOT assume that the reception of a packet for a new object means that there are no more packets in transit for the previous one, at least for some amount of time.

A receiver MAY be concurrently joined to multiple LCT sessions from one or more senders. The receiver MUST perform congestion control on each such LCT session. If the congestion control protocol allows the receiver some flexibility in terms of its actions within a session, then the receiver MAY make choices to optimize the packet flow performance across the multiple LCT sessions, as long as the receiver still adheres to the congestion control rules for each LCT session individually.

## 7. Requirements from Other Building Blocks

As described in [RFC3048], LCT is a building block that is intended to be used, in conjunction with other building blocks, to help specify a protocol instantiation. A congestion control building block that uses the Congestion Control information field within the

LCT header MUST be used by any protocol instantiation that uses LCT; other building blocks MAY also be used, such as a reliability building block.

The congestion control MUST be applied to the LCT session as an entity, i.e., over the aggregate of the traffic carried by all of the LCT channels associated with the LCT session. The Congestion Control Information field in the LCT header is an opaque field that is reserved to carry information related to congestion control. There MAY also be congestion control Header Extension fields that carry additional information related to congestion control.

The particular layered encoder and congestion control protocols used with LCT have an impact on the performance and applicability of LCT. For example, some layered encoders used for video and audio streams can produce a very limited number of layers, thus providing a very coarse control in the reception rate of packets by receivers in a session. When LCT is used for reliable data transfer, some FEC codecs are inherently limited in the size of the object they can encode, and for objects larger than this size the reception overhead on the receivers can grow substantially.

A more in-depth description of the use of FEC in Reliable Multicast Transport (RMT) protocols is given in [RFC3453]. Some of the FEC codecs that MAY be used in conjunction with LCT for reliable content delivery are specified in [RFC5052]. The Codepoint field in the LCT header is an opaque field that can be used to carry information related to the encoding of the packet payload.

LCT also requires receivers to obtain a session description, as described in Section 6.1. The session description could be in a form such as SDP as defined in [RFC4566], or another format appropriate to a particular application and may be distributed with SAP as defined in [RFC2974], using HTTP, or in other ways. It is RECOMMENDED that an authentication protocol be used to deliver the session description to receivers to ensure the correct session description arrives.

It is RECOMMENDED that LCT implementors use some packet authentication scheme to protect the protocol from attacks. An example of a possibly suitable scheme is described in [Perrig2001].

Some protocol instantiations that use LCT MAY use building blocks that require the generation of feedback from the receivers to the sender. However, the mechanism for doing this is outside the scope of LCT.

## 8. Security Considerations

LCT is a building block as defined in [RFC3048] and as such does not define a complete protocol. Protocol instantiations that use the LCT building block MUST address the potential vulnerabilities described in the following sections. For an example, see [ALC-PI].

Protocol instantiations could address the vulnerabilities described below by taking measures to prevent receivers from accepting incorrect packets, for example, by using a source authentication and content integrity mechanism. See also Sections 6.2 and 7 for discussion of packet authentication requirements.

Note that for correct operation, LCT assumes availability of session description information (see Sections 4 and 7). Incorrect or maliciously modified session description information may result in receivers being unable to correctly receive the session content, or that receivers inadvertently try to receive at a much higher rate than they are capable of, thereby disrupting traffic in portions of the network. Protocol instantiations MUST address this potential vulnerability, for example, by providing source authentication and integrity mechanisms for the session description. Additionally, these mechanisms MUST allow the receivers to securely verify the correspondence between session description and LCT data packets.

The following sections consider further each of the services provided by LCT.

### 8.1. Session and Object Multiplexing and Termination

The Transport Session Identifier and the Transport Object Identifier in the LCT header provide for multiplexing of sessions and objects. Modification of these fields by an attacker could have the effect of depriving a session or object of data and potentially directing incorrect data to another session or object, in both cases effecting a denial-of-service attack.

Additionally, injection of forged packets with fake TSI or TOI values may cause receivers to allocate resources for additional sessions or objects, again potentially effecting a DoS attack.

The Close Object and Close Session bits in the LCT header provide for signaling of the end of a session or object. Modification of these fields by an attacker could cause receivers to incorrectly behave as if the session or object had ended, resulting in a denial-of-service attack, or conversely to continue to unnecessarily utilize resources after the session or object has ended (although resource utilization in this case is largely an implementation issue).

As a result of the above vulnerabilities, these fields MUST be protected by protocol instantiation security mechanisms (for example, source authentication and data integrity mechanisms).

### 8.2. Time Synchronization

The SCT and ERT mechanisms provide rudimentary time synchronization features which can both be subject to attacks. Indeed an attacker can easily de-synchronize clients, sending erroneous SCT information, or mount a DoS attack by informing all clients that the session (respectively, a particular object) is about to be closed.

As a result of the above vulnerabilities, these fields MUST be protected by protocol instantiation security mechanisms (for example, source authentication and data integrity mechanisms).

### 8.3. Data Transport

The LCT protocol provides for transport of information for other building blocks, specifically the PSI field for the protocol instantiation, the Congestion Control field for the Congestion Control building block, the Codepoint field for the FEC building block, the EXT-AUTH Header Extension (used by the protocol instantiation) and the packet payload itself.

Modification of any of these fields by an attacker may result in a denial-of-service attack. In particular, modification of the Codepoint or packet payload may prevent successful reconstruction or cause inaccurate reconstruction of large portions of an object by receivers. Modification of the Congestion Control field may cause receivers to attempt to receive at an incorrect rate, potentially worsening or causing a congestion situation and thereby effecting a DoS attack.

As a result of the above vulnerabilities, these fields MUST be protected by protocol instantiation security mechanisms (for example, source authentication and data integrity mechanisms).

## 9. IANA Considerations

### 9.1. Namespace Declaration for LCT Header Extension Types

This document defines a new namespace for "LCT Header Extension Types". Values in this namespace are integers between 0 and 255 (inclusive).

Values in the range 0 to 63 (inclusive) are reserved for use for variable-length LCT Header Extensions and assignments shall be made through "IETF Review" as defined in [RFC5226].

Values in the range 64 to 127 (inclusive) are reserved for variable-length LCT Header Extensions and assignments shall be made on the "Specification Required" basis as defined in [RFC5226].

Values in the range 128 to 191 (inclusive) are reserved for use for fixed-length LCT Header Extensions and assignments shall be made through "IETF Review" as defined in [RFC5226].

Values in the range 192 to 255 (inclusive) are reserved for fixed-length LCT Header Extensions and assignments shall be made on the "Specification Required" basis as defined in [RFC5226].

Initial values for the LCT Header Extension Type registry are defined in Section 9.2.

Note that the previous Experimental version of this specification reserved values in the ranges [64, 127] and [192, 255] for PI-specific LCT Header Extensions. In the interest of simplification and since there were no overlapping allocations of these LCT Header Extension Type values by PIs, this document specifies a single flat space for LCT Header Extension Types.

### 9.2. LCT Header Extension Type Registration

This document registers three values in the LCT Header Extension Type namespace as follows:

| Value | Name | Reference |
|---|---|---|
| 0 | EXT_NOP | This specification |
| 1 | EXT_AUTH | This specification |
| 2 | EXT_TIME | This specification |

## 10. Acknowledgments

This specification is substantially based on RFC 3451 [RFC3451] and thus credit for the authorship of this document is primarily due to the authors of RFC 3451: Mike Luby, Jim Gemmel, Lorenzo Vicisano, Luigi Rizzo, Mark Handley, and Jon Crowcroft. Bruce Lueckenhoff,

Hayder Radha, and Justin Chapweske also contributed to RFC 3451. Additional thanks are due to Vincent Roca, Rod Walsh, and Toni Paila for contributions to this update to Proposed Standard.

## 11. Changes from RFC 3451

This section summarizes the changes that were made from the Experimental version of this specification published as RFC 3451 [RFC3451]:

- Removed the 'Statement of Intent' from the introduction. (The statement of intent was meant to clarify the "Experimental" status of RFC 3451.)
- Inclusion of material from ALC that is applicable in the more general LCT context.
- Creation of an IANA registry for LCT Header Extensions.
- Allocation of the 2 'reserved' bits in the LCT header as "Protocol-Specific Indication" - usage to be defined by protocol instantiations.
- Removal of the Sender Current Time and Expected Residual Time LCT header fields.
- Inclusion of a new Header Extension, EXT_TIME, to replace the SCT and ERT and provide for future extension of timing capabilities.

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