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Stream Schedulers and User Message Interleaving for the Stream Control Transmission Protocol
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Abstract

The Stream Control Transmission Protocol (SCTP) is a message oriented transport protocol supporting arbitrarily large user messages. This document adds a new chunk to SCTP for carrying payload data. This allows a sender to interleave different user messages that would otherwise result in head of line blocking at the sender.

Whenever an SCTP sender is allowed to send user data, it may choose from multiple outgoing SCTP streams. Multiple ways for performing this selection, called stream schedulers, are defined. A stream scheduler can choose to either implement, or not implement, user message interleaving.

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1. Introduction

1.1. Overview

When SCTP [RFC4960] was initially designed it was mainly envisioned for the transport of small signaling messages. Late in the design stage it was decided to add support for fragmentation and reassembly of larger messages with the thought that someday Session Initiation Protocol (SIP) [RFC3261] style signaling messages may also need to use SCTP and a single Maximum Transmission Unit (MTU) sized message would be too small. Unfortunately this design decision, though valid at the time, did not account for other applications that might send large messages over SCTP. The sending of such large messages over SCTP as specified in [RFC4960] can result in a form of sender side head of line blocking (e.g., when the transmission of an urgent message is blocked from transmission because the sender has started the transmission of another, possibly large, message). This head of line blocking is caused by the use of the Transmission Sequence Number (TSN) for three different purposes:

1. As an identifier for DATA chunks to provide a reliable transfer.

2. As an identifier for the sequence of fragments to allow reassembly.

3. As a sequence number allowing to have up to 2**16 - 1 Stream Sequence Numbers (SSNs) outstanding.

The protocol requires all fragments of a user message to have consecutive TSNs. Therefore it is impossible for the sender to interleave different user messages.

This document also defines several stream schedulers for general SCTP associations. They can be used with and without user message interleaving being negotiated and possibly behave differently.

Figure 1 illustrates the behaviour of a round robin stream scheduler using DATA chunks when three streams with the Stream Identifiers (SIDs) 0, 1, and 2 are used. Please note that the use of such a

scheduler implies late TSN assignment but it can be used with an [RFC4960] compliant implementation not supporting user message interleaving.

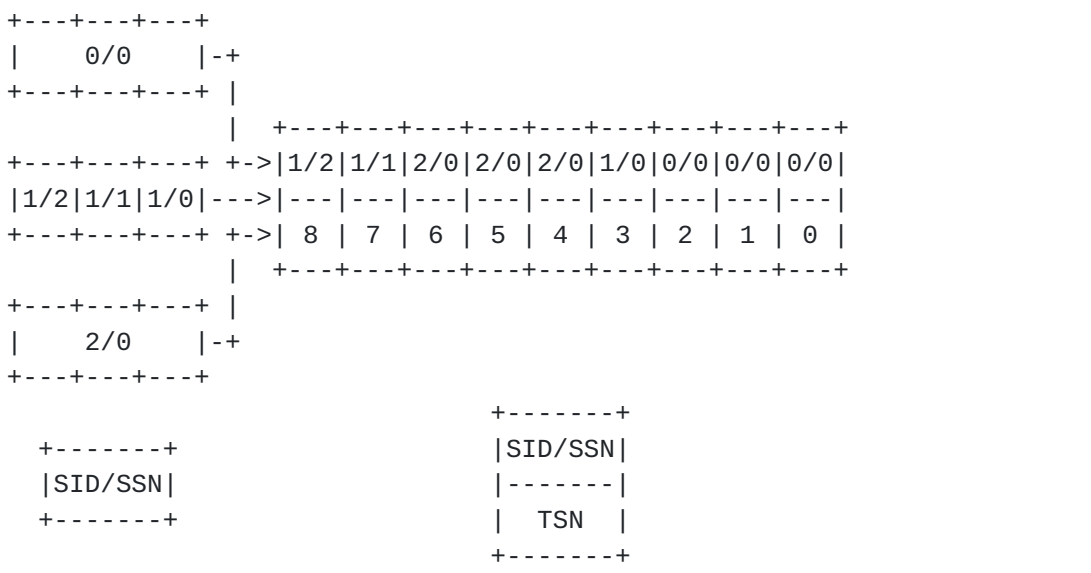


Figure 1: Round Robin Scheduler without User Message Interleaving

This document describes a new chunk carrying payload data called I-DATA. This chunk incorporates the properties of the current SCTP DATA chunk, all the flags and fields except the Stream Sequence Number (SSN), but also adds two new fields in its chunk header, the Fragment Sequence Number (FSN) and the Message Identifier (MID). The FSN is only used for reassembling all fragments having the same MID and ordering property. The TSN is only used for the reliable transfer in combination with Selective Acknowledgment (SACK) chunks.

In addition, the MID is also used for ensuring ordered delivery instead of using the stream sequence number, which has been omitted from the I-DATA chunk.

Figure 2 illustrates the behaviour of an interleaving round robin stream scheduler using I-DATA chunks.

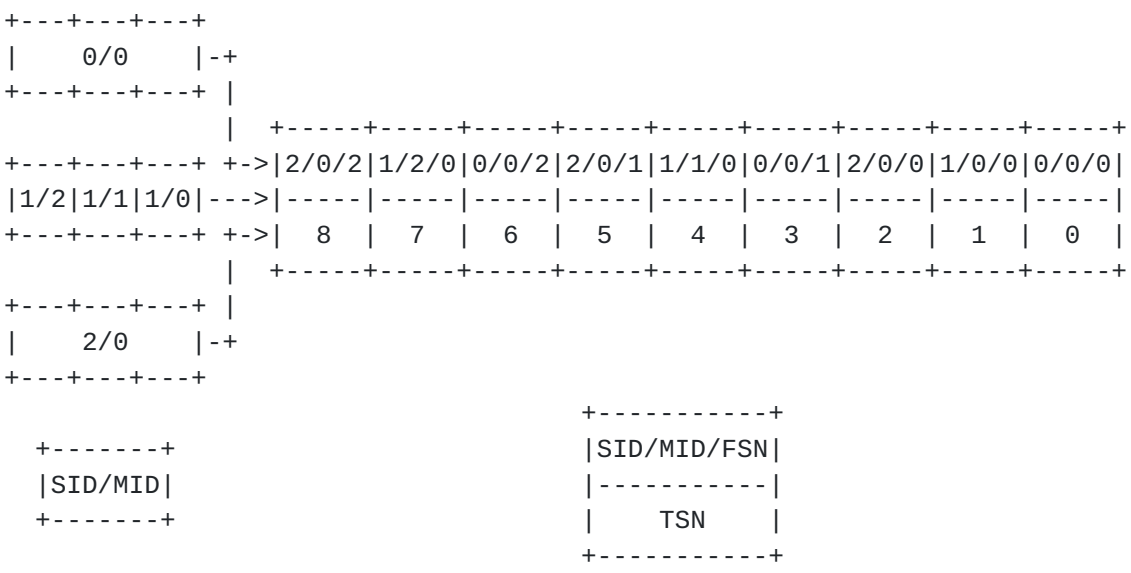


Figure 2: Round Robin Scheduler with User Message Interleaving

The support of the I-DATA chunk is negotiated during the association setup using the Supported Extensions Parameter as defined in [RFC5061]. If I-DATA support has been negotiated for an association I-DATA chunks are used for all user-messages. DATA chunks are not permitted when I-DATA support has been negotiated. It should be noted that an SCTP implementation supporting I-DATA chunks needs to allow the coexistence of associations using DATA chunks and associations using I-DATA chunks.

In Section 2 this document specifies the user message interleaving by defining the I-DATA chunk, the procedures to use it and its interactions with other SCTP extensions. Multiple stream schedulers are defined in Section 3 followed in Section 4 by describing an extension to the socket API for using what is specified in this document.

1.2. Conventions

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. User Message Interleaving

The protocol mechanisms described in this document allow the interleaving of user messages sent on different streams. They do not support the interleaving of multiple messages (ordered or unordered) sent on the same stream.

The interleaving of user messages is required for WebRTC Datachannels as specified in [I-D.ietf-rtcweb-data-channel].

An SCTP implementation supporting user message interleaving is REQUIRED to support the coexistence of associations using DATA chunks and associations using I-DATA chunks. If an SCTP implementation supports user message interleaving and the extension described in [RFC3758] or [RFC6525], it is REQUIRED to implement the corresponding changes specified in Section 2.3.

2.1. The I-DATA Chunk Supporting User Message Interleaving

The following Figure 3 shows the new I-DATA chunk allowing user message interleaving.

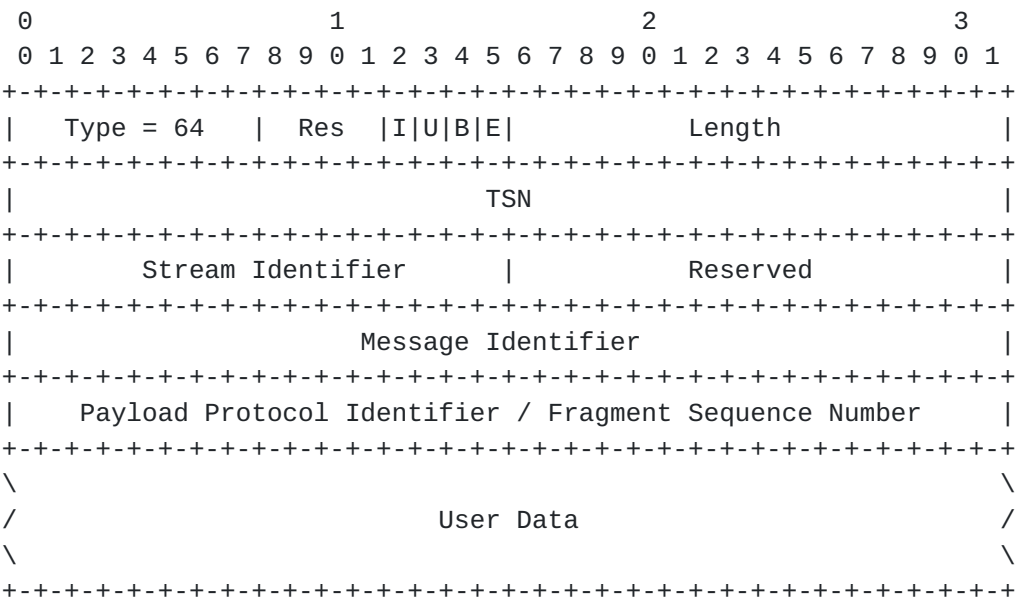


Figure 3: I-DATA chunk format

The only differences between the I-DATA chunk in Figure 3 and the DATA chunk defined in [RFC4960] and [RFC7053] are the addition of the new Message Identifier (MID) and the new Fragment Sequence Number (FSN) and the removal of the Stream Sequence Number (SSN). The Payload Protocol Identifier (PPID) and the FSN are stored at the same location of the packet using the B-bit to determine which value is stored at the location. The length of the I-DATA chunk header is 20 bytes, which is 4 bytes more than the length of the DATA chunk header defined in [RFC4960] and [RFC7053].

The new fields are:

Reserved: 16 bits (unsigned integer)

This field is reserved. It MUST be set to 0 by the sender and MUST be ignored by the receiver.

Message Identifier (MID): 32 bits (unsigned integer)
The MID is the same for all fragments of a user message, it is used to determine which fragments (enumerated by the FSN) belong to the same user message. For ordered user messages, the MID is also used by the SCTP receiver to deliver the user messages in the correct order to the upper layer (similar to the SSN of the DATA chunk defined in [RFC4960]). The sender uses two counters for each outgoing stream, one for ordered messages, one for unordered messages. All counters are independent and initially 0. They are incremented by 1 for each user message. Please note that the serial number arithmetic defined in [RFC1982] using SERIAL_BITS = 32 applies. Therefore, the sender MUST NOT have more than 2**31 - 1 ordered messages for each outgoing stream in flight and MUST NOT have more than 2**31 - 1 unordered messages for each outgoing stream in flight. A message is considered in flight, if at least on of its I-DATA chunks is not acknowledged in a non-renegable way. Please note that the MID is in "network byte order", a.k.a. Big Endian.

Payload Protocol Identifier (PPID) / Fragment Sequence Number (FSN): 32 bits (unsigned integer)
If the B bit is set, this field contains the PPID of the user message. Note that in this case, this field is not touched by an SCTP implementation; therefore, its byte order is not necessarily in network byte order. The upper layer is responsible for any byte order conversions to this field, similar to the PPID of DATA chunks. In this case the FSN is implicitly considered to be 0.
If the B bit is not set, this field contains the FSN. The FSN is used to enumerate all fragments of a single user message, starting from 0 and incremented by 1. The last fragment of a message MUST have the 'E' bit set. Note that the FSN MAY wrap completely multiple times allowing arbitrarily large user messages. For the FSN the serial number arithmetic defined in [RFC1982] applies with SERIAL_BITS = 32. Therefore, a sender MUST NOT have more than 2**31 - 1 fragments of a single user message in flight. A fragment is considered in flight, if it is not acknowledged in a non-renegable way. Please note that the FSN is in "network byte order", a.k.a. Big Endian.

2.2. Procedures

This subsection describes how the support of the I-DATA chunk is negotiated and how the I-DATA chunk is used by the sender and receiver.

2.2.1. Negotiation

A sender MUST NOT send an I-DATA chunk unless both peers have indicated its support of the I-DATA chunk type within the Supported Extensions Parameter as defined in [RFC5061]. If I-DATA support has been negotiated for an association, I-DATA chunks MUST be used for all user messages and DATA-chunks MUST NOT be used. If I-DATA support has not been negotiated for an association, DATA chunks MUST be used for all user messages and I-DATA chunks MUST NOT be used.

A sender MUST NOT use the I-DATA chunk unless the user has requested its use (e.g. via the socket API, see Section 4.3). This constraint is made since the usage of this chunk requires that the application is willing to interleave messages upon reception within an association. This is not the default choice within the socket API (see the SCTP_FRAGMENT_INTERLEAVE socket option in Section 8.1.20 of [RFC6458]) thus the user MUST indicate to the SCTP implementation its support for receiving completely interleaved messages. Note that for stacks that do not implement [RFC6458] they may use other methods to indicate interleaved message support and thus enable the usage of the I-DATA chunk. The crucial point is that the SCTP stack MUST know that the application has indicated its choice in wanting to use the extension.

2.2.2. Sender Side Considerations

The sender side usage of the I-DATA chunk is quite simple. Instead of using the TSN for fragmentation purposes, the sender uses the new FSN field to indicate which fragment number is being sent. The first fragment MUST have the 'B' bit set. The last fragment MUST have the 'E' bit set. All other fragments MUST NOT have the 'B' or 'E' bit set. All other properties of the existing SCTP DATA chunk also apply to the I-DATA chunk, i.e. congestion control as well as receiver window conditions MUST be observed as defined in [RFC4960].

Note that the usage of this chunk implies the late assignment of the actual TSN to any chunk being sent. Each I-DATA chunk uses a single TSN. This way messages from other streams may be interleaved with the fragmented message. Please note that this is the only form of interleaving support. For example, it is not possible to interleave multiple ordered or unordered user messages from the same stream.

The sender MUST NOT be fragmenting more than one user message in any given stream at any time. At any time, a sender MAY fragment multiple user messages, each of them on different streams.

The sender MUST assign TSNs in a way that the receiver can make progress. One way to achieve this is to assign a higher TSN to the later fragments of a user message and send out the TSNs in sequence.

2.2.3. Receiver Side Considerations

Upon reception of an SCTP packet containing an I-DATA chunk whose user message needs to be reassembled, the receiver MUST first use the SID to identify the stream, consider the U bit to determine if it is part of an ordered or unordered message, find the user message identified by the MID and finally use the FSN for reassembly of the message and not the TSN. The receiver MUST NOT make any assumption about the TSN assignments of the sender. Note that a non-fragmented message is indicated by the fact that both the 'E' and 'B' bits are set. A message (either ordered or unordered) may be identified as being fragmented whose 'E' and 'B' bits are not set both.

2.3. Interaction with other SCTP Extensions

The usage of the I-DATA chunk might interfere with other SCTP extensions. Future SCTP extensions MUST describe if and how they interfere with the usage of I-DATA chunks. For the SCTP extensions already defined when this document was published, the details are given in the following subsections.

2.3.1. SCTP Partial Reliability Extension

When the SCTP extension defined in [RFC3758] is used in combination with the user message interleaving extension, the new I-FORWARD-TSN chunk MUST be used instead of the FORWARD-TSN chunk. The difference between the FORWARD-TSN and the I-FORWARD-TSN chunk is that the 16-bit Stream Sequence Number (SSN) has been replaced by the 32-bit Message Identifier (MID) and the largest skipped MID can also be provided for unordered messages. Therefore, the principle applied to ordered message when using FORWARD-TSN chunks is applied to ordered and unordered messages when using I-FORWARD-TSN chunks.

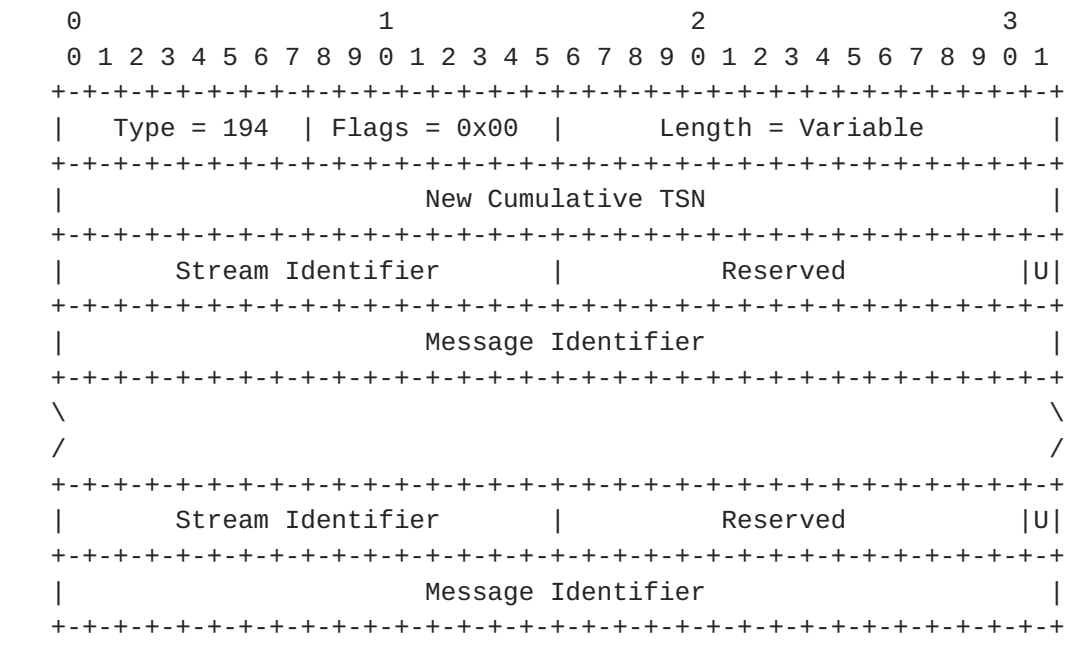


Figure 4: I-FORWARD-TSN chunk format

The relevant new fields are:

Stream Identifier (SID): 16-bits (unsigned integer)
   This field holds the stream number this entry refers to.

Reserved: 15 bits
   This field is reserved. It MUST be set to 0 by the sender and
   MUST be ignored by the receiver.

U bit: 1 bit
   The U bit specifies if the Message Identifier of this entry refers
   to unordered messages (U bit is set) or ordered messages (U bit is
   not set).

Message Identifier (MID): 32 bits (unsigned integer)
   This field holds the largest Message Identifier for ordered or
   unordered messages indicated by the U-bit that was skipped for the
   stream specified by the Stream Identifier. For ordered messages
   this is similar to the FORWARD-TSN chunk, just replacing the
   16-bit SSN by the 32-bit MID.

The FORWARD-TSN chunk MUST be used in combination with the DATA chunk and MUST NOT be used in combination with the I-DATA chunk. The I-FORWARD-TSN chunk MUST be used in combination with the I-DATA chunk and MUST NOT be used in combination with the DATA chunk.

Support for the I-FORWARD-TSN chunk is negotiated during the SCTP association setup via the Supported Extensions Parameter as defined in [RFC5061]. Only if both end points support the I-DATA chunk and the I-FORWARD-TSN chunk, the partial reliability extension can be used in combination with user message interleaving.

2.3.2. SCTP Stream Reconfiguration Extension

When an association resets the SSN using the SCTP extension defined in [RFC6525], the two counters (one for the ordered messages, one for the unordered messages) used for the MIDs MUST be reset to 0.

Since most schedulers, especially all schedulers supporting user message interleaving, require late TSN assignment, it should be noted that the implementation of [RFC6525] needs to handle this.

3. Stream Schedulers

This section defines several stream schedulers. The stream schedulers may behave differently depending on whether user message interleaving has been negotiated for the association or not. An implementation MAY implement any subset of them.

The selection of the stream scheduler is done at the sender side. There is no mechanism provided for signalling the stream scheduler being used to the receiver side or even let the receiver side influence the selection of the stream scheduler used at the sender side.

3.1. First Come First Served (SCTP_SS_FCFS)

The simple first-come, first-served scheduler of user messages is used. It just passes through the messages in the order in which they have been delivered by the application. No modification of the order is done at all. The usage of user message interleaving does not affect the sending of the chunks, except that I-DATA chunks are used instead of DATA chunks.

3.2. Round Robin Scheduler (SCTP_SS_RR)

When not using user message interleaving, this scheduler provides a fair scheduling based on the number of user messages by cycling around non-empty stream queues. When using user message interleaving, this scheduler provides a fair scheduling based on the number of I-DATA chunks by cycling around non-empty stream queues.

3.3. Round Robin Scheduler per Packet (SCTP_SS_RR_PKT)

This is a round-robin scheduler which only switches streams when starting to fill a new packet. It bundles only DATA or I-DATA chunks referring to the same stream in a packet. This scheduler minimizes head-of-line blocking when a packet is lost because only a single stream is affected.

3.4. Priority Based Scheduler (SCTP_SS_PRIO)

Scheduling of user messages with strict priorities is used. The priority is configurable per outgoing SCTP stream. Streams having a higher priority will be scheduled first and when multiple streams have the same priority, the scheduling between them is implementation dependent. When using user message interleaving, the sending of lower priority user messages will not block the sending of higher priority user messages.

3.5. Fair Bandwidth Scheduler (SCTP_SS_FB)

A fair bandwidth distribution between the streams is used. This scheduler considers the lengths of the messages of each stream and schedules them in a specific way to maintain an equal bandwidth for all streams. The details are implementation dependent. Using user message interleaving allows for a better realization of the fair bandwidth usage.

3.6. Weighted Fair Queueing Scheduler (SCTP_SS_WFQ)

A weighted fair queueing scheduler between the streams is used. The weight is configurable per outgoing SCTP stream. This scheduler considers the lengths of the messages of each stream and schedules them in a specific way to use the bandwidth according to the given weights. If the weight of stream S1 is n times the weight of stream S2, the scheduler should assign to stream S1 n times the bandwidth it assigns to stream S2. The details are implementation dependent. Using user message interleaving allows for a better realization of the bandwidth usage according to the given weights.

This scheduler in combination with user message interleaving is used for WebRTC Datachannels as specified in [I-D.ietf-rtcweb-data-channel].

4. Socket API Considerations

This section describes how the socket API defined in [RFC6458] is extended to allow applications to use the extension described in this document.

Please note that this section is informational only.

4.1. Exposition of the Stream Sequence Number (SSN)

The socket API defined in [RFC6458] defines several structures in which the SSN of a received user message is exposed to the application. The list of these structures includes:

struct sctp_sndrcvinfo
: Specified in Section 5.3.2 of [RFC6458] and marked as deprecated.

struct sctp_extrcvinfo
: Specified in Section 5.3.3 of [RFC6458] and marked as deprecated.

struct sctp_rcvinfo
: Specified in Section 5.3.5 of [RFC6458].

If user message interleaving is used, the lower order 16 bits of the MID are used as the SSN when filling out these structures.

4.2. SCTP_ASSOC_CHANGE Notification

When an SCTP_ASSOC_CHANGE notification (specified in Section 6.1.1 of [RFC6458]) is delivered indicating a sac_state of SCTP_COMM_UP or SCTP_RESTART for an SCTP association where both peers support the I-DATA chunk, SCTP_ASSOC_SUPPORTS_INTERLEAVING should be listed in the sac_info field.

4.3. Socket Options

option name	data type	get	set
SCTP_INTERLEAVING_SUPPORTED	struct sctp_assoc_value	X	X
SCTP_STREAM_SCHEDULER	struct sctp_assoc_value	X	X
SCTP_STREAM_SCHEDULER_VALUE	struct sctp_stream_value	X	X

4.3.1. Enable or Disable the Support of User Message Interleaving (SCTP_INTERLEAVING_SUPPORTED)

This socket option allows the enabling or disabling of the negotiation of user message interleaving support for future associations. For existing associations it allows to query whether user message interleaving support was negotiated or not on a particular association.

This socket option uses IPPROTO_SCTP as its level and SCTP_INTERLEAVING_SUPPORTED as its name. It can be used with getsockopt() and setsockopt(). The socket option value uses the following structure defined in [RFC6458]:

```
struct sctp_assoc_value {
  sctp_assoc_t assoc_id;
  uint32_t assoc_value;
};
```

assoc_id: This parameter is ignored for one-to-one style sockets. For one-to-many style sockets, this parameter indicates upon which association the user is performing an action. The special sctp_assoc_t SCTP_FUTURE_ASSOC can also be used, it is an error to use SCTP_{CURRENT|ALL}_ASSOC in assoc_id.

assoc_value: A non-zero value encodes the enabling of user message interleaving whereas a value of 0 encodes the disabling of user message interleaving.

sctp_opt_info() needs to be extended to support SCTP_INTERLEAVING_SUPPORTED.

An application using user message interleaving should also set the fragment interleave level to 2 by using the SCTP_FRAGMENT_INTERLEAVE socket option specified in Section 8.1.20 of [RFC6458]. This allows the interleaving of user messages from different streams. Please note that it does not allow the interleaving of ordered and unordered user messages on the same stream. Failure to set this option can possibly lead to application deadlock. Some implementations might therefore put some restrictions on setting combinations of these values. Setting the interleaving level to at least 2 before enabling the negotiation of user message interleaving should work on all platforms. Since the default fragment interleave level is not 2, user message interleaving is disabled per default.

4.3.2. Get or Set the Stream Scheduler (SCTP_STREAM_SCHEDULER)

A stream scheduler can be selected with the SCTP_STREAM_SCHEDULER option for setsockopt(). The struct sctp_assoc_value is used to specify the association for which the scheduler should be changed and the value of the desired algorithm.

The definition of struct sctp_assoc_value is the same as in [RFC6458]:

```
struct sctp_assoc_value {
  sctp_assoc_t assoc_id;
  uint32_t assoc_value;
};
```

assoc_id: Holds the identifier for the association of which the scheduler should be changed. The special SCTP_{FUTURE|CURRENT|ALL}_ASSOC can also be used. This parameter is ignored for one-to-one style sockets.

assoc_value: This specifies which scheduler is used. The following constants can be used:

SCTP_SS_DEFAULT: The default scheduler used by the SCTP implementation. Typical values are SCTP_SS_FCFS or SCTP_SS_RR.

SCTP_SS_FCFS: Use the scheduler specified in Section 3.1.

SCTP_SS_RR: Use the scheduler specified in Section 3.2.

SCTP_SS_RR_PKT: Use the scheduler specified in Section 3.3.

SCTP_SS_PRIO: Use the scheduler specified in Section 3.4. The priority can be assigned with the sctp_stream_value struct. The higher the assigned value, the lower the priority, that is the default value 0 is the highest priority and therefore the default scheduling will be used if no priorities have been assigned.

SCTP_SS_FB: Use the scheduler specified in Section 3.5.

SCTP_SS_WFQ: Use the scheduler specified in Section 3.6. The weight can be assigned with the sctp_stream_value struct.

sctp_opt_info() needs to be extended to support SCTP_STREAM_SCHEDULER.

4.3.3. Get or Set the Stream Scheduler Parameter (SCTP_STREAM_SCHEDULER_VALUE)

Some schedulers require additional information to be set for individual streams as shown in the following table:

name	per stream info
SCTP_SS_DEFAULT	n/a
SCTP_SS_FCFS	no
SCTP_SS_RR	no
SCTP_SS_RR_PKT	no
SCTP_SS_PRIO	yes
SCTP_SS_FB	no
SCTP_SS_WFQ	yes

This is achieved with the SCTP_STREAM_SCHEDULER_VALUE option and the corresponding struct sctp_stream_value. The definition of struct sctp_stream_value is as follows:

```
struct sctp_stream_value {
  sctp_assoc_t assoc_id;
  uint16_t stream_id;
  uint16_t stream_value;
};
```

assoc_id: Holds the identifier for the association of which the scheduler should be changed. The special SCTP_{FUTURE|CURRENT|ALL}_ASSOC can also be used. This parameter is ignored for one-to-one style sockets.

stream_id: Holds the stream id of the stream for which additional information has to be provided.

stream_value: The meaning of this field depends on the scheduler specified. It is ignored when the scheduler does not need additional information.

sctp_opt_info() needs to be extended to support SCTP_STREAM_SCHEDULER_VALUE.

4.4. Explicit EOR Marking

Using explicit End of Record (EOR) marking for an SCTP association supporting user message interleaving allows the user to interleave the sending of user messages on different streams.

5. IANA Considerations

[NOTE to RFC-Editor:

"RFCXXXX" is to be replaced by the RFC number you assign this document.

]

[NOTE to RFC-Editor:

The suggested values for the chunk types and the chunk flags are tentative and to be confirmed by IANA.

]

This document (RFCXXXX) is the reference for all registrations described in this section.

Two new chunk types have to be assigned by IANA.

5.1. I-DATA Chunk

IANA should assign the chunk type for this chunk from the pool of chunks with the upper two bits set to '01'. This requires an additional line in the "Chunk Types" registry for SCTP:

ID Value	Chunk Type	Reference
64	Payload Data supporting Interleaving (I-DATA)	[RFCXXXX]

The registration table as defined in [RFC6096] for the chunk flags of this chunk type is initially given by the following table:

Chunk Flag Value	Chunk Flag Name	Reference
0x01	E bit	[RFCXXXX]
0x02	B bit	[RFCXXXX]
0x04	U bit	[RFCXXXX]
0x08	I bit	[RFCXXXX]
0x10	Unassigned	
0x20	Unassigned	
0x40	Unassigned	
0x80	Unassigned	

5.2. I-FORWARD-TSN Chunk

IANA should assign the chunk type for this chunk from the pool of chunks with the upper two bits set to '11'. This requires an additional line in the "Chunk Types" registry for SCTP:

ID Value	Chunk Type	Reference
194	I-FORWARD-TSN	[RFCXXXX]

The registration table as defined in [RFC6096] for the chunk flags of this chunk type is initially empty.

6. Security Considerations

This document does not add any additional security considerations in addition to the ones given in [RFC4960] and [RFC6458].

It should be noted that the application has to consent that it is willing to do the more complex reassembly support required for user message interleaving. When doing so, an application has to provide up to two reassembly buffers (one for ordered messages, one for unordered messages) for each incoming stream. It has to protect itself against these buffers taking too many resources. If user message interleaving is not used, only a single reassembly buffer needs to be provided. But the application has to protect itself for excessive resource usages there too.

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