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Saratoga: A Scalable Data Transfer Protocol
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Abstract

This document specifies the Saratoga transfer protocol. Saratoga was originally developed to transfer remote-sensing imagery efficiently from a low-Earth-orbiting satellite constellation, but is useful for many other scenarios, including ad-hoc peer-to-peer communications, delay-tolerant networking, and grid computing. Saratoga is a simple, lightweight, content dissemination protocol that builds on UDP, and optionally uses UDP-Lite. Saratoga is intended for use when moving files or streaming data between peers which may have permanent, sporadic or intermittent connectivity, and is capable of transferring very large amounts of data reliably under adverse conditions. The Saratoga protocol is designed to cope with highly asymmetric link or path capacity between peers, and can support fully-unidirectional data transfer if required. Saratoga can also cope with very large files for exascale computing. In scenarios with dedicated links, Saratoga focuses on high link utilization to make the most of limited connectivity times, while standard congestion control mechanisms can be implemented for operation over shared links. Loss recovery is implemented via a simple negative-ack ARQ mechanism. The protocol specified in this document is considered to be appropriate for experimental use on private IP networks.

Status of This Memo

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

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This Internet-Draft will expire on December 12, 2013.

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1. Background and Introduction

Saratoga is a file transfer and content dissemination protocol capable of efficiently sending both small (kilobyte) and very large (exabyte) files, as well as streaming continuous content. Saratoga was originally designed for the purpose of large file transfer from small low-Earth-orbiting satellites. It has been used in daily operations since 2004 to move mission imaging data files of the order of several hundred megabytes each from the Disaster Monitoring Constellation (DMC) remote-sensing satellites to ground stations.

The DMC satellites, built at the University of Surrey by Surrey Satellite Technology Ltd (SSTL), all use IP for payload communications and delivery of Earth imagery. At the time of this writing, in March 2013, nine DMC satellites have been launched into orbit since 2003, five of those are currently operational in orbit, and three more are planned. The DMC satellites use Saratoga to provide Earth imagery under the aegis of the International Charter on Space and Major Disasters. A pass of connectivity between a satellite and ground station offers an 8-12 minute time window in which to transfer imagery files using a minimum of an 8.1 Mbps downlink and a 9.6 kbps uplink. The latest operational DMC satellites have faster downlinks, capable of 20, 40, 80, 105 or 201 Mbps. Newer satellites are expected to use downlinks to 400 Mbps, without significant increases in uplink rates. This high degree of link asymmetry, with the need to fully utilize the available downlink capacity to move the volume of data required within the limited time available, motivates much of Saratoga's design.

Further details on how these DMC satellites use IP to communicate with the ground and the terrestrial Internet are discussed elsewhere [Hogie05][Wood07a]. Saratoga has also been evaluated for use in high-speed private ground networks supporting radio astronomy sensors [Wood11].

Store-and-forward delivery relies on reliable hop-by-hop transfers of files, removing the need for the final receiver to talk to the original sender across long delays and allowing for the possibility that an end-to-end path may never exist between sender and receiver at any given time. Breaking an end-to-end path into multiple hops

allows data to be transferred as quickly as possible across each link; congestion on a longer Internet path is then not detrimental to the transfer rate on a space downlink. Use of store-and-forward hop-by-hop delivery is typical of scenarios in space exploration for both near-Earth and deep-space missions, and useful for other scenarios, such as underwater networking, ad-hoc sensor networks, and some message-ferrying relay scenarios. Saratoga is intended to be useful for relaying data in these scenarios.

Saratoga can optionally also be used to carry the Bundle Protocol "bundles" intended for Delay and Disruption-Tolerant Networking (DTN) by the IRTF DTN Research Group [RFC5050]. This has been tested from orbit using the UK-DMC satellite [Ivancic10]. How Saratoga can optionally function as a "bundle convergence layer" alongside a DTN bundle agent is specified in a companion document [I-D.wood-dtnrg-saratoga].

Saratoga contains a Selective Negative Acknowledgement (SNACK) 'holestofill' mechanism to provide reliable retransmission of data. This is intended to correct losses of corrupted link-layer frames due to channel noise over a space link. Packet losses in the DMC are due to corruption introducing non-recoverable errors in the frame. The DMC design uses point-to-point links and scheduling of applications in order, so that the link is dedicated to one application transfer at a time, meaning that packet loss cannot be due to congestion when applications compete for link capacity simultaneously. In other wireless environments that may be shared by many nodes and applications, allocation of channel resources to nodes becomes a MAC-layer function. Forward Error Coding (FEC) to get the most reliable transmission through a channel is best left near the physical layer so that it can be tailored for the channel. Use of FEC complements Saratoga's transport-level negative-acknowledgement approach that provides a reliable ARQ mechanism.

Saratoga is scalable in that it is capable of efficiently transferring small or large files, by choosing a width of file offset descriptor appropriate for the filesize, and advertising accepted offset descriptor sizes. 16-bit, 32-bit, 64-bit and 128-bit descriptors can be selected, for maximum file sizes of 64KiB-1 (<64 Kilobytes of disk space), 4GiB-1 (<4 Gigabytes), 16EiB-1 (<16 Exabytes) and 256 EiEiB-1 (<256 Exa-exabytes) respectively.

Earth imaging files currently transferred by Saratoga are mostly up to a few gigabytes in size. Some implementations do transfer more than 4 GiB in size, and so require offset descriptors larger than 32 bits. We believe that supporting a 128-bit descriptor can satisfy all future needs, but we expect current implementations to only support up to 32-bit or 64-bit descriptors, depending on their

application needs. The 16-bit descriptor is useful for small messages, including messages from 8-bit devices, and is always supported. The 128-bit descriptor can be used for moving very large files stored on a 128-bit filesystem, such as on OpenSolaris ZFS.

As a UDP-based protocol, Saratoga can be used with either IPv4 or IPv6. Compatibility between Saratoga and the wide variety of links that can already carry IP traffic is assured.

High link utilization is important during periods of limited connectivity. Given that Saratoga was originally developed for scheduled peer-to-peer communications over dedicated links in private networks, where each application has the entire link for the duration of its transfer, many Saratoga implementations deliberately lack any form of congestion control and send at line rate to maximise throughput and link utilisation in their limited, carefully controlled, environments. In accordance with UDP Guidelines [RFC5405] for protocols able to traverse the public Internet, newer implementations may perform TCP-Friendly Rate Control (TFRC) [RFC5348] or other congestion control mechanisms. This is described further in [I-D.wood-tsvwg-saratoga-congestion-control].

Saratoga was originally implemented as outlined in [Jackson04], but the specification given here differs substantially, as we have added a number of capabilities while cleaning up the initial Saratoga specification. The original Saratoga code uses a version number of 0, while code that implements this version of the protocol advertises a version number of 1. Further discussion of the history and development of Saratoga is given in [Wood07b].

This document contains an overview of the transfer process and sessions using Saratoga in Section 2, followed by a formal definition of the packet types used by Saratoga in Section 4, and the details of the various protocol mechanisms in Section 6.

Here, Saratoga session types are labelled with underscores around lowercase names (such as a "_get_" session), while Saratoga packet types are labelled in all capitals (such as a "REQUEST" packet) in order to distinguish between the two.

The remainder of this specification uses ’file’ as a shorthand for ’binary object’, which may be a file, or other type of data, such as a DTN bundle. This specification uses ’file’ when also discussing streaming of data of indeterminate length. Saratoga uses unsigned integers in its fields, and does not use signed types.

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 RFC 2119. [RFC2119]

2. Overview of Saratoga File Transfer

Saratoga is a peer-to-peer protocol in the sense that multiple files may be transferred in both directions simultaneously between two communicating Saratoga peers, and there is not intended to be a strict client-to-server relationship.

Saratoga nodes can act as simple file servers. Saratoga supports several types of operations on files including "pull" downloads, "push" uploads, directory listing, and deletion requests. Each operation is handled as a distinct "session" between the peers.

Saratoga nodes MAY advertise their presence, capabilities, and desires by sending BEACON packets. These BEACONs are sent to either a reserved, unforwardable, multicast address when using IPv4, or a link-local all-Saratoga-peers multicast address when using IPv6. A BEACON might also be unicast to another known node as a sort of "keepalive". Saratoga nodes may dynamically discover other Saratoga nodes, either through listening for BEACONs, through pre-configuration, via some other trigger from a user, lower-layer protocol, or another process. The BEACON is useful in many situations, such as ad-hoc networking, as a simple, explicit, confirmation that another node is present; a BEACON is not required in order to begin a Saratoga session.. BEACONs have been used by the DMC satellites to indicate to ground stations that a link has become functional, a solid-state data recorder is online, and the software is ready to transfer any requested files.

A Saratoga session begins with either a _get_, _put_, _getdir_, or _delete_ session REQUEST packet corresponding to a desired download, upload, directory listing, or deletion operation. _put_ sessions may instead begin directly with METADATA and DATA, without an initial REQUEST/OKAY STATUS exchange; these are known as ’blind puts’. The most common envisioned session is the _get_, which begins with a single Saratoga REQUEST packet sent from the peer wishing to receive the file, to the peer who currently has the file. If the session is rejected, then a brief STATUS packet that conveys rejection is generated. If the file-serving peer accepts the session, an OKAY STATUS can be optional; the peer can immediately generate and send a more useful descriptive METADATA packet, along with some number of DATA packets constituting the requested file.

These DATA packets are finished by (and can intermittently include) a DATA packet with a flag bit set that demands the file-receiver send a

reception report in the form of a STATUS packet. This DATA-driven cycle is shown in Figure 1. The STATUS packet can include 'holestofill' Selective Negative Acknowledgement (SNACK) information listing spans of octets within the file that have not yet been received, as well as whether or not the METADATA packet was received, or an error code terminating the transfer session. Once the information in this STATUS packet is received, the file-sender can begin a cycle of selective retransmissions of missing DATA packets, until it sees a STATUS packet that acknowledges total reception of all file data.

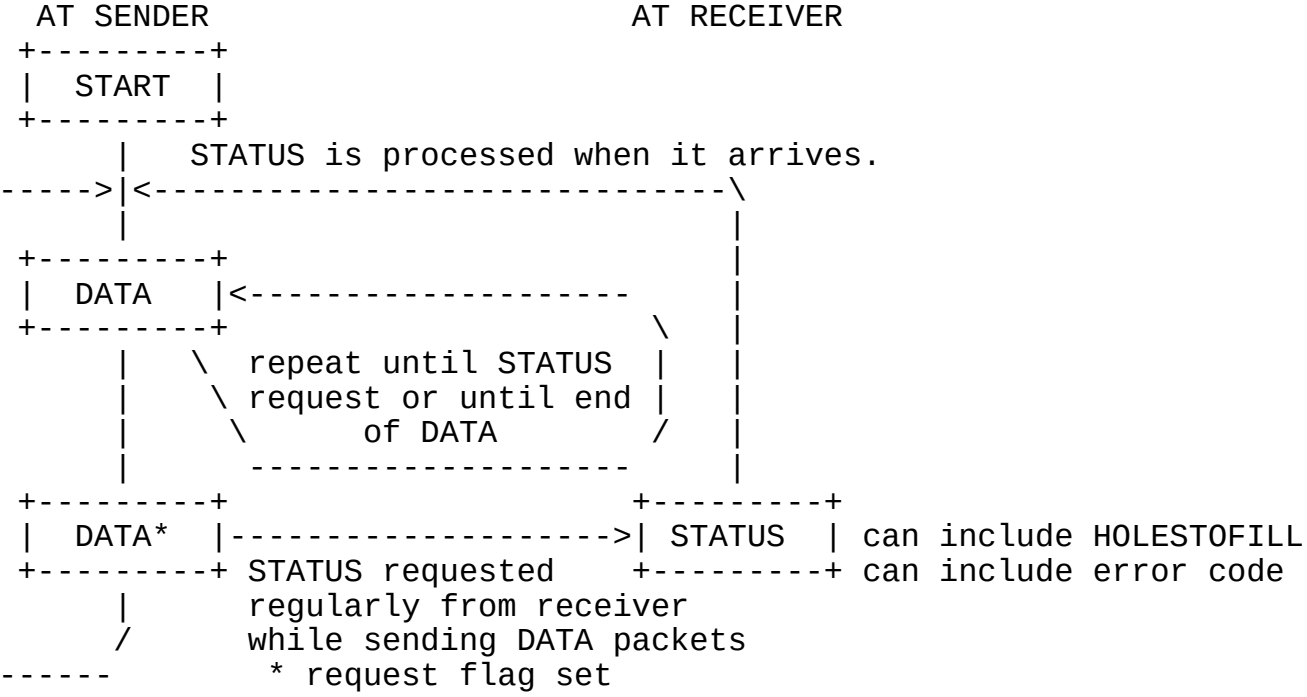


Figure 1: STATUS and DATA cycle

In the example scenario in Figure 2, a _get_ request is granted. The reliable file delivery experiences loss of a single DATA packet due to channel-induced errors.

File-Receiver File-Sender

GET REQUEST ---------->

(indicating error/reject) <---- STATUS

or

<------- METADATA

<---------- DATA #1

```
     STATUS -----------------> (voluntarily sent at start)
                 (lost) <------ DATA #2
        <---------------------- DATA #3 (bit set
                                   requesting STATUS)
     STATUS ----------------->
(indicating that range in DATA #2 was lost)
        <------------------------ DATA #2 (bit set
                                   requesting STATUS)
     STATUS ----------------->
(complete file and METADATA received)
```

Figure 2: Example _get_ session sequence

A _put_ is similar to _get_, although once the OKAY STATUS is received, DATA is sent from the peer that originated the _put_ request. A 'blind _put_' does not require an REQUEST and OKAY STATUS to be exchanged before sending DATA packets, and is efficient for long-delay or unidirectional links.

A _getdir_ request proceeds similarly, though the DATA transfer contains a directory record with one or more directory entries, described later, rather than a given file's bytes. _getdir_ is the only request to also apply to directories, where one or more directory entries for individual files is received.

The STATUS and DATA packets are allowed to be sent at any time within the scope of a session, in order for the file-sending node to optimize buffer management and transmission order. For example, if the file-receiver already has the first part of a file from a previous disrupted transfer, it may send a STATUS at the beginning of the session indicating that it has the first part of the file, and so only needs the last part of the file. Thus, efficient recovery from interrupted sessions between peers becomes possible, similar to ranged FTP and HTTP requests. (Note that METADATA with a checksum is useful to verify that the parts are of the same file and that the file is reassembled correctly.)

The Saratoga 'blind _put_' session is initiated by the file-sender sending an optional METADATA packet followed by immediate DATA packets, without requiring a REQUEST or waiting for a STATUS response. This can be considered an "optimistic" mode of protocol operation, as it assumes the implicit session request will be granted. If the sender of a PUT request sees a STATUS packet indicating that the request was declined, it MUST stop sending any DATA packets within that session immediately. Since this type of _put_ is open-loop for some period of time, it should not be used in scenarios where congestion is a valid concern; in these cases, the file-sender should wait on its METADATA to be acknowledged by a STATUS before sending DATA packets within the session.

Figure 3 illustrates the sequence of packets in an example _put_ session, beginning directly with METADATA and DATA as in a blind put, where the second DATA packet is lost. Other than the way that it is initiated, the mechanics of data delivery of a blind _put_ session are similar to a _get_ session.

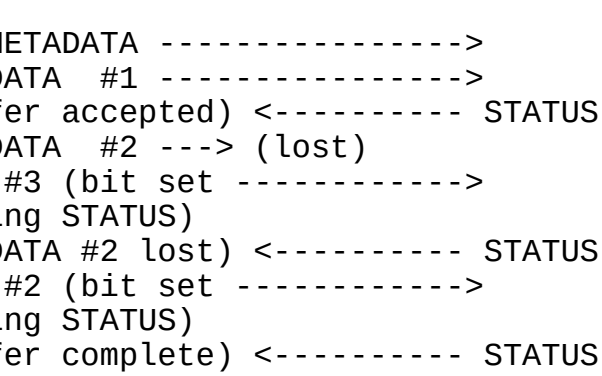


Figure 3: Example PUT session sequence

In large-distance scenarios such as for deep space, the large propagation delays and round-trip times involved discourage use of ping-pong packet exchanges (such as TCP's SYN/ACK) for starting sessions, and unidirectional transfers via these optimistic 'blind _put_s' are desirable. Blind _puts_ are the only mode of transfer suitable for unidirectional links. Senders sending on unidirectional links SHOULD send a copy of the METADATA in advance of DATA packets, and MAY resend METADATA at intervals.

The _delete_ sessions are simple single packet requests that trigger a STATUS packet with a status code that indicates whether the file was deleted or not. If the file is not able to be deleted for some reason, this reason can be conveyed in the Status field of the STATUS packet.

A _get_ REQUEST packet that does not specify a filename (i.e. the request contains a zero-length File Path field) is specially defined to be a request for any chosen file that the peer wishes to send it. This 'blind _get_' allows a Saratoga peer to request any files that the other Saratoga peer has ready for it, without prior knowledge of the directory listing, and without requiring the ability to examine files or decode remote file names/paths for meaningful information such as final destination.

If a file is larger than Saratoga can be expected to transfer during a time-limited contact, there are at least two feasible options:

(1) The application can use proactive fragmentation to create multiple smaller-sized files. Saratoga can transfer some number of these smaller files fully during a contact.

(2) To avoid file fragmentation, a Saratoga file-receiver can retain a partially-transferred file and request transfer of the unreceived bytes during a later contact. This uses a STATUS packet to make clear how much of the file has been successfully received and where transfer should be resumed from, and relies on use of METADATA to identify the file. On resumption of a transfer, the new METADATA (including file length, file timestamps, and possibly a file checksum) MUST match that of the previous METADATA in order to re-establish the transfer. Otherwise, the file-receiver MUST assume that the file has changed and purge the DATA payload received during previous contacts.

Like the BEACON packets, a _put_ or a response to a _get_ MAY be sent to the dedicated IPv4 Saratoga multicast address (allocated to 224.0.0.108) or the dedicated IPv6 link-local multicast address (allocated to FF02:0:0:0:0:0:0:6C) for multiple file-receivers on the link to hear. This is at the discretion of the file-sender, if it believes that there is interest from multiple receivers. In-progress DATA transfers MAY also be moved seamlessly from unicast to multicast if the file-sender learns during a transfer, from receipt of further unicast _get_ REQUEST packets, that multiple nodes are interested in the file. The associated METADATA packet is multicast when this transition takes place, and is then repeated periodically while the DATA stream is being sent, to inform newly-arrived listeners about the file being multicast. Acknowledgements MUST NOT be demanded by multicast DATA packets, to prevent ack implosion at the file-sender, and instead status SNACK information is aggregated and sent voluntarily by all file-receivers. File-receivers respond to multicast DATA with multicast STATUS packets. File-receivers SHOULD introduce a short random delay before sending a multicast STATUS packet, to prevent ack implosion after a channel-induced loss, and MUST listen for STATUS packets from others, to avoid duplicating fill

requests. The file-sender SHOULD repeat any initial unicast portion of the transfer as multicast last of all, and may repeat and cycle through multicast of the file several times while file-receivers express interest via STATUS or _get_ packets. Once in multicast and with METADATA being repeated periodically, new file-receivers do not need to send individual REQUEST packets. If a transfer has been started using UDP-Lite and new receivers indicate UDP-only capability, multicast transfers MUST switch to using UDP to accommodate them.

3. Optional Parts of Saratoga

Implementing support for some parts of Saratoga is optional. These parts are grouped into three sections, namely useful capabilities in Saratoga that are likely to be supported by implementations, congestion control that is needed in shared networks and across the public Internet, and functionality requiring other protocols that is less likely to be supported.

3.1. Optional but useful functions in Saratoga

These are useful capabilities in Saratoga that implementations SHOULD support, but may not, depending on scenarios:

- sending and parsing BEACONs.

- sending METADATA. However, sending and receiving METADATA is considered extremely useful, is strongly recommended, and SHOULD be done. A METADATA that is received MUST be parsed.

- streaming data, including real-time streaming of content of unknown length. This streaming can be unreliable (without resend requests) or reliable (with resend requests). Session protocols such as http expect reliable streaming. Although Saratoga data delivery is inherently one-way, where a stream of DATA packets elicits a stream of STATUS packets, bidirectional duplex communication can be established by using two Saratoga transfers flowing in opposite directions.

- multicast DATA transfers, if judged useful for the environment in which Saratoga is deployed, when multiple receivers are participating and are receiving the same file or stream.

- sending and parsing STATUS messages, which are expected for bidirectional communication, but cannot be sent on and are not required for sending over unidirectional links.

- sending and responding to packet timestamps in DATA and STATUS packets. These timestamps are useful for streaming and for giving a file-sender an indication of path latency for rate control. There is no need for a file-receiver to understand the format used for these timestamps for it to be able to receive them from and reflect them back to the file-sender.

- support for descriptor sizes greater than 16 bits, for handling small files, is optional, as is support for descriptor sizes greater than 32 bits, and support for descriptor sizes greater than 64 bits. If a descriptor size is implemented, all sizes below that size MUST be implemented.

3.2. Optional congestion control

Saratoga can be implemented to perform congestion control at the sender, based on feedback from acknowledgement STATUS packets [I-D.wood-tsvwg-saratoga-congestion-control], or have the sender configured to use simple open-loop rate control to only use a fixed amount of link capacity. Congestion control is expected to be undesirable for many of Saratoga's use cases and expected environmental conditions in private networks, where sending as quickly as possible or simple rate control at a fixed output speed are considered useful.

In accordance with the UDP Guidelines [RFC5405], congestion control MUST be supported if Saratoga is being used across the public Internet, and SHOULD be supported in environments where links are shared by traffic flows. Congestion control MAY NOT be supported across private, single-flow links engineered for performance: Saratoga's primary use case.

3.3. Optional functionality requiring other protocols

The functionality listed here is useful in rare cases, but requires use of other, optional, protocols. This functionality MAY be supported by Saratoga implementations:

- support for working with the Bundle Protocol for Delay-Tolerant Networking. Saratoga can optionally also be used to carry the Bundle Protocol "bundles" that is proposed for use in Delay and Disruption-Tolerant Networking (DTN) by the IRTF DTN Research Group [RFC5050]. The bundle agent acts as an application driving Saratoga. Use of a filesystem is expected. This approach has been tested from orbit using the UK-DMC satellite [Ivancic10]. How Saratoga can optionally function as a "bundle convergence layer" alongside a DTN bundle agent is specified in a companion document [I-D.wood-dtnrg-saratoga].

- transfers permitting some errors in content delivered, using UDP-Lite [RFC3828]. These can be useful for decreasing delivery time over unreliable channels, especially for unidirectional links, or in decreasing computational overhead for the UDP Lite checksum. To be really usefuly, error tolerance requires that lower-layer frames permit delivery of unreliable data, while header information is still checked to assure that e.g. destination information is reliable.

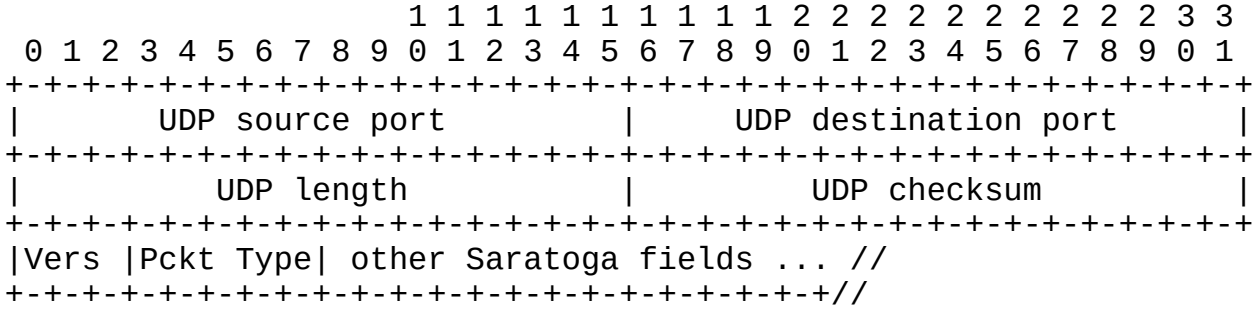
If a file contains separate parts that require reliable transmission without errors or that can tolerate errors in delivered content, proactive fragmentation can be used to split the file into separate reliable and unreliable files that can be transferred separately, using UDP or UDP-Lite.

If parts of a file require reliability but the rest can be sent by unreliable transfer, the file-sender can use its knowledge of the internal file structure and vary DATA packet size so that the reliable parts always start after the offset field and are covered by the UDP-Lite checksum.

A file that permits unreliable delivery can be transferred onwards using UDP. If the current sender does not understand the internal file format to be able to decide what parts must be protected with payload checksum coverage, the current sender or receiver does not support UDP-Lite, or the current protocol stack only implements error-free frame delivery below the UDP layer, then the file MAY be delivered using UDP.

4. Packet Types

Saratoga is defined for use with UDP over either IPv4 or IPv6 [RFC0768]. UDP checksums, which are mandatory with IPv6, MUST be used with IPv4. Within either version of IP datagram, a Saratoga packet appears as a typical UDP header followed by an octet indicating how the remainder of the packet is to be interpreted:



Saratoga data transfers can also be carried out using UDP-Lite [RFC3828]. If Saratoga can be carried over UDP-Lite, the implementation MUST also support UDP. All packet types except DATA MUST be sent using UDP with checksums turned on. For reliable transfers, DATA packets are sent using UDP with checksums turned on. For files where unreliable transfer has been indicated as desired and possible, the sender MAY send DATA packets unreliably over UDP-Lite, where UDP-Lite protects only the Saratoga headers and parts of the file that must be transmitted reliably.

The three-bit Saratoga version field ("Ver") identifies the version of the Saratoga protocol that the packet conforms to. The value 001 MUST be used in this field for implementations conforming to the specification in this document, which specifies version 1 of Saratoga. The value 000 was used in earlier implementations, prior to the formal specification and public submission of the protocol design, and is incompatible with version 001 in many respects.

The five-bit Saratoga "Packet Type" field indicates how the remainder of the packet is intended to be decoded and processed:

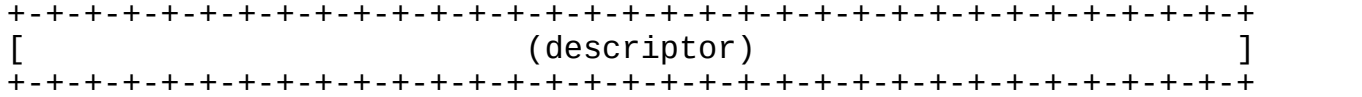
#	Type	Use
0	BEACON	Beacon packet indicating peer status.
1	REQUEST	Commands peer to start a transfer.
2	METADATA	Carries file transfer metadata.
3	DATA	Carries octets of file data.
4	STATUS	responds to REQUEST or DATA. Can signal list of unreceived data to sender during a transfer.

Several of these packet types include a Flags field, for which only some of the bits have defined meanings and usages in this document. Other, undefined, bits may be reserved for future use. Following the principle of being conservative in what you send and liberal in what you accept, a packet sender MUST set any undefined bits to zero, and a packet recipient MUST NOT rely on these undefined bits being zero on reception.

The specific formats for the different types of packets are given in this section. Some packet types contain file offset descriptor fields, which contain unsigned integers. The lengths of the offset descriptors are fixed within a transfer, but vary between file transfers. The size is set for each particular transfer, depending on the choice of offset descriptor width made in the METADATA packet, which in turn depends on the size of file being transferred.

In this document, all of the packet structure figures illustrating a packet format assume 32-bit lengths for these offset descriptor fields, and indicate the transfer-dependent length of the fields by using a "(descriptor)" designation within the [field] in all packet diagrams. That is:

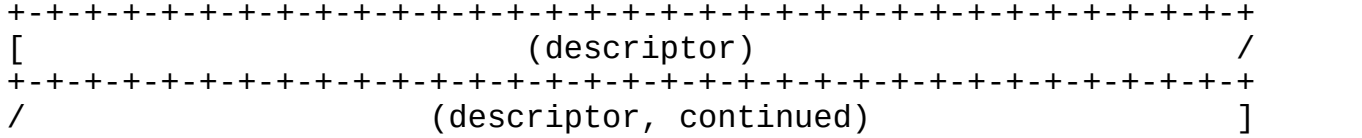
The example 32-bit descriptors shown in all diagrams here



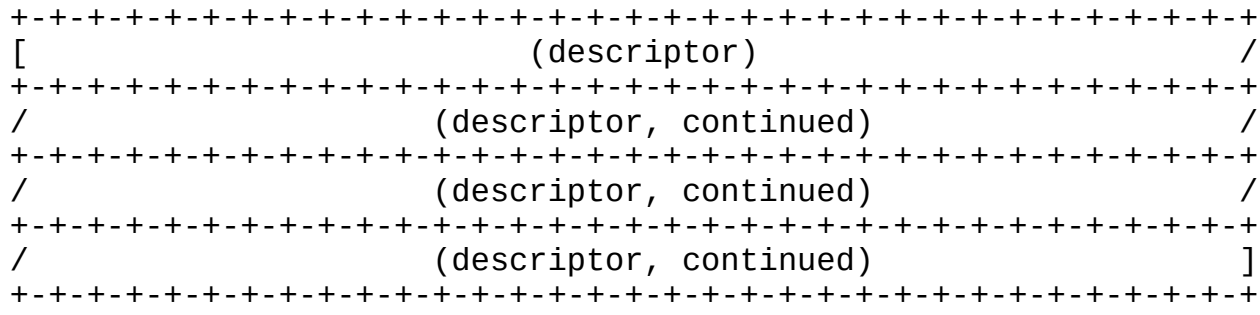
are suitable for files of up to 4GiB - 1 octets in length, and may be replaced in a file transfer by descriptors using a different length, depending on the size of file to be transferred:

16-bit descriptor for short files of up to 64KiB - 1 octets in size (MUST be supported)

64-bit descriptor for longer files of up to 16EiB - 1 octets in size (optional)



128-bit descriptor for very long files of up to 256 EiEiB - 1 octets in size (optional)



Descriptors are used for the descriptor size less one octet, e.g. 16-bit for files up to 64KB - 1 octets in size, before switching to the larger descriptor, e.g. using the 32-bit descriptor for a 64KB file and larger.

For offset descriptors and types of content being transferred, the related flag bits in BEACON and REQUEST indicate capabilities, while in METADATA and DATA those flag bits are used slightly differently, to indicate the content being transferred.

Saratoga packets are intended to fit within link MTUs to avoid the inefficiencies and overheads of lower-layer fragmentation. A Saratoga implementation does not itself perform any form of MTU discovery, but is assumed to be configured with knowledge of usable maximum IP MTUs for the link interfaces it uses.

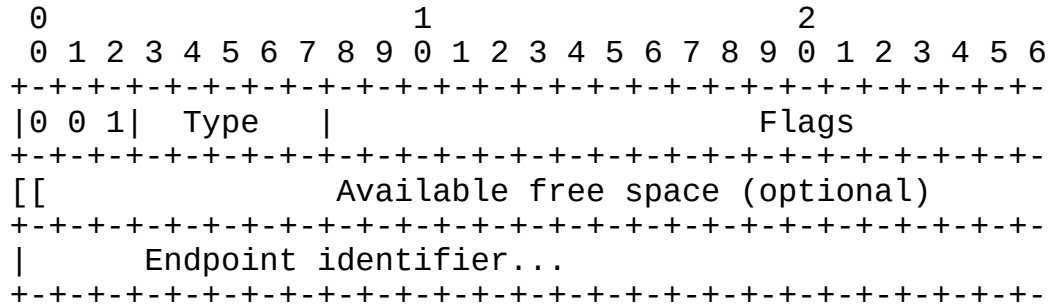
4.1. BEACON

BEACON packets may be multicast periodically by nodes willing to act as Saratoga peers, or unicast to individual peers to indicate properties for that peer. Some implementations have sent BEACONS every 100 milliseconds, but this rate is arbitrary, and should be chosen to be appropriate for the environment and implementation.

The main purpose for sending BEACONs is to announce the presence of the node to potential peers (e.g. satellites, ground stations) to provide automatic service discovery, and also to confirm the activity or presence of the peer.

The Endpoint Identifier (EID) in the BEACON serves to uniquely identify the Saratoga peer. Whenever the Saratoga peer begins using a new IP address, it SHOULD issue a BEACON on it and repeat the BEACON periodically, to enable listeners to associate the IP address with the EID and the peer.

Format



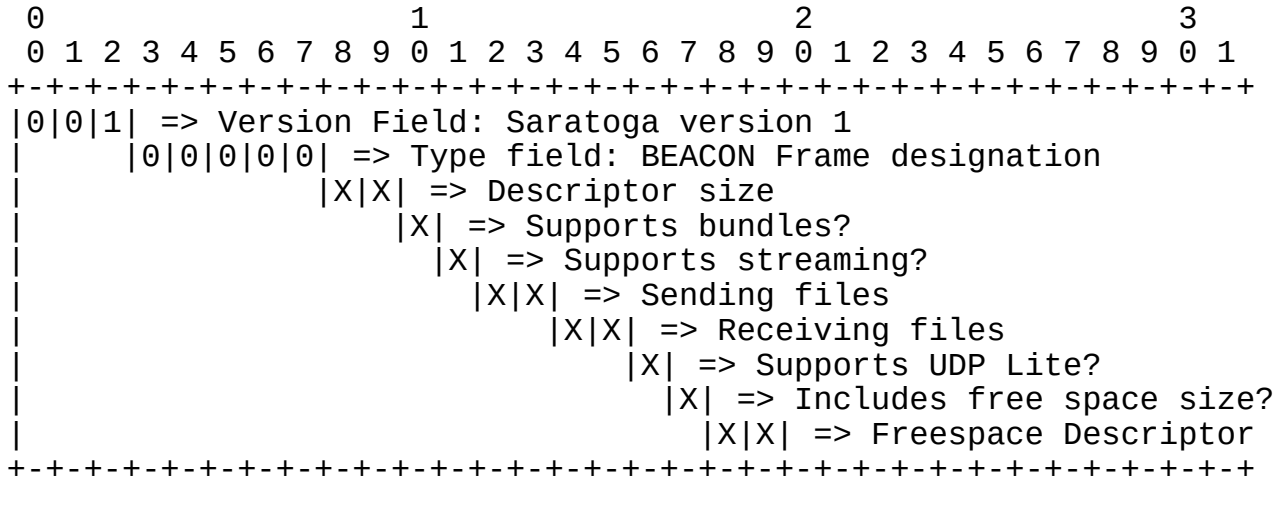
where

Field	Description
Type	0
Flags	convey whether or not the peer is ready to send/receive, what the maximum supported file size range and descriptor is, and whether and how free space is indicated.
Available free space	This optional field can be used to indicate the current free space available for storage.
Endpoint identifier	This can be used to uniquely identify the sending Saratoga peer, or the administrative node that the BEACON-sender is associated with. If Saratoga is being used with a bundle agent, a bundle endpoint ID (EID) can be used here.

The Flags field is used to provide some additional information about the peer. The first two octets of the Flags field is currently in use. The later octet is reserved for future use, and MUST be set to zero.

The BEACON flags field, expanding a line of flag bits with descriptions of each flag, is as follows:

BEACON Flags



The two highest-order bits (bits 8 and 9 above) indicate the maximum supported file size parameters that the peer's Saratoga implementation permits. Other Saratoga packet types contain variable-length fields that convey file sizes or offsets into a file -- the file offset descriptors. These descriptors may be 16-bit, 32-bit, 64-bit, or 128-bit in length, depending on the size of the file being transferred and/or the integer types supported by the sending peer.

The indicated bounds for the possible values of these bits are summarized below:

Bit 8	Bit 9	Supported Field Sizes	Maximum File Size
0	0	16 bits	2^16 - 1 octets.
0	1	16 or 32 bits	2^32 - 1 octets.
1	0	16, 32, or 64 bits	2^64 - 1 octets.
1	1	16, 32, 64, or 128 bits	2^128 - 1 octets.

If a Saratoga peer advertises it is capable of receiving a certain size of file, then it MUST also be capable of receiving files sent using smaller descriptor values. This avoids overhead on small files, while increasing interoperability between peers.

It is likely when sending unbounded streams that a larger offset descriptor field size will be preferred to minimise problems with offset sequence numbers wrapping. Protecting against sequence number wrapping is discussed in the STATUS section.

Bit	Value	Meaning
10	0	not able to pass bundles to a local bundle agent; handles files only.
10	1	handles files, but can also pass marked bundles to a local bundle agent.

Bit 10 is reserved for DTN bundle agent use, indicating whether the sender is capable of handling bundles via a local bundle agent. This is described in [I-D.wood-dtnrg-saratoga].

Bit	Value	Meaning
11	0	not capable of supporting streaming.
11	1	capable of supporting streaming.

Bit 11 is used to indicate whether the sender is capable of sending and receiving continuous streams.

Bit 12	Bit 13	Capability and willingness to send files
0	0	cannot send files at all.
0	1	invalid.
1	0	capable of sending, but not willing right now.
1	1	capable of and willing to send files.

Bit 14	Bit 15	Capability and willingness to receive files
0	0	cannot receive files at all.
0	1	invalid.
1	0	capable of receiving, but unwilling. Will reject METADATA or DATA packets.
1	1	capable of and willing to receive files.

Also in the Flags field, bits 12 and 14 act as capability bits, while bits 13 and 15 augment those flags with bits indicating current willingness to use the capability.

Bits 12 and 13 deal with sending, while bits 14 and 15 deal with receiving. If bit 12 is set, then the peer has the capability to send files. If bit 14 is set, then the peer has the capability to receive files. Bits 13 and 15 indicate willingness to send and receive files, respectively.

A peer that is able to act as a file-sender MUST set the capability bit 12 in all BEACONs that it sends, regardless of whether it is willing to send any particular files to a particular peer at a particular time. Bit 13 indicates the current presence of data to send and a willingness to send it in general, in order to augment the capability advertised by bit 12.

If bit 14 is set, then the peer is capable of acting as a receiver, although it still might not currently be ready or willing to receive files (for instance, it may be low on free storage). This bit MUST be set in any BEACON packets sent by nodes capable of acting as file-receivers. Bit 15 augments this by expresses a current general willingness to receive and accept files.

Bit	Value	Meaning
16	0	supports DATA transfers over UDP only.
16	1	supports DATA transfers over both UDP and UDP-Lite.

Bit 16 is used to indicate whether the sender is capable of sending and receiving unreliable transfers via UDP-Lite.

Bit	Value	Meaning
17	0	available free space is not advertised in this BEACON.
17	1	available free space is advertised in this BEACON.

Bit 17 is used to indicate whether the sender includes an optional field in this BEACON packet that tells how much free space is available. If bit 17 is set, then bits 18 and 19 are used to

indicate the size in bits of the optional free-space-size field. If bit 17 is not set, then bits 18 and 19 are zero.

Bit 18	Bit 19	Size of free space field
0	0	16 bits.
0	1	32 bits.
1	0	64 bits.
1	1	128 bits.

The free space field size can vary as indicated by a varying-size field indicated in bits 18 and 19 of the flags field. Unlike other offset descriptor use where the value in the descriptor indicates a byte or octet position for retransmission, or gives a file size in bytes, this particular field indicates the available free space in KIBIBYTES (KiB, multiples of 1024 octets), rather than octets. Available free space is rounded down to the nearest KiB, so advertising zero means that less than 1KiB is free and available. Advertising the maximum size possible in the field means that more free space than that is available. While this field is intended to be scalable, it is expected that 32 bits (up to 4TiB) will be most common in use.

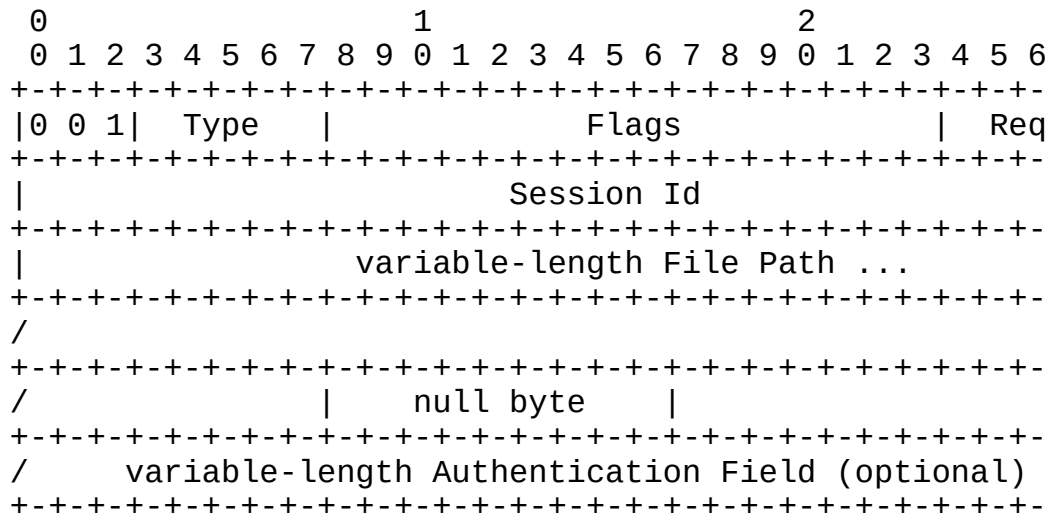
A BEACON unicast to an individual peer MAY choose to indicate the free space available for use by that particular peer, and MAY indicate capabilities only available to that particular peer, overriding or supplementing the properties advertised to all local peers by multicast BEACONs.

Any type of host identifier can be used in the endpoint identifier field, as long as it is a reasonably unique string within the range of operational deployment. This field encompasses the remainder of the packet, and might contain non-UTF-8 and/or null characters.

4.2. REQUEST

A REQUEST packet is an explicit command to perform either a _put_, _get_, _getdir_, or _delete_ session.

Format



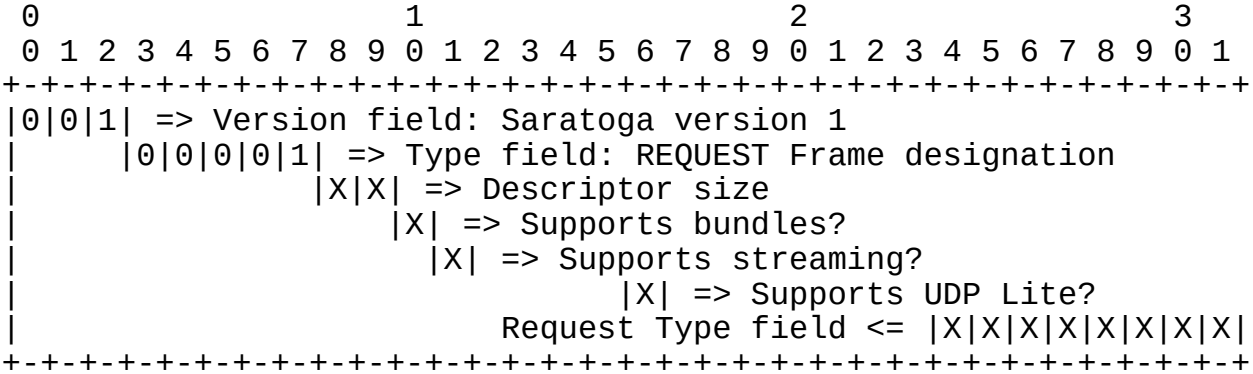
where

Field	Description
Type	1
Flags	provide additional information about the requested file/operation; see table below for definition.
Request Type	identifies the type of request being made; see table further below for request values.
Id	uniquely identifies the session between two peers.
File Path	the path of the requested file/directory following the rules described below.

The Id that is used during sessions serves to uniquely associate a given packet with a particular sessions. This enables multiple simultaneous data transfer or request/status sessions between two peers, with each peer deciding how to multiplex and prioritise the parallel flows it sends. The Id for a session is selected by the initiator so as to not conflict with any other in-progress or recent sessions with the same host. This Id should be unique and generated using properties of the file, which will remain constant across a host reboot. The 3-tuple of both host identifiers and a carefully-generated session Id field can be used to uniquely index a particular session’s state.

The REQUEST flags field, expanding a line of flag bits with descriptions of each flag, is as follows:

REQUEST Flags



In the Flags field, the bits labelled 8 and 9 in the figure above indicate the maximum supported file length fields that the peer can handle, and are interpreted exactly as the bits 8 and 9 in the BEACON packet described above. Bits 12 and 13, and 14 and 15, indicate capability and willingness to send and receive files, as described above. Making a _get_ request would require that the requester is capable and willing to receive files. The remaining defined individual bits are as summarised as follows:

Bit	Value	Meaning
10	0	The requester cannot handle bundles locally.
10	1	The requester can handle bundles.
11	0	The requester cannot receive streams.
11	1	The requester is also able to receive streams.
16	0	The requester is able to receive DATA over UDP only.
16	1	The requester is also able to receive DATA over UDP-Lite.

The Request Type field is an octet that contains a value indicated the type of request being made. Possible values are:

Value	Meaning
0	No action is to be taken; similar to a BEACON.
1	A _get_ session is requested. The File Path field holds the name of the file to be sent.

2	A _put_ session is requested. The File Path field suggests the name of the file that will be delivered only after an OK STATUS is received from the file receiver.
3	A _get_ session is requested, and once received successfully, the original copy should be deleted. The File Path field holds the name of the file to be sent. (This get+delete is known as a 'take'.)
4	A _put_ session is requested, and once sent successfully, the original copy will be deleted. The File Path field holds the name of the file to be sent. (This put+delete is known as a 'give'.)
5	A _delete_ session is requested, and the File Path field specifies the name of the file to be deleted.
6	A _getdir_ session is requested. The File Path field holds the name of the directory or file on which the directory record is created.

The File Path portion of a _get_ packet is a null-terminated UTF-8 encoded string [RFC3629] that represents the path and base file name on the file-sender of the file (or directory) that the file-receiver wishes to perform the _get_, _getdir_, or _delete_ operation on. Implementations SHOULD only send as many octets of File Path as are needed for carrying this string, although some implementations MAY choose to send a fixed-size File Path field in all REQUEST packets that is filled with null octets after the last UTF-8 encoded octet of the path. A maximum of 1024 octets for this field, and for the File Path fields in other Saratoga packet types, is used to limit the total packet size to within a single IPv6 minimum MTU (minus some padding for network layer headers), and thus avoid the need for fragmentation. The 1024-octet maximum applies after UTF-8 encoding and null termination.

As in the standard Internet File Transfer Protocol (FTP) [RFC0959], for path separators, Saratoga allows the local naming convention on the peers to be used. There are security implications to processing these strings without some intelligent filtering and checking on the filesystem items they refer to. See also the Security Considerations section later within this document.

If the File Path field is empty, i.e. is a null-terminated zero-length string one octet long, then this indicates that the file-receiver is ready to receive any file that the file-sender would like to send it, rather than requesting a particular file. This allows the file-sender to determine the order and selection of files that it would like to forward to the receiver in more of a "push" manner. Of

course, file retrieval could also follow a "pull" manner, with the file-receiving host requesting specific files from the file-sender. This may be desirable at times if the file-receiver is low on storage space, or other resources. The file-receiver could also use the Saratoga _getdir_ session results in order to select small files, or make other optimizations, such as using its local knowledge of contact times to pick files of a size likely to be able to be delivered completely. File transfer through pushing sender-selected files implements delivery prioritization decisions made solely at the Saratoga file-sending node. File transfer through pulling specific receiver-selected files implements prioritization involving more participation from the Saratoga file-receiver. This is how Saratoga implements Quality of Service (QoS).

The null-terminated File Path string MAY be followed by an optional Authentication Field that can be used to validate the REQUEST packet. Any value in the Authentication Field is the result of a computation of packet contents that SHOULD include, at a minimum, source and destination IP addresses and port numbers and packet length in a 'pseudo-header', as well as the content of all Saratoga fields from Version to File Path, excluding the predictable null-termination octet. This Authentication Field can be used to allow the REQUEST receiver to discriminate between other peers, and permit and deny various REQUEST actions as appropriate. The format of this field is unspecified for local use.

Combined get+delete (take) and put+delete (give) requests should only have the delete carried out once the deleting peer is certain that the file-receiver has a good copy of the file. This may require the file receiver to verify checksums before sending a final STATUS message acknowledging successful delivery of the final DATA segment, or aborting the transfer if the checksum fails. If the transfer fails and an error STATUS is sent for any reason, the file should not be deleted.

REQUEST packets may be sent multicast, to learn about all listening nodes. A multicast _get_ request for a file that elicits multiple METADATA or DATA responses should be followed by unicast STATUS packets with status errors cancelling all but one of the proposed transfers. File timestamps in the Directory Entry can be used to select the most recent version of an offered file, and the host to fetch it from.

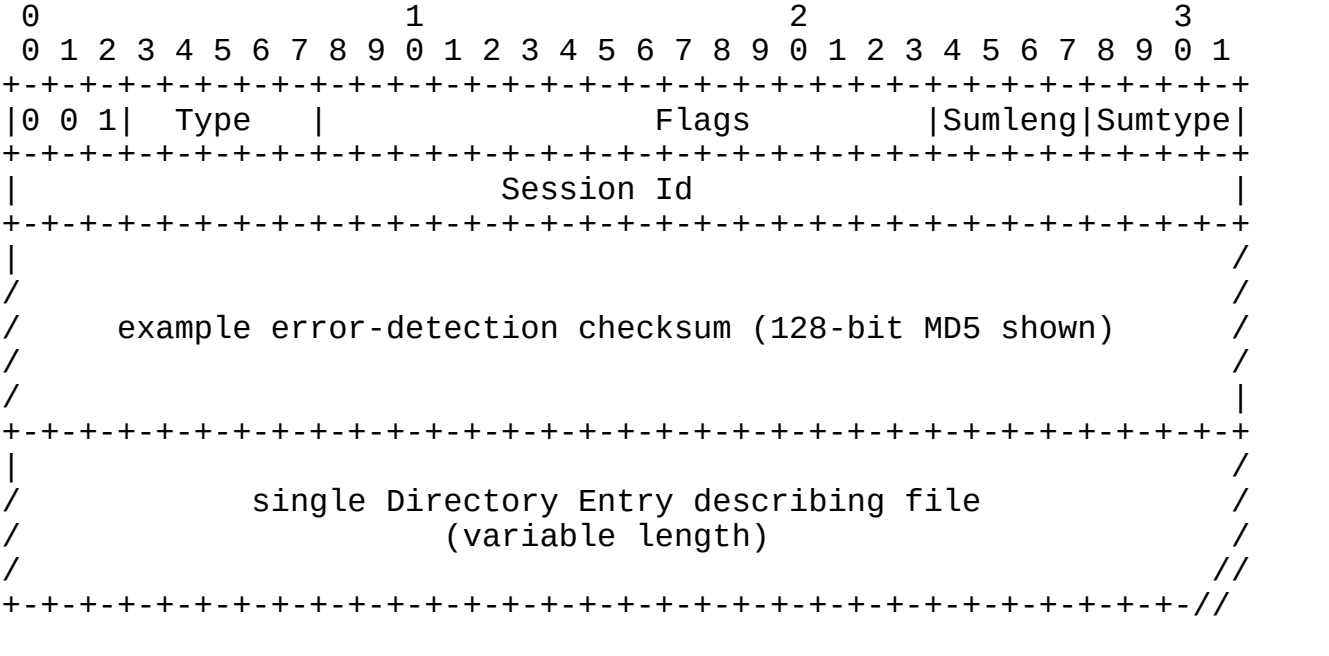
If the receiver already has the file at the expected file path and is requesting an update to that file, REQUEST can be sent after a METADATA advertising that file, to allow the sender to determine whether a replacement for the file should be sent.

Delete requests are ignored for files currently being transferred.

4.3. METADATA

METADATA packets are sent as part of a data transfer session (_get_, _getdir_, and _put_). A METADATA packet says how large the file is and what its name is, as well as what size of file offset descriptor is chosen for the session. METADATA packets are optional, but SHOULD be sent. A METADATA packet that is received MUST be parsed. A METADATA packet is normally sent at the start of a DATA transfer, but can be repeated throughout the transfer. Sending METADATA at the start if using checksums allows for incremental checksum calculation by the receiver, and is a good idea.

Format



where

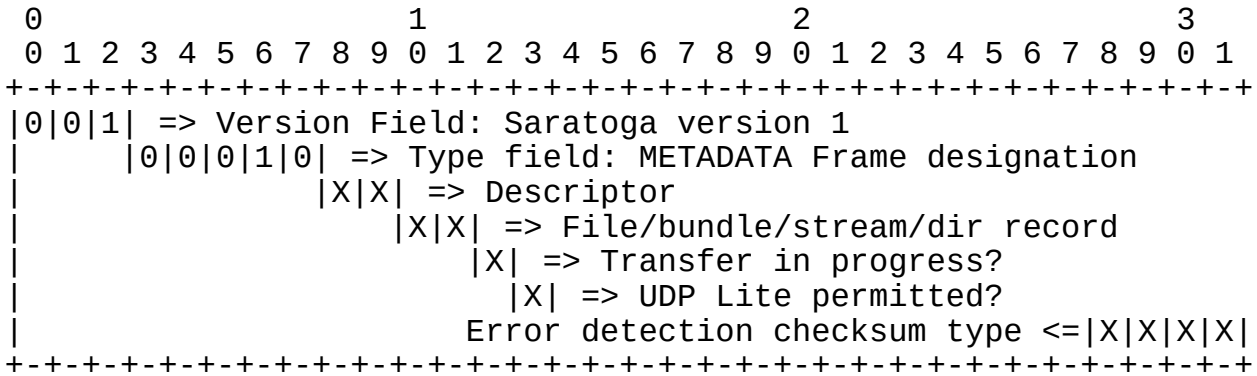
Field	Description
Type	2
Flags	indicate additional boolean metadata about a file.
Sumleng	indicates the length of a checksum, as a multiple of 32 bits.
Sumtype	indicates whether a checksum is present after the Id, and what type it is.

Id	identifies the session that this packet describes.
Checksum	an example included checksum covering file contents.
Directory Entry	describes file system information about the file, including file length, file timestamps, etc.; the format is specified in Section 5.

The first octet of the Flags field is currently specified for use. The later two octets are reserved for future use, and MUST be set to zero.

The METADATA flags field is as follows, expanding a line of flag bits with explanations of each field:

METADATA Flags



In the Flags field, the bits labelled 8 and 9 in the figure above indicate the exact size of the offset descriptor fields used in this particular packet and are interpreted exactly as the bits 8 and 9 in the BEACON packet described above. The value of these bits determines the size of the File Length field in the current packet, as well as indicating the size of the offset fields used in DATA and STATUS packets within the session that will follow this packet.

Bit 10	Bit 11	Type of transfer
0	0	a file is being sent.
0	1	the file being sent should be interpreted as a Directory Record.
1	0	a bundle is being sent.

1	1	an indefinite-length stream is being sent.

Also inside the Flags field, bits 10 and 11 indicate what is being transferred - a file, special directory record file that contains one or more directory entries, bundle, or stream. The value 01 indicates that the METADATA and DATA packets are being generated in response to a _getdir_ REQUEST, and that the assembled DATA contents should be interpreted as a Directory Record containing directory entries, as defined in Section 5.

Bit	Value	Meaning
12	0	This transfer is in progress.
12	1	This transfer is no longer in progress, and has been terminated.

Bit 12 indicates whether the transfer is in progress, or has been terminated by the sender. It is normally set to 1 only when METADATA is resent to indicate that a stream transfer has been ended.

Bit 13	Use
0	This file’s content MUST be delivered reliably without errors using UDP.
1	This file’s content MAY be delivered unreliably, or partly unreliably, where errors are tolerated, using UDP-Lite.

Bit 13 indicates whether the file must be sent reliably or can be sent at least partly unreliably, using UDP-Lite. This flag SHOULD only be set if the originator of the file knows that at least some of the file content is suitable for sending unreliably and is robust to errors. This flag reflects a property of the file itself. This flag may still be set if the immediate file-receiver is only capable of UDP delivery, on the assumption that this preference will be preserved for later transfers where UDP-Lite transfers may be taken advantage of by senders with knowledge of the internal file structure. The file-sender may know that the receiver is capable of handling UDP-Lite, either from a _get_ REQUEST, from exchange of BEACONs, or a-priori.

The high four bits of the Flags field, bits 28-31, are used to indicate if an error-detection checksum has been included in the METADATA for the file to be transferred. Here, bits 0000 indicate that no checksum is present, with the implicit assumption that the application will do its own end-to-end check. Other values indicate the type of checksum to use. The choice of checksum depends on the available computing power and the length of the file to be checksummed. Longer files require stronger checksums to ensure error-free delivery. The checksum of the file to be transferred is carried as shown, with a fixed-length field before the varying-length File Length and File Name information fields.

Assigned values for the checksum type field are:

Value (0-15)	Use
0	No checksum is provided.
1	32-bit CRC32 checksum, suitable for small files.
2	128-bit MD5 checksum, suitable for larger files.
3	160-bit SHA-1 checksum, suitable for larger files but slower to process than MD5.

The length of the checksum cannot be inferred from the checksum type field, particularly for unknown checksum types. The next-highest four bits of the 32-bit word holding the Flags, bits 24-27, indicate the length of the checksum bit field, as a multiple of 32 bits.

Example Value (0-15)	Use
0	No checksum is provided.
1	32-bit checksum field, e.g. CRC32.

4	128-bit checksum field, e.g. MD5.
5	160-bit checksum field, e.g. SHA-1.

For a 32-bit CRC, the length field holds 1 and the type field holds 1. For MD5, the length field holds 4 and the type field holds 2. For SHA-1, the length field holds 5 and the type field holds 3.

It is expected that higher values will be allocated to new and stronger checksums able to better protect larger files. These checksums can be expected to be longer, with larger checksum length fields.

A checksum SHOULD be included for files being transferred. The checksum SHOULD be as strong as possible. Streaming of an indefinite-length stream MUST set the checksum type field to zero.

It is expected that a minimum of the MD5 checksum will be used, unless the Saratoga implementation is used exclusively for small transfers at the low end of the 16-bit file descriptor range, such as on low-performing hardware, where the weaker CRC-32c checksum can suffice.

The CRC32 checksum is computed as described for the CRC-32c algorithm given in [RFC3309].

The MD5 Sum field is generated via the MD5 algorithm [RFC1321], computed over the entire contents of the file being transferred. The file-receiver can compute the MD5 result over the reassembled Saratoga DATA packet contents, and compare this to the METADATA's MD5 Sum field in order to gain confidence that there were no undetected protocol errors or UDP checksum weaknesses encountered during the transfer. Although MD5 is known to be less than optimal for security uses, it remains excellent for non-security use in error detection (as is done here in Saratoga), and has better performance implications than cryptographically-stronger alternatives given the limited available processing of many use cases [RFC6151].

Checksums may be privately keyed for local use, to allow transmission of authenticated or encrypted files delivered in DATA packets. This has limitations, discussed further in Section 8 at end.

Use of the checksum to ensure that a file has been correctly relayed to the receiving node is important. A provided checksum MUST be checked against the received data file. If checksum verification fails, either due to corruption or due to the receiving node not having the right key for a keyed checksum), the file MUST be

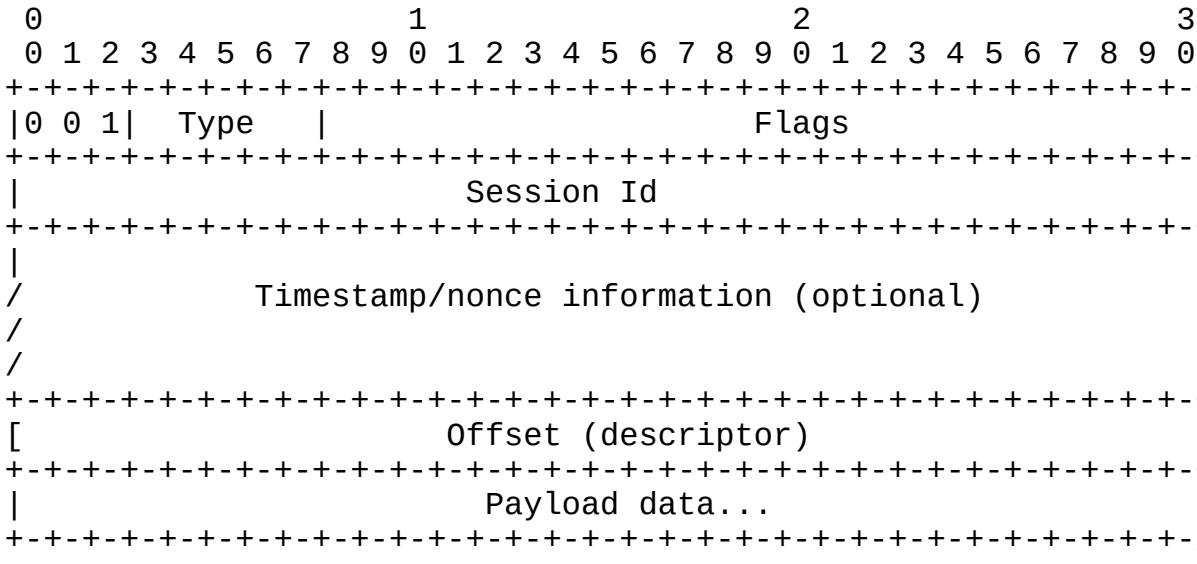
discarded. If the file is to be relayed onwards later to another Saratoga peer, the metadata, including the checksum, MUST be retained with the file and SHOULD be retransmitted onwards unchanged with the file for end-to-end coverage. If it is necessary to recompute the checksum or encrypted data for the new peer, either because a different key is in use or the existing checksum algorithm is not supported, the new checksum MUST be computed before the old checksum is verified, to ensure overlapping checksum coverage and detect errors introduced in file storage.

METADATA can be used as an indication to update copies of files. If the METADATA is in response to a _get_ REQUEST including a file record, and the record information for the held file matches what the requester already has, as has been indicated by a previously-received METADATA advertisement from the requester, then only the METADATA is sent repeating this information and verifying that the file is up to date. If the record information does not match and a newer file can be supplied, the METADATA begins a transfer with following DATA packets to update the file.

4.4. DATA

A series of DATA packets form the main part of a data transfer session (_get_, _put_, or _getdir_). The payloads constitute the actual file data being transferred.

Format



where

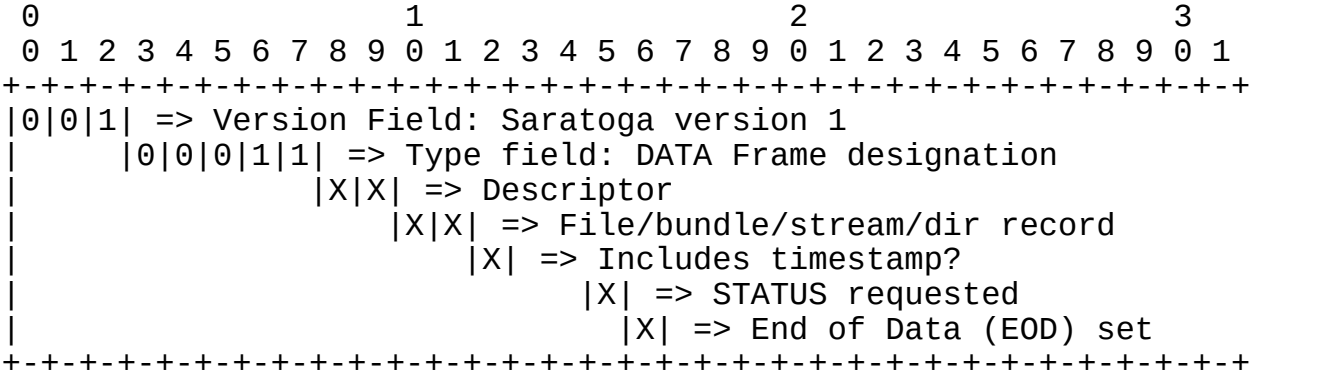
Field	Description
Type	3
Flags	are described below.
Id	identifies the session to which this packet belongs.
Timestamp/nonce	is an optional 128-bit field providing timing or identification information unique to this packet. See Appendix A for details.
Offset	the offset in octets to the location where the first byte of this packet's payload is to be written.

The DATA packet has a minimum size of ten octets, using sixteen-bit descriptors and no timestamps.

DATA packets are normally checked by the UDP checksum to prevent errors in either the header or the payload content. However, for transfers that can tolerate content errors, DATA packets MAY be sent using UDP-Lite. If UDP-Lite is used, the file-sender must know that the file-receiver is capable of handling UDP-Lite, and the file contents to be transferred should be resilient to errors. The UDP-Lite checksum MUST protect the Saratoga headers, up to and including the offset descriptor, and MAY protect more of each packet's payload, depending on the file-sender's knowledge of the internal structure of the file and the file's reliability requirements.

The DATA flags field is as follows, expanding a line of flag bits with explanations of each field:

DATA Flags



Bit 8	Bit 9	Type of transfer
0	0	16-bit descriptors are in use in this transfer.
0	1	32-bit descriptors are in use in this transfer.
1	0	64-bit descriptors are in use in this transfer.
1	1	128-bit descriptors are in use in this transfer.

Flag bits 8 and 9 are set to indicate the size of the offset descriptor as described for BEACON and METADATA packets, so that each DATA packet is self-describing. This allows the DATA packet to be used to construct a file even when an initial METADATA is lost and must be resent. The flag values for bits 8 and 9 MUST be the same as indicated in any expected METADATA packet.

Bit 10	Bit 11	Type of transfer
0	0	a file is being sent.
0	1	the file being sent should be interpreted as a directory record.
1	0	a bundle is being sent.
1	1	an indefinite-length stream is being sent.

Also inside the Flags field, bits 10 and 11 indicate what is being transferred - a file, special file that contains a Directory Records, bundle, or stream. The value 01 indicates that the METADATA and DATA packets are being generated in response to a _getdir_ REQUEST, and that the assembled DATA contents should be interpreted as a Directory Record containing directory entries, as defined in Section 5. The flag values for bits 10 and 11 MUST be the same as indicated in the initial METADATA packet.

Bit	Value	Meaning
12	0	This packet does not include an optional timestamp/nonce field.

12	1	This packet includes an optional timestamp/nonce field.

Flag bit 12 indicates that an optional packet timestamp/nonce is carried in the packet before the offset field. This packet timestamp /nonce field is always sixteen octets (128 bits) long. Timestamps can be useful to the sender even when the receiver does not understand them, as the receiver can simply echo any provided timestamps back, as specified for STATUS packets, to allow the sender to monitor flow conditions. Packet timestamps are particularly useful when streaming. Packet timestamps are discussed further in Appendix A.

Bit	Value	Meaning
15	0	No response is requested.
15	1	A STATUS packet is requested.

Within the Flags field, if bit 15 of the packet is set, the file-receiver is expected to immediately generate a STATUS packet to provide the file-sender with up-to-date information regarding the status of the file transfer. This flag is set carefully and rarely. This flag may be set periodically, but infrequently. Asymmetric links with constrained backchannels can only carry a limited amount of STATUS packets before ack congestion becomes a problem. This flag SHOULD NOT be set if an unreliable stream is being transferred, or if multicast is in use. This flag SHOULD be set periodically for reliable file transfers, or reliable streaming. The file-receiver MUST respond to the flag by generating a STATUS packet, unless it knows that doing so will lead to local congestion, in which case it may choose to send a later voluntary STATUS message. Voluntary STATUS packets MAY be sent if a request for one has not been made within an appropriate time.

Bit	Value	Meaning
16	0	Normal use.
16	1	The EOD End of Data flag is set.

The End of Data flag is set in DATA packets carrying the last byte of a transfer. This is particularly useful for streams and for the rare Saratoga implementations that do not send or receive METADATA.

Immediately following the DATA header is the payload, which consumes the remainder of the packet and whose length is implicitly defined by the end of the packet. The payload octets are directly formed from the continuous octets starting at the specified Offset in the file being transferred. No special coding is performed. A zero-octet payload length is allowable, and a single DATA packet indicating zero payload, consisting only of a header with the EOD flag set, may be useful to simply elicit a STATUS response from the receiver.

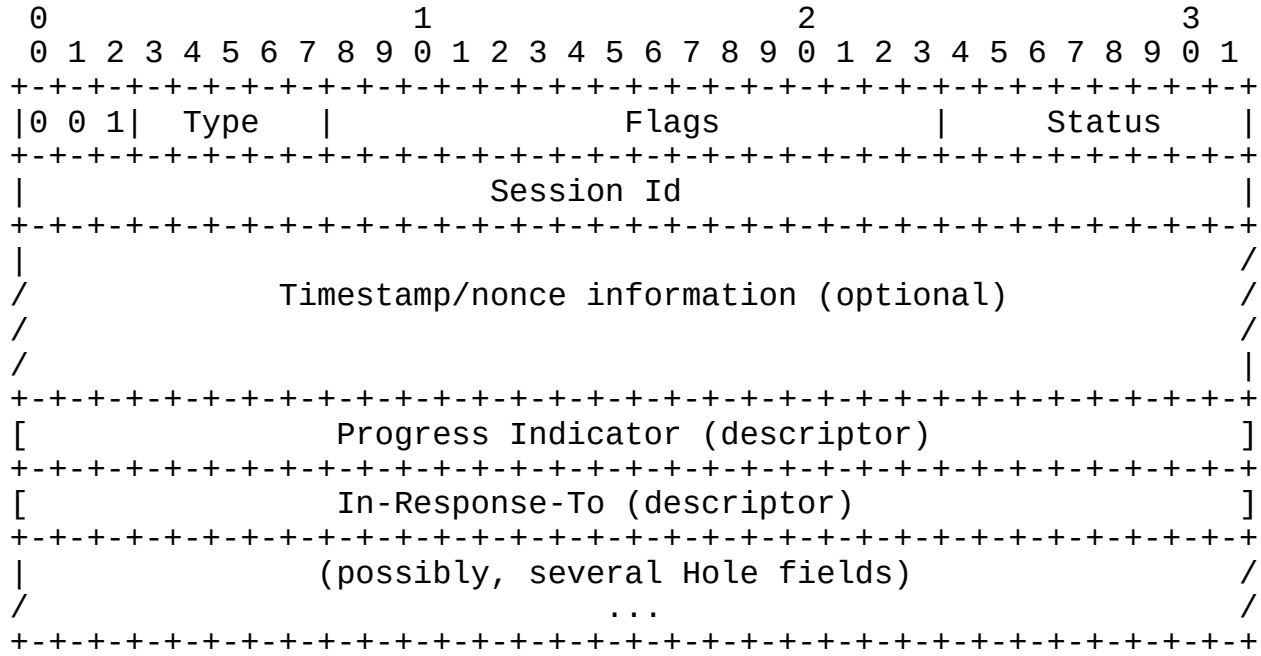
The length of the Offset fields used within all DATA packets for a given session MUST be consistent with the length indicated by bits 8 and 9 of any accompanying METADATA packet. If the METADATA packet has not yet been received, a file-receiver that supports METADATA MUST indicate that it has not been received via a STATUS packet, and MAY choose to enqueue received DATA packets for later processing after the METADATA arrives.

4.5. STATUS

The STATUS packet type is the single acknowledgement method that is used for feedback from a Saratoga receiver to a Saratoga sender to indicate session progress, both as a response to a REQUEST, and as a response to a DATA packet when demanded or volunteered.

When responding to a DATA packet, the STATUS packet MAY, as needed, include selective acknowledgement (SNACK) ’hole’ information to enable transmission (usually re-transmission) of specific sets of octets within the current session (called "holes"). This ’holestofill’ information can be used to clean up losses (or indicate no losses) at the end of, or during, a session, or to efficiently resume a transfer that was interrupted in a previous session.

Format



where

Field	Description
Type	4
Flags	are defined below.
Id	identifies the session that this packet belongs to.
Status	a value of 00 indicates the transfer is sucessfully proceeding. All other values are errors terminating the transfer, explained below.
Zero-Pad	an octet fixed at 00 to allow later fields to be conveniently aligned for processing.
Timestamp (optional)	an optional fixed 128-bit field, that is only present and used to return a packet timestamp if the timestamp flag is set. If the STATUS packet is voluntary and the voluntary flag is set, this should repeat the timestamp of the DATA packet containing the highest offset seen. If the STATUS packet is in response to a mandatory request, this will repeat the timestamp of the requesting DATA packet. The file-sender may use these timestamps to estimate latency. Packet timestamps are particularly useful when streaming. There are

	special considerations for streaming, discussed further below, to protect against the ambiguity of wrapped offset descriptor sequence numbers. Packet timestamps are discussed further in Appendix A.
Progress Indicator (descriptor)	the offset of the lowest-numbered octet of the file not yet received, and expected.
In-Response-To (descriptor)	the offset of the octet following the DATA packet that generated this STATUS packet, or the offset of the next expected octet following the highest DATA packet seen if this STATUS is generated voluntarily and the voluntary flag is set.
Holes	indications of offset ranges of missing data, defined below.

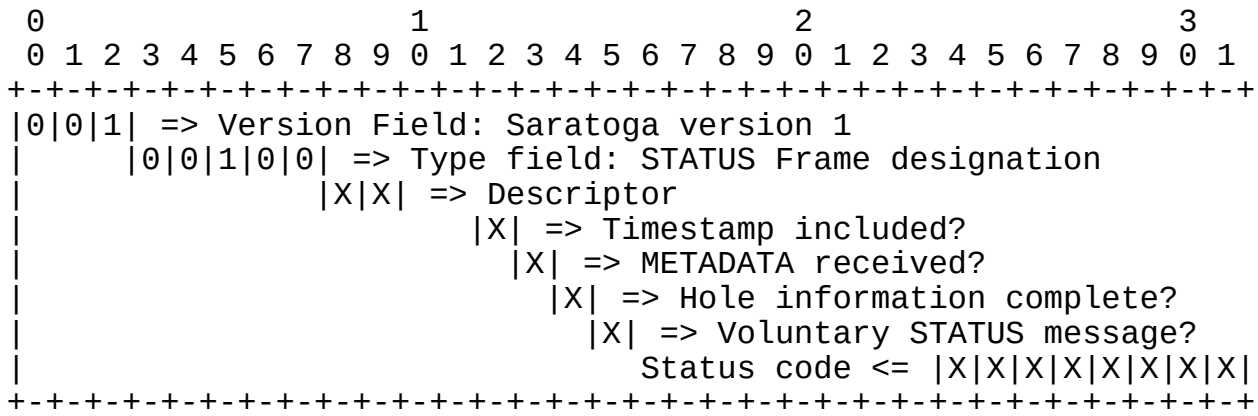
The STATUS packet has a minimum size of twelve octets, using sixteen-bit descriptors, a progress indicator but no Hole fields, and no timestamps. The progress indicator is always zero when responding to requests that may initiate a transfer.

The Id field is needed to associate the STATUS packet with the session that it refers to.

The Progress Indicator and In-Response-To fields mark the ’left edge’ and ’right edge’ of the incomplete working area where holes are being filled in. If there are no holes, these fields will hold the same value. At the start of a transfer, both fields begin by expecting octet zero. When a transfer has completed successfully, these fields will contain the length of the file.

The STATUS flags field is as follows, expanding a line of flag bits with explanations of each field:

STATUS Flags



Flags bits 8 and 9 are set to indicate the size of the offset descriptor as described for BEACON and METADATA packets, so that each STATUS packet is self-describing. The flag values here MUST be the same as indicated in the initial METADATA and DATA packets.

Other bits in the Flags field are defined as:

Bit	Value	Meaning
12	0	This packet does not include a timestamp field.
12	1	This packet includes an optional timestamp field.

Flag bit 12 indicates that an optional sixteen-byte packet timestamp/ nonce field is carried in the packet before the Progress Indicator descriptor, as discussed for the DATA packet format. Packet timestamps are discussed further in Appendix A.

Bit	Value	Meaning
13	0	file’s METADATA has been received.
13	1	file’s METADATA has not been received.

If bit 13 of a STATUS packet has been set to indicate that the METADATA has not yet been received, then any METADATA SHOULD be resent. This flag should normally be clear.

A receiver SHOULD tolerate lost METADATA that is later resent, but MAY insist on receiving METADATA at the start of a transfer. This is

done by responding to early DATA packets with a voluntary STATUS packet that sets this flag bit, reports a status error code 10, sets the Progress Indicator field to zero, and does not include HOLESTOFILL information.

Bit	Value	Meaning
14	0	this packet contains the complete current set of holes at the file-receiver.
14	1	this packet contains incomplete hole-state; holes shown in this packet should supplement other incomplete hole-state known to the file-sender.

Bit 14 of a 'holestofill' STATUS packet is only set when there are too many holes to fit within a single STATUS packet due to MTU limitations. This causes the hole list to be spread out over multiple STATUS packets, each of which conveys distinct sets of holes. This could occur, for instance, in a large file _put_ scenario with a long-delay feedback loop and poor physical layer conditions. These multiple STATUS packets will share In-Response-To information. When losses are light and/or hole reporting and repair is relatively frequent, all holes should easily fit within a single STATUS packet, and this flag will be clear. Bit 14 should normally be clear.

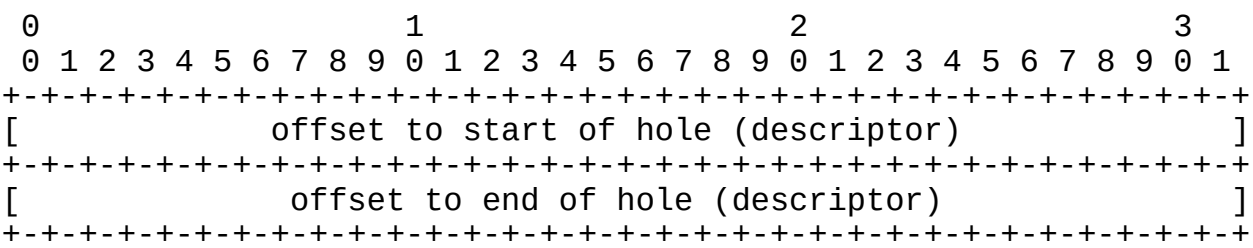
In some rare cases of high loss, there may be too many holes in the received data to convey within a single STATUS's size, which is limited by the link MTU size. In this case, multiple STATUS packets may be generated, and Flags bit 14 should be set on each STATUS packet accordingly, to indicate that each packet holds incomplete results. The complete group of STATUS packets, each containing incomplete information, will share common In-Response-To information to distinguish them from any earlier groups.

Bit	Value	Meaning
15	0	This STATUS was requested by the file-sender.
15	1	This STATUS is sent voluntarily.

Flag bit 15 indicates whether the STATUS is sent voluntarily or due to a request by the sender. It affects content of the In-Response-To timestamp and descriptor fields.

In the case of a transfer proceeding normally, immediately following the STATUS packet header shown above, is a set of "Hole" definitions indicating any lost packets. Each Hole definition is a pair of unsigned integers. For a 32-bit offset descriptor, each Hole definition consists of two four-octet unsigned integers:

Hole Definition Format



The start of the hole means the offset of the first unreceived byte in that hole. The end of the hole means the last unreceived byte in that hole.

For 16-bit descriptors, each Hole definition holds two two-octet unsigned integers, while Hole definitions for 64- and 128-bit descriptors require two eight- and two sixteen-octet unsigned integers respectively.

Holes MUST be listed in order, lowest values first.

Since each Hole definition takes up eight octets when 32-bit offset lengths are used, we expect that well over 100 such definitions can fit in a single STATUS packet, given the IPv6 minimum MTU. (There may be cases where there is a very constrained backchannel compared to the forward channel streaming DATA packets. For these cases, implementations might deliberately request large holes that span a number of smaller holes and intermediate areas where DATA has already been received, so that previously-received DATA is deliberately resent. This aggregation of separate holes keeps the backchannel STATUS packet size down to avoid backchannel congestion.)

A ’voluntary’ STATUS can be sent at the start of each session. This indicates that the receiver is ready to receive the file, or indicates an error or rejection code, described below. A STATUS indicating a successfully established transfer has a Progress Indicator of zero and an In-Response-To field of zero.

On receiving a STATUS packet, the sender SHOULD prioritize sending the necessary data to fill those holes, in order to advance the Progress Indicator at the receiver.

4.5.1. Errors and aborting sessions

In the case of an error causing a session to be aborted, the Status field holds a code that can be used to explain the cause of the error to the other peer. A zero value indicates that there have been no significant errors (this is called a "success STATUS" within this document), while any non-zero value means the session should be aborted (this is called a "failure STATUS").

Error Code Status Value	Meaning
0x00	Success, No Errors.
0x01	Unspecified Error.
0x02	Unable to send file due to resource constraints.
0x03	Unable to receive file due to resource constraints.
0x04	File not found.
0x05	Access Denied.
0x06	Unknown Id field for session.
0x07	Did not delete file.
0x08	File length is longer than receiver can support.
0x09	File offset descriptors do not match expected use or file length.
0x0A	Unsupported Saratoga packet type received.
0x0B	Unsupported Request Type received.
0x0C	REQUEST is now terminated due to an internal timeout.
0x0D	DATA flag bits describing transfer have changed unexpectedly.
0x0E	Receiver is no longer interested in receiving this file.
0x0F	File is in use.
0x10	METADATA required before transfer can be accepted.
0x11	A STATUS error message has been received unexpectedly, so REQUEST is terminated.

The recipient of a failure STATUS MUST NOT try to process the Progress Indicator, In-Response-To, or Hole offsets, because, in some types of error conditions, the packet’s sender may not have any way of setting them to the right length for the session.

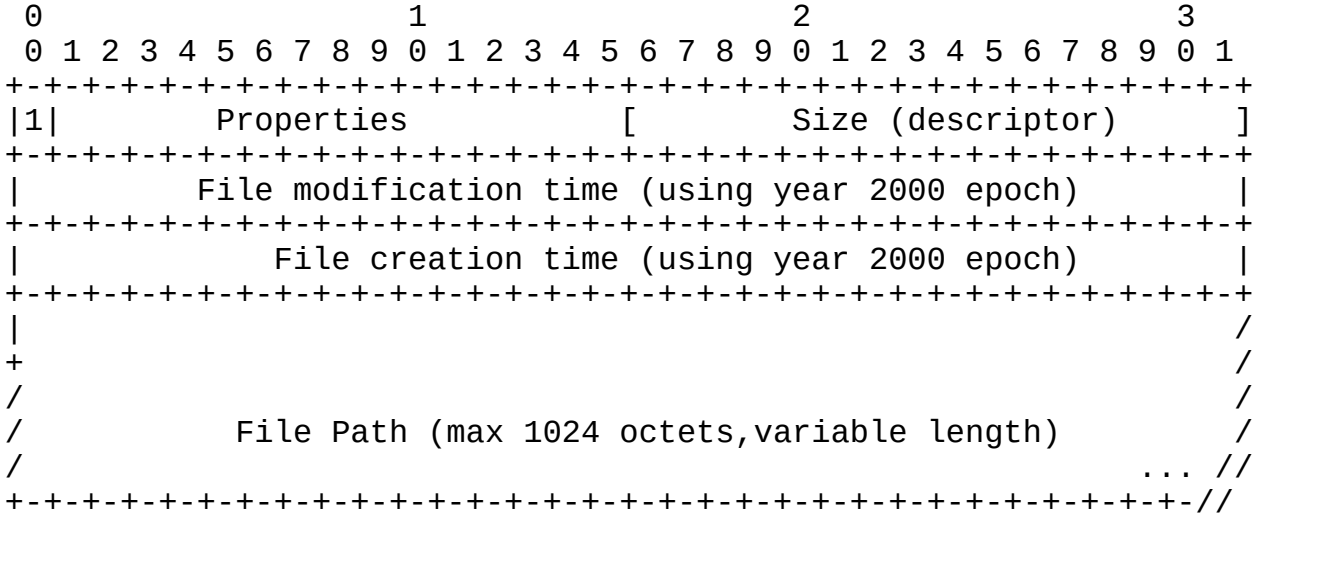
5. The Directory Entry

Directory Entries have two uses within Saratoga:

1. Within a METADATA packet, a Directory Entry is used to give information about the file being transferred, in order to facilitate proper reassembly of the file and to help the file-receiver understand how recently the file may have been created or modified.

2. When a peer requests a directory record via a _getdir_ REQUEST, the other peer generates a file containing a series of one or more concatenated Directory Entry records, and transfers this file as it would transfer the response to a normal _get_ REQUEST, sending the records together within DATA packets. This file may be either temporary or within-memory and not actually a part of the host's file system itself.

Directory Entry Format



where

field	description
Properties	if set, bit 7 of this field indicates that the entry corresponds to a directory. Bit 6, if set, indicates that the file is "special". A special file may not be directly transferable as it corresponds to a symbolic link, a named pipe, a device node, or some other "special" filesystem

		object. A file-sender may simply choose not to include these types of files in the results of a _getdir_ request. Bits 8 and 9 are flags that indicate the width of the following descriptor field that gives file size. Bit 10 indicates that the file is to be handled by Saratoga as a bundle, and passed to a bundle agent.
Size		the size of each file or directory in octets. This is a descriptor, varying as needed in each entry for the size of the file. For convenience in the figure, it is shown here as a 16-bit descriptor for a small file.
Mtime		a timestamp showing when the file or directory was modified.
Ctime		a timestamp of the last status change for this file or directory.
File Path		contains the file's name relative within the requested path of the _getdir_ session, a maximum of 1024-octet UTF-8 string, which is null-terminated to indicate its end. The File Path may contain additional null padding in the null termination to allow Directory Entries to each be allocated a fixed amount of space or to place an integer number of Directory Entries in each DATA packet for debugging purposes.

The first bit of the Directory Entry is always 1, to indicate the start of the record and the end of any padding from previous Directory Entries.

Bit 6	Bit 7	Properties conveyed
0	0	normal file.
0	1	normal directory.
1	0	special file.
1	1	special directory.

Streams listed in a directory should be marked as special. If a stream is being transferred, its size is unknown -- otherwise it would be a file. The size property of a Directory Entry for a stream is therefore expected to be zero.

Bit 8	Bit 9	Properties conveyed
0	0	File size is indicated in a 16-bit descriptor.
0	1	File size is indicated in a 32-bit descriptor.
1	0	File size is indicated in a 64-bit descriptor.
1	1	File size is indicated in a 128-bit descriptor.

Flag bits 8 and 9 of Properties are descriptor size flags, with similar meaning as before, describing the size of the File Size descriptor that follows the Properties field. When a single Directory Entry appears in the METADATA packet, these flags SHOULD match flag bits 8 and 9 in the METADATA header. (A smaller descriptor size may be indicated in the Directory Entry when doing test transfers of small files using large descriptors.)

Bit 10	Properties conveyed
0	File really is a file.
1	File is to be treated as a bundle.

Bit 10 of Directory Entry Properties is a bundle flag, as indicated in and matching the METADATA header. Use of Saratoga with bundles is discussed further in [I-D.wood-dtnrg-saratoga].

Bit 13	Use
0	This file’s content MUST be delivered reliably without errors using UDP.
1	This file’s content MAY be delivered unreliably, or partly unreliably, where errors are tolerated, using UDP-Lite.

Bit 13 indicates whether the file must be sent reliably or can be sent at least partly unreliably, using UDP-Lite. This matches METADATA flag use.

Undefined or unused flag bits of the Properties field default to zero. Bit 0 is always 1, to indicate the start of a Directory Entry. In general, bits 1-7 of Properties are for matters related to the

sender's filesystem, while bits 8-15 are for matters related to transport over Saratoga.

It may be reasonable that files are visible in Directory Entries only when they can be transferred to the requester - this may depend on e.g. having appropriate access permissions or being able to handle large filesizes. But requesters only capable of handling small files MUST be able to skip through large descriptors for large file sizes. Directory sizes are not calculated or sent, and a Size of 0 is given instead for directories, which are considered zero-length files.

The "epoch" format used in file creation and modification timestamps in directory entries indicates the unsigned number of seconds since the start of January 1, 2000 in UTC. The times MUST include all leap seconds. Using unsigned 32-bit values means that these time fields will not wrap until after the year 2136.

Converting from unix CTime/MTime holding a time past January 1, 2000 but with the traditional 1970 epoch means subtracting the fixed value of 946 684 822 seconds, which includes the 22 leap seconds that were added to UTC between 1 January 1970 and 1 January 2000. A unix time before 2000 is rounded to January 1, 2000.

A file-receiver should preserve the timestamp information received in the METADATA for its own copy of the file, to allow newer versions of files to propagate and supercede older versions.

6. Behaviour of a Saratoga Peer

This section describes some details of Saratoga implementations and uses the RFC 2119 standards language to describe which portions are needed for interoperability.

6.1. Saratoga Sessions

Following are descriptions of the packet exchanges between two peers for each type of session. Exchanges rely on use of the Id field to match responses to requests, as described earlier in Section 4.2.

6.1.1. The _get_ Session

1. A peer (the file-receiver) sends a REQUEST packet to its peer (the file-sender). The Flags bits are set to indicate that this is not a _delete_ request, nor does the File Path indicate a directory. Each _get_ session corresponds to a single file, and fetching multiple files requires sending multiple REQUEST packets and using multiple different Session Ids so that responses can be differentiated and matched to REQUESTs based on the Id field. If

a specific file is being requested, then its name is filled into the File Path field, otherwise it is left null and the file-sender will send a file of its choice.

2. If the _get_ request is rejected, then a STATUS packet containing an error code in the Status field is sent and the session is terminated. This STATUS packet MUST be sent to reject and terminate the session. The error code MAY make use of the "Unspecified Error" value for security reasons. Some REQUESTs might also be rejected for specifying files that are too large to have their lengths encoded within the maximum integer field width advertised by bits 8 and 9 of the REQUEST.

3. If the _get_ request is accepted, then a STATUS packet MAY be sent with an error code of 00 and an In-Response-To field of zero, to indicate acceptance. Sending other packets (METADATA or DATA) also indicates acceptance. The file-sender SHOULD generate and send a METADATA packet. A METADATA packet that is received MUST be parsed. The sender MUST send the contents of the file or stream as a series of DATA packets. In the absence of STATUS packets being requested from the receiver, if the file-sender believes it has finished sending the file and is not on a unidirectional link, it MUST send the last DATA packet with the Flags bit set requesting a STATUS response from the file-receiver. The last DATA packet MUST always have its End of Data (EOD) bit set. This can be followed by empty DATA packets with the Flags bits set with EOD and requesting a STATUS until either a STATUS packet is received, or the inactivity timer expires. All of the DATA packets MUST use field widths for the file offset descriptor fields that match what the Flags of the METADATA packet specified. Some arbitrarily selected DATA packets may have the Flags bit set that requests a STATUS packet. The file-receiver MAY voluntarily send STATUS packets at other times, where the In-Response-To field MUST set to zero. The file-receiver SHOULD voluntarily send a STATUS packet in response to the first DATA packet.

4. As the file-receiver takes in the DATA packets, it writes them into the file locally. The file-receiver keeps track of missing data in a hole list. Periodically the file sender will set the ack flag bit in a DATA packet and request a STATUS packet from the file-receiver. The STATUS packet can include a copy of this hole list if there are holes. File-receivers MUST send a STATUS packet immediately in response to receiving a DATA packet with the Flags bit set requesting a STATUS.

5. If the file-sender receives a STATUS packet with a non-zero number of holes, it re-fetches the file data at the specified

offsets and re-transmits it. If the METADATA packet has not been received, this is indicated by a bit in the STATUS packet, and the METADATA packet can be retransmitted. The file-sender MUST retransmit data from any holes reported by the file-receiver before proceeding further with new DATA packets.

6. When the file-receiver has fully received the file data and any METADATA packet, then it sends a STATUS packet indicating that the session is complete, and it terminates the session locally, although it MUST persist in responding to any further DATA packets received from the file-sender with 'completed' STATUSes, as described in Section 4.5, for some reasonable amount of time. Starting a timer on sending a completed STATUS and resetting it whenever a received DATA/sent 'completed' STATUS session takes place, then removing all session state on timer expiry, is one approach to this.

Given that there may be a high degree of asymmetry in link bandwidth between the file-sender and file-receiver, the STATUS packets should be carefully generated so as to not congest the feedback path. This means that both a file-sender should be cautious in setting the DATA Flags bit requesting STATUSes, and also that a file-receiver should be cautious in gratuitously generating STATUS packets of its own volition. When sending on known unidirectional links, a file-sender cannot reasonably expect to receive STATUS packets, so should never request them.

6.1.2. The _getdir_ Session

A _getdir_ session to obtain a Directory Record proceeds through the same states as the _get_ session. Rather than transferring the contents of a file from the file-receiver to the file-sender, a set of records representing the contents of a directory are transferred as a file. These records can be parsed and dealt with by the file-receiver as desired. There is no requirement that a Saratoga peer send the full contents of a directory listing; a peer may filter the results to only those entries that are actually accessible to the requesting peer.

Any file system entries that would normally be contained in the directory records, but that have sizes greater than the receiver has indicated that it can support in its BEACON, MUST be filtered out.

6.1.3. The _delete_ Session

1. A peer sends a REQUEST packet with the bit set indicating that it is a deletion request and the path to be deleted is filled into the File Path field. The File Path MUST be filled in for _delete_ sessions, unlike for _get_ sessions.

2. The other peer replies with a feedback STATUS packet whose Id matches the Id field of the _delete_ REQUEST. This STATUS has a Status code that indicates that the file is not currently present on the filesystem (indicated by the 00 Status field in a success STATUS), or whether some error occurred (indicated by the non-zero Status field in a failure STATUS). This STATUS packet MUST have no Holes and 16-bit width zero-valued Progress Indicator and In-Response-To fields.

If a request is received to delete a file that is already deleted, a STATUS with Status code 00 and other fields as described above is sent back in acknowledgement. This response indicates that the indicated file is not present, not the exact action sequence that led to a not-present file. This idempotent behaviour ensures that loss of STATUS acknowledgements and repeated _delete_ requests are handled properly.

6.1.4. The _put_ Session

A _put_ session proceeds as a _get_ does, except the file-sender and file-receiver roles are exchanged between peers. In a _put_ a PUT REQUEST is sent.

However, in a 'blind _put_', no REQUEST packet is ever sent. The file-sending end senses that the session is in progress when it receives METADATA or DATA packets for which it has no knowledge of the Id field.

If the file-receiver decides that it will store and handle the _put_ request (at least provisionally), then it MUST send a voluntary (ie, not requested) success STATUS packet to the file-sender. Otherwise, it sends a failure STATUS packet. After sending a failure STATUS packet, it may ignore future packets with the same Id field from the file-sender, but it should, at a low rate, periodically regenerate the failure STATUS packet if the flow of packets does not stop.

6.2. Beacons

Sending BEACON packets is not required in any of the sessions discussed in this specification, but optional BEACONs can provide useful information in many situations. If a node periodically generates BEACON packets, then it should do so at a low rate which does not significantly affect in-progress data transfers.

A node that supports multiple versions of Saratoga (e.g. version 1 from this specification along with the older version 0), MAY send multiple BEACON packets showing different version numbers. The version number in a single BEACON should not be used to infer the larger set of protocol versions that a peer is compatible with. Similarly, a node capable of communicating via IPv4 and IPv6 MAY send separate BEACONs via both protocols, or MAY only send BEACONs on its preferred protocol.

If a node receives BEACONs from a peer, then it SHOULD NOT attempt to start any _get_, _getdir_, or _delete_ sessions with that peer if bit 14 is not set in the latest received BEACONs. Likewise, if received BEACONs from a peer do not have bit 15 set, then _put_ sessions SHOULD NOT be attempted to that peer. Unlike the capabilities bits which prevent certain types of sessions from being attempted, the willingness bits are advisory, and sessions MAY be attempted even if the node is not advertising a willingness, as long as it advertises a capability. This avoids waiting for a willingness indication across long-delay links.

6.3. Upper-Layer Interface

No particular application interface functionality is required in implementations of this specification. The means and degree of access to Saratoga configuration settings, and session control that is offered to upper layers and applications, are completely implementation-dependent. In general, it is expected that upper layers (or users) can set timeout values for session requests and for inactivity periods during the session, on a per-peer or per-session basis, but in some implementations where the Saratoga code is restricted to run only over certain interfaces with well-understood operational latency bounds, then these timers MAY be hard-coded.

6.4. Inactivity Timer

In order to determine the liveliness of a session, Saratoga nodes may implement an inactivity timer for each peer they are expecting to see packets from. For each packet received from a peer, its associated inactivity timer is reset. If no packets are received for some amount of time, and the inactivity timer expires, this serves as a

signal to the node that it should abort (and optionally retry) any sessions that were in progress with the peer. Information from the link interface (i.e. link down) can override this timer for point-to-point links.

The actual length of time that the inactivity timer runs for is a matter of both implementation and deployment situation. Relatively short timers (on the order of several round-trip times) allow nodes to quickly react to loss of contact, while longer timers allow for session robustness in the presence of transient link problems. This document deliberately does not specify a particular inactivity timer value nor any rules for setting the inactivity timer, because the protocol is intended to be used in both long- and short-delay regimes.

Specifically, the inactivity timer is started on sending REQUEST or STATUS packets. When sending packets not expected to elicit responses (BEACON, METADATA, or DATA without acknowledgement requests), there is no point to starting the local inactivity timer.

For normal file transfers, there are simple rules for handling expiration of the inactivity timer during a _get_ or _put_ session. Once the timer expires, the file-sender SHOULD terminate the session state and cease to send DATA or METADATA packets. The file-receiver SHOULD stop sending STATUS packets, and MAY choose to store the file in some cache location so that the transfer can be recovered. This is possible by waiting for an opportunity to re-attempt the session and immediately sending a STATUS that only lists the parts of the file not yet received if the session is granted. In any case, a partially-received file MUST NOT be handled in any way that would allow another application to think it is complete.

The file-sender may implement more complex timers to allow rate-based pacing or simple congestion control using information provided in STATUS packets, but such possible timers and their effects are deliberately not specified here.

6.5. Streams and wrapping

When sending an indefinite-length stream, the possibility of offset sequence numbers wrapping back to zero must be considered. This can be protected against by using large offsets, and by the stream receiver. The receiver MUST separate out holes before the offset wraps to zero from holes after the wrap, and send Hole definitions in different STATUS packets, with Flag 14 set to mark them as incomplete. Any Hole straddling a sequence wrap MUST be broken into two separate Holes, with the second Hole starting at zero. The timestamps in STATUS packets carrying any pre-wrap holes should be

earlier than the timestamp in later packets, and should repeat the timestamp of the last DATA packet seen for that offset sequence before the following wrap to zero occurred. Receivers indicate that they no longer wish to receive streams by sending Status Code 0C.

6.6. Completing file delivery and ending the session

The sender infers a completely-received transfer from the reported receiver window position. In the final STATUS packet sent by the receiver once the file to be transferred has been completely received, bit 14 MUST be 0 (indicating a complete set of holes in this packet), there MUST NOT be any holestofill offset pairs indicating holes, the In-Response-To and Progress Indicator fields contain the length of the file (i.e. point to the next octet after the file), and the voluntary flag MUST be set. This 'completed' STATUS may be repeated, depending on subsequent sender behaviour, while internal state about the transfer remains available to the receiver.

Because METADATA not mandatory for implementations, the file receiver may not know the length of a file if METADATA is never sent. The sender MUST set the EOD End of Data flag in each DATA packet that sends the last byte of the file, and SHOULD request a STATUS acknowledgement when the EOD flag is set. If METADATA has been sent and the EOD comes earlier than a previously reported length of a file, an unspecified error 0x01, as described below, is returned in the STATUS message responding to that DATA packet and EOD flag. If a stream is being marked EOD, the receiver acknowledges this with a Success 0x00 code.

7. Mailing list

There is a mailing list for discussion of Saratoga and its implementations. Contact Lloyd Wood for details.

8. Security Considerations

The design of Saratoga provides limited, deliberately lightweight, services for authentication of session requests, and for authentication or encryption of data files via keyed metadata checksums. This document does not specify privacy or access control for data files transferred. Privacy, access, authentication and encryption issues may be addressed within an implementation or deployment in several ways that do not affect the file transfer protocol itself. As examples, IPSec may be used to protect Saratoga implementations from forged packets, to provide privacy, or to authenticate the identity of a peer. Other implementation-specific or configuration-specific mechanisms and policies might also be

employed for authentication and authorization of requests. Protection of file data and meta-data can also be provided by a higher-level file encryption facility. If IPsec is not required, use of encryption before the file is given to Saratoga is preferable.

Basic security practices like not accepting paths with "..", not following symbolic links, and using a chroot() system call, among others, should also be considered within an implementation.

Note that Saratoga is intended for single-hop transfers between peers. A METADATA checksum using a previously shared key can be used to decrypt or authenticate delivered DATA files. Saratoga can only provide payload encryption across a single Saratoga transfer, not end-to-end across concatenated separate hop-by-hop transfers through untrusted peers, as checksum verification of file integrity is required at each node. End-to-end data encryption, if required, MUST be implemented by the application using Saratoga.

9. IANA Considerations

IANA has allocated port 7542 (tcp/udp) for use by Saratoga.

saratoga	7542/tcp	Saratoga Transfer Protocol
saratoga	7542/udp	Saratoga Transfer Protocol

IANA has allocated a dedicated IPv4 all-hosts multicast address (224.0.0.108) and a dedicated IPv6 link-local multicast addresses (FF02:0:0:0:0:0:0:6c) for use by Saratoga.

10. Acknowledgements

Developing and deploying the on-orbit IP-based infrastructure of the Disaster Monitoring Constellation, in which Saratoga has proven useful, has taken the efforts of hundreds of people over more than a decade. We thank them all.

We thank James H. McKim as an early contributor to Saratoga implementations and specifications, while working for RSIS Information Systems at NASA Glenn. We regard Jim as an author of this document, but are prevented by the boilerplate five-author limit from naming him earlier.

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11. A Note on Naming

Saratoga is named for the USS Saratoga (CV-3), the aircraft carrier sunk at Bikini Atoll that is now a popular diving site.

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Appendix A. Timestamp/Nonce field considerations

Timestamps are useful in DATA packets when the time that the packet or its payload was generated is of importance; this can be necessary when streaming sensor data recorded and packetized in real time. The format of the optional timestamp, whose presence is indicated by a flag bit, is implementation-dependent within the available fixed-length 128-bit field. How the contents of this timestamp field are used and interpreted depends on local needs and conventions and the local implementation.

However, one simple suggested format for timestamps is to begin with a POSIX time_t representation of time, in network byte order. This is either a 32-bit or 64-bit signed integer representing the number of seconds since 1970. The remainder of this field can be used either for a representation of elapsed time within the current second, if that level of accuracy is required, or as a nonce field uniquely identifying the packet or including other information. Any locally-meaningful flags identifying a type of timestamp or timebase can be included before the end of the field. Unused parts of this field MUST be set to zero.

There are many different representations of timestamps and timebases, and this draft is too short to cover them in detail. One suggested flag representation of different timestamp fields is to use the least significant bits at the end of the timestamp/nonce field as:

Status Value	Meaning
00	No flags set, local interpretation of field.
01	32-bit POSIX timestamp at start of field indicating whole seconds from epoch.
02	64-bit POSIX timestamp at start of field indicating whole seconds elapsed from epoch.
03	32-bit POSIX timestamp, as in 01, followed by 32-bit timestamp indicating fraction of the second elapsed.
04	64-bit POSIX timestamp, as in 02, followed by 32-bit timestamp indicating fraction of the second elapsed.
05	32-bit timestamp giving seconds elapsed since the 2000 epoch, as in file timestamps. This option is likely only useful for very slow links.

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Other values may indicate specific epochs or timebases, as local requirements dictate. There are many ways to define and use time usefully.

Echoing timestamps back to the file-sender is also useful for tracking flow conditions. This does not require the echoing receiver to understand the timestamp format or values in use. The use of timestamp values may assist in developing algorithms for flow control (including TCP-Friendly Rate Control [I-D.wood-tsvwg-saratoga-congestion-control]) or other purposes. Timestamp values provide a useful mechanism for Saratoga peers to measure path and round-trip latency.

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