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Abstract

This specification describes an optimized expression of the semantics of the Hypertext Transfer Protocol (HTTP), referred to as HTTP version 2 (HTTP/2). HTTP/2 enables a more efficient use of network resources and a reduced latency by introducing field compression and allowing multiple concurrent exchanges on the same connection.

This document obsoletes RFCs 7540 and 8740.

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1. Introduction

The performance of applications using the Hypertext Transfer Protocol (HTTP, [\[HTTP\]](#)) is linked to how each version of HTTP uses the underlying transport, and the conditions under which the transport operates.

Making multiple concurrent requests can reduce latency and improve application performance. HTTP/1.0 allowed only one request to be outstanding at a time on a given TCP [\[TCP\]](#) connection. HTTP/1.1 [\[HTTP/1.1\]](#) added request pipelining, but this only partially addressed request concurrency and still suffers from application-layer head-of-line blocking. Therefore, HTTP/1.0 and HTTP/1.1 clients use multiple connections to a server to make concurrent requests.

Furthermore, HTTP fields are often repetitive and verbose, causing unnecessary network traffic as well as causing the initial TCP congestion window to quickly fill. This can result in excessive latency when multiple requests are made on a new TCP connection.

HTTP/2 addresses these issues by defining an optimized mapping of HTTP's semantics to an underlying connection. Specifically, it allows interleaving of messages on the same connection and uses an efficient coding for HTTP fields. It also allows prioritization of requests, letting more important requests complete more quickly, further improving performance.

The resulting protocol is more friendly to the network because fewer TCP connections can be used in comparison to HTTP/1.x. This means less competition with other flows and longer-lived connections, which in turn lead to better utilization of available network capacity. Note, however, that TCP head-of-line blocking is not addressed by this protocol.

Finally, HTTP/2 also enables more efficient processing of messages through use of binary message framing.

This document obsoletes RFCs 7540 and 8740. [Appendix B](#) lists notable changes.

2. HTTP/2 Protocol Overview

HTTP/2 provides an optimized transport for HTTP semantics. HTTP/2 supports all of the core features of HTTP but aims to be more efficient than HTTP/1.1.

HTTP/2 is a connection-oriented application-layer protocol that runs over a TCP connection ([TCP]). The client is the TCP connection initiator.

The basic protocol unit in HTTP/2 is a frame (Section 4.1). Each frame type serves a different purpose. For example, HEADERS and DATA frames form the basis of HTTP requests and responses (Section 8.1); other frame types like SETTINGS, WINDOW_UPDATE, and PUSH_PROMISE are used in support of other HTTP/2 features.

Multiplexing of requests is achieved by having each HTTP request/response exchange associated with its own stream (Section 5). Streams are largely independent of each other, so a blocked or stalled request or response does not prevent progress on other streams.

Effective use of multiplexing depends on flow control and prioritization. Flow control (Section 5.2) ensures that it is possible to efficiently use multiplexed streams by restricting data that is transmitted to what the receiver is able to handle. Prioritization (Section 5.3) ensures that limited resources are used most effectively. This revision of HTTP/2 deprecates the priority signaling scheme from [RFC7540].

Because HTTP fields used in a connection can contain large amounts of redundant data, frames that contain them are compressed (Section 4.3). This has especially advantageous impact upon request sizes in the common case, allowing many requests to be compressed into one packet.

Finally, HTTP/2 adds a new, optional interaction mode whereby a server can push responses to a client (Section 8.4). This is intended to allow a server to speculatively send data to a client that the server anticipates the client will need, trading off some network usage against a potential latency gain. The server does this by synthesizing a request, which it sends as a PUSH_PROMISE frame. The server is then able to send a response to the synthetic request on a separate stream.

2.1. Document Organization

The HTTP/2 specification is split into four parts:

- Starting HTTP/2 (Section 3) covers how an HTTP/2 connection is initiated.
- The frame (Section 4) and stream (Section 5) layers describe the way HTTP/2 frames are structured and formed into multiplexed streams.
- Frame (Section 6) and error (Section 7) definitions include details of the frame and error types used in HTTP/2.
- HTTP mappings (Section 8) and additional requirements (Section 9) describe how HTTP semantics are expressed using frames and streams.

While some of the frame- and stream-layer concepts are isolated from HTTP, this specification does not define a completely generic frame layer. The frame and stream layers are tailored to the needs of HTTP.

2.2. Conventions and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

All numeric values are in network byte order. Values are unsigned unless otherwise indicated. Literal values are provided in decimal or hexadecimal as appropriate. Hexadecimal literals are prefixed with "0x" to distinguish them from decimal literals.

This specification describes binary formats using the conventions described in [Section 1.3](#) of RFC 9000 [QUIC]. Note that this format uses network byte order and that high-valued bits are listed before low-valued bits.

The following terms are used:

client The endpoint that initiates an HTTP/2 connection. Clients send HTTP requests and receive HTTP responses.

connection Transport-layer connection between two endpoints.

connection error An error that affects the entire HTTP/2 connection.

error:

endpoint Either the client or server of the connection.

frame The smallest unit of communication within an HTTP/2 connection, consisting of a header and a variable-length sequence of octets structured according to the frame type.

peer An endpoint. When discussing a particular endpoint, "peer" refers to the endpoint that is remote to the primary subject of discussion.

receiver An endpoint that is receiving frames.

sender An endpoint that is transmitting frames.

server The endpoint that accepts an HTTP/2 connection. Servers receive HTTP requests and send HTTP responses.

stream A bidirectional flow of frames within the HTTP/2 connection.

stream error An error on the individual HTTP/2 stream.

error:

Finally, the terms "gateway", "intermediary", "proxy", and "tunnel" are defined in [Section 3.7](#) of [HTTP]. Intermediaries act as both client and server at different times.

The term "content" as it applies to message bodies is defined in [Section 6.4](#) of [HTTP].

3. Starting HTTP/2

Implementations that generate HTTP requests need to discover whether a server supports HTTP/2.

HTTP/2 uses the "http" and "https" URI schemes defined in [Section 4.2](#) of [HTTP], with the same default port numbers as HTTP/1.1 [HTTP/1.1]. These URIs do not include any indication about what HTTP versions an upstream server (the immediate peer to which the client wishes to establish a connection) supports.

The means by which support for HTTP/2 is determined is different for "http" and "https" URIs. Discovery for "https" URIs is described in [Section 3.2](#). HTTP/2 support for "http" URIs can only be discovered by out-of-band means and requires prior knowledge of the support as described in [Section 3.3](#).

3.1. HTTP/2 Version Identification

The protocol defined in this document has two identifiers. Creating a connection based on either implies the use of the transport, framing, and message semantics described in this document.

The string "h2" identifies the protocol where HTTP/2 uses Transport Layer Security (TLS); see [Section 9.2](#). This identifier is used in the [TLS Application-Layer Protocol Negotiation \(ALPN\) extension](#) [TLS-ALPN] field and in any place where HTTP/2 over TLS is identified.

The "h2" string is serialized into an ALPN protocol identifier as the two-octet sequence: 0x68, 0x32.

The "h2c" string was previously used as a token for use in the HTTP Upgrade mechanism's Upgrade header field ([Section 7.8](#) of [HTTP]). This usage was never widely deployed and is deprecated by this document. The same applies to the HTTP2-Settings header field, which was used with the upgrade to "h2c".

3.2. Starting HTTP/2 for "https" URIs

A client that makes a request to an "https" URI uses TLS [TLS13] with the [ALPN extension](#) [TLS-ALPN].

HTTP/2 over TLS uses the "h2" protocol identifier. The "h2c" protocol identifier MUST NOT be sent by a client or selected by a server; the "h2c" protocol identifier describes a protocol that does not use TLS.

Once TLS negotiation is complete, both the client and the server MUST send a connection preface ([Section 3.4](#)).

3.3. Starting HTTP/2 with Prior Knowledge

A client can learn that a particular server supports HTTP/2 by other means. For example, a client could be configured with knowledge that a server supports HTTP/2.

A client that knows that a server supports HTTP/2 can establish a TCP connection and send the connection preface ([Section 3.4](#)) followed by HTTP/2 frames. Servers can identify these connections by the presence of the connection preface. This only affects the establishment of HTTP/2 connections over cleartext TCP; HTTP/2 connections over TLS MUST use [protocol negotiation in TLS](#) [TLS-ALPN].

Likewise, the server MUST send a connection preface ([Section 3.4](#)).

Without additional information, prior support for HTTP/2 is not a strong signal that a given server will support HTTP/2 for future connections. For example, it is possible for server configurations to change, for configurations to differ between instances in clustered servers, or for network conditions to change.

3.4. HTTP/2 Connection Preface

In HTTP/2, each endpoint is required to send a connection preface as a final confirmation of the protocol in use and to establish the initial settings for the HTTP/2 connection. The client and server each send a different connection preface.

The client connection preface starts with a sequence of 24 octets, which in hex notation is:

```
0x505249202a20485454502f322e300d0a0d0a534d0d0a0d0a
```

That is, the connection preface starts with the string "PRI * HTTP/2.0\r\n\r\nSM\r\n\r\n". This sequence **MUST** be followed by a **SETTINGS** frame (Section 6.5), which **MAY** be empty. The client sends the client connection preface as the first application data octets of a connection.

Note: The client connection preface is selected so that a large proportion of HTTP/1.1 or HTTP/1.0 servers and intermediaries do not attempt to process further frames. Note that this does not address the concerns raised in [TALKING].

The server connection preface consists of a potentially empty **SETTINGS** frame (Section 6.5) that **MUST** be the first frame the server sends in the HTTP/2 connection.

The **SETTINGS** frames received from a peer as part of the connection preface **MUST** be acknowledged (see Section 6.5.3) after sending the connection preface.

To avoid unnecessary latency, clients are permitted to send additional frames to the server immediately after sending the client connection preface, without waiting to receive the server connection preface. It is important to note, however, that the server connection preface **SETTINGS** frame might include settings that necessarily alter how a client is expected to communicate with the server. Upon receiving the **SETTINGS** frame, the client is expected to honor any settings established. In some configurations, it is possible for the server to transmit **SETTINGS** before the client sends additional frames, providing an opportunity to avoid this issue.

Clients and servers **MUST** treat an invalid connection preface as a connection error (Section 5.4.1) of type **PROTOCOL_ERROR**. A **GOAWAY** frame (Section 6.8) **MAY** be omitted in this case, since an invalid preface indicates that the peer is not using HTTP/2.

4. HTTP Frames

Once the HTTP/2 connection is established, endpoints can begin exchanging frames.

4.1. Frame Format

All frames begin with a fixed 9-octet header followed by a variable-length frame payload.

```
HTTP Frame {
  Length (24),
  Type (8),

  Flags (8),

  Reserved (1),
  Stream Identifier (31),

  Frame Payload (...),
}
```

Figure 1: Frame Layout

The fields of the frame header are defined as:

Length The length of the frame payload expressed as an unsigned 24-bit integer in units of octets.

Values greater than 2^{14} (16,384) MUST NOT be sent unless the receiver has set a larger value for [SETTINGS_MAX_FRAME_SIZE](#).

The 9 octets of the frame header are not included in this value.

Type The 8-bit type of the frame. The frame type determines the format and semantics of the frame. Frames defined in this document are listed in [Section 6](#). Implementations MUST ignore and discard frames of unknown types.

Flags An 8-bit field reserved for boolean flags specific to the frame type.

Flags are assigned semantics specific to the indicated frame type. Unused flags are those that have no defined semantics for a particular frame type. Unused flags MUST be ignored on receipt and MUST be left unset (0x00) when sending.

Reserved A reserved 1-bit field. The semantics of this bit are undefined, and the bit MUST remain unset (0x00) when sending and MUST be ignored when receiving.

Stream Identifier An stream identifier (see [Section 5.1.1](#)) expressed as an unsigned 31-bit integer. The value 0x00 is reserved for frames that are associated with the connection as a whole as opposed to an individual stream.

The structure and content of the frame payload are dependent entirely on the frame type.

4.2. Frame Size

The size of a frame payload is limited by the maximum size that a receiver advertises in the [SETTINGS_MAX_FRAME_SIZE](#) setting. This setting can have any value between 2^{14} (16,384) and $2^{24}-1$ (16,777,215) octets, inclusive.

All implementations MUST be capable of receiving and minimally processing frames up to 2^{14} octets in length, plus the 9-octet frame header ([Section 4.1](#)). The size of the frame header is not included when describing frame sizes.

Note: Certain frame types, such as PING ([Section 6.7](#)), impose additional limits on the amount of frame payload data allowed.

An endpoint MUST send an error code of [FRAME_SIZE_ERROR](#) if a frame exceeds the size defined in [SETTINGS_MAX_FRAME_SIZE](#), exceeds any limit defined for the frame type, or is too small to contain

mandatory frame data. A frame size error in a frame that could alter the state of the entire connection **MUST** be treated as a connection error ([Section 5.4.1](#)); this includes any frame carrying a field block ([Section 4.3](#)) (that is, [HEADERS](#), [PUSH_PROMISE](#), and [CONTINUATION](#)), a [SETTINGS](#) frame, and any frame with a stream identifier of 0.

Endpoints are not obligated to use all available space in a frame. Responsiveness can be improved by using frames that are smaller than the permitted maximum size. Sending large frames can result in delays in sending time-sensitive frames (such as [RST_STREAM](#), [WINDOW_UPDATE](#), or [PRIORITY](#)), which, if blocked by the transmission of a large frame, could affect performance.

4.3. Field Section Compression and Decompression

Field section compression is the process of compressing a set of field lines ([Section 5.2](#) of [HTTP]) to form a field block. Field section decompression is the process of decoding a field block into a set of field lines. Details of HTTP/2 field section compression and decompression are defined in [[COMPRESSION](#)], which, for historical reasons, refers to these processes as header compression and decompression.

Each field block carries all of the compressed field lines of a single field section. Header sections also include control data associated with the message in the form of pseudo-header fields ([Section 8.3](#)) that use the same format as a field line.

Note: [RFC 7540](#) [RFC7540] used the term "header block" in place of the more generic "field block".

Field blocks carry control data and header sections for requests, responses, promised requests, and pushed responses (see [Section 8.4](#)). All these messages, except for interim responses and requests contained in [PUSH_PROMISE](#) ([Section 6.6](#)) frames, can optionally include a field block that carries a trailer section.

A field section is a collection of field lines. Each of the field lines in a field block carries a single value. The serialized field block is then divided into one or more octet sequences, called field block fragments. The first field block fragment is transmitted within the frame payload of [HEADERS](#) ([Section 6.2](#)) or [PUSH_PROMISE](#) ([Section 6.6](#)), each of which could be followed by [CONTINUATION](#) ([Section 6.10](#)) frames to carry subsequent field block fragments.

The [Cookie header field](#) [COOKIE] is treated specially by the HTTP mapping (see [Section 8.2.3](#)).

A receiving endpoint reassembles the field block by concatenating its fragments and then decompresses the block to reconstruct the field section.

A complete field section consists of either:

- a single [HEADERS](#) or [PUSH_PROMISE](#) frame, with the [END_HEADERS](#) flag set, or
- a [HEADERS](#) or [PUSH_PROMISE](#) frame with the [END_HEADERS](#) flag unset and one or more [CONTINUATION](#) frames, where the last [CONTINUATION](#) frame has the [END_HEADERS](#) flag set.

Each field block is processed as a discrete unit. Field blocks **MUST** be transmitted as a contiguous sequence of frames, with no interleaved frames of any other type or from any other stream. The last frame in a sequence of [HEADERS](#) or [CONTINUATION](#) frames has the [END_HEADERS](#) flag set. The last frame in a sequence of [PUSH_PROMISE](#) or [CONTINUATION](#) frames has the [END_HEADERS](#) flag set. This allows a field block to be logically equivalent to a single frame.

Field block fragments can only be sent as the frame payload of [HEADERS](#), [PUSH_PROMISE](#), or [CONTINUATION](#) frames because these frames carry data that can modify the compression context maintained by a receiver. An endpoint receiving [HEADERS](#), [PUSH_PROMISE](#), or [CONTINUATION](#) frames needs to reassemble field blocks and perform decompression even if the frames are to be discarded. A receiver **MUST** terminate the connection with a connection error ([Section 5.4.1](#)) of type [COMPRESSION_ERROR](#) if it does not decompress a field block.

A decoding error in a field block **MUST** be treated as a connection error ([Section 5.4.1](#)) of type [COMPRESSION_ERROR](#).

4.3.1. Compression State

Field compression is stateful. Each endpoint has an HPACK encoder context and an HPACK decoder context that are used for encoding and decoding all field blocks on a connection. [Section 4](#) of [COMPRESSION] defines the dynamic table, which is the primary state for each context.

The dynamic table has a maximum size that is set by an HPACK decoder. An endpoint communicates the size chosen by its HPACK decoder context using the `SETTINGS_HEADER_TABLE_SIZE` setting; see [Section 6.5.2](#). When a connection is established, the dynamic table size for the HPACK decoder and encoder at both endpoints starts at 4,096 bytes, the initial value of the `SETTINGS_HEADER_TABLE_SIZE` setting.

Any change to the maximum value set using `SETTINGS_HEADER_TABLE_SIZE` takes effect when the endpoint acknowledges settings ([Section 6.5.3](#)). The HPACK encoder at that endpoint can set the dynamic table to any size up to the maximum value set by the decoder. An HPACK encoder declares the size of the dynamic table with a Dynamic Table Size Update instruction ([Section 6.3](#) of [COMPRESSION]).

Once an endpoint acknowledges a change to `SETTINGS_HEADER_TABLE_SIZE` that reduces the maximum below the current size of the dynamic table, its HPACK encoder **MUST** start the next field block with a Dynamic Table Size Update instruction that sets the dynamic table to a size that is less than or equal to the reduced maximum; see [Section 4.2](#) of [COMPRESSION]. An endpoint **MUST** treat a field block that follows an acknowledgment of the reduction to the maximum dynamic table size as a connection error ([Section 5.4.1](#)) of type `COMPRESSION_ERROR` if it does not start with a conformant Dynamic Table Size Update instruction.

Implementers are advised that reducing the value of `SETTINGS_HEADER_TABLE_SIZE` is not widely interoperable. Use of the connection preface to reduce the value below the initial value of 4,096 is somewhat better supported, but this might fail with some implementations.

5. Streams and Multiplexing

A "stream" is an independent, bidirectional sequence of frames exchanged between the client and server within an HTTP/2 connection. Streams have several important characteristics:

- A single HTTP/2 connection can contain multiple concurrently open streams, with either endpoint interleaving frames from multiple streams.
- Streams can be established and used unilaterally or shared by either endpoint.
- Streams can be closed by either endpoint.
- The order in which frames are sent is significant. Recipients process frames in the order they are received. In particular, the order of **HEADERS** and **DATA** frames is semantically significant.
- Streams are identified by an integer. Stream identifiers are assigned to streams by the endpoint initiating the stream.

5.1. Stream States

The lifecycle of a stream is shown in [Figure 2](#).

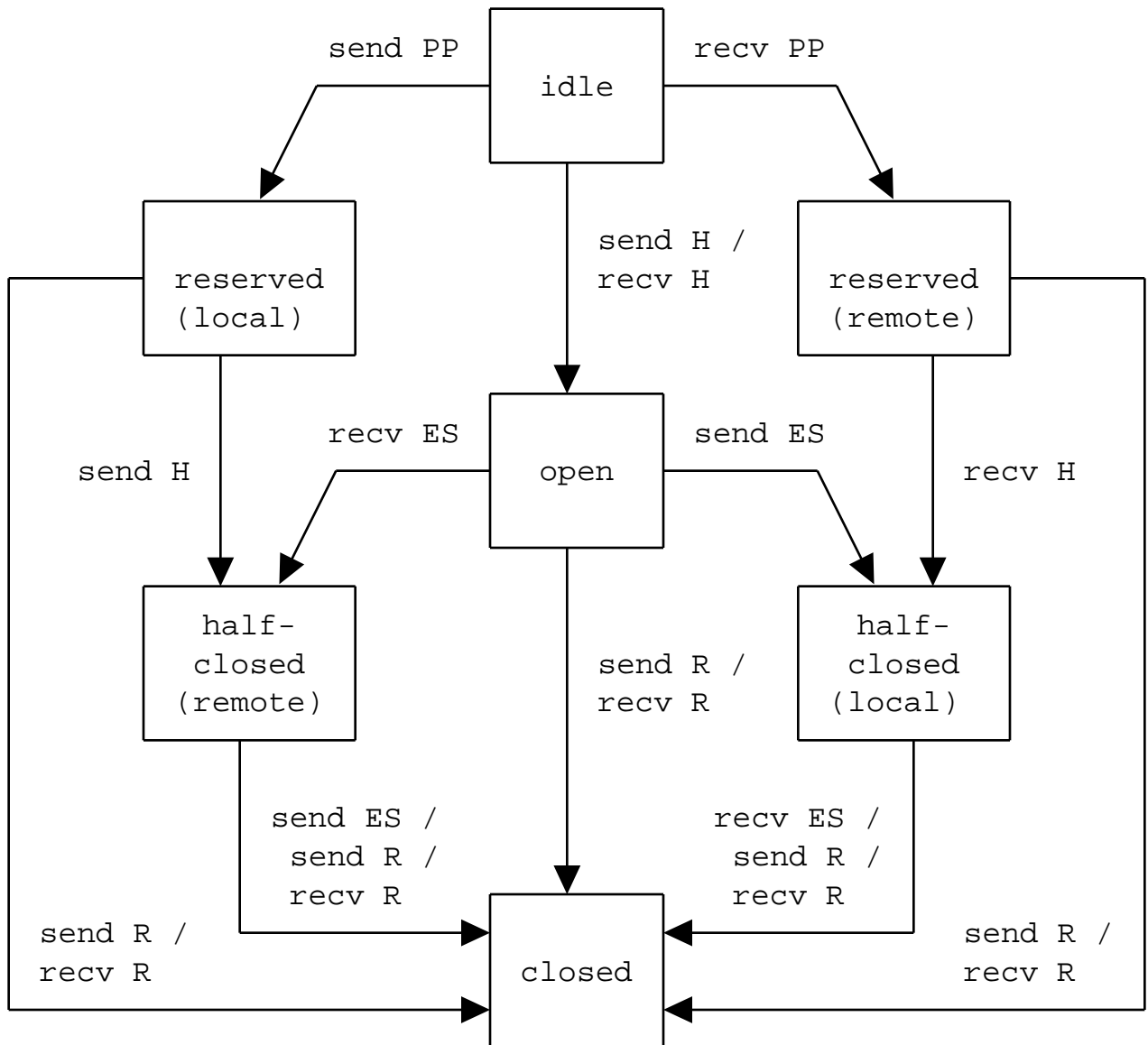


Figure 2: Stream States

send: endpoint sends this frame

recv: endpoint receives this frame

H: **HEADERS** frame (with implied **CONTINUATION** frames)

ES: **END_STREAM** flag

R: **RST_STREAM** frame

PP: **PUSH_PROMISE** frame (with implied **CONTINUATION** frames); state transitions are for the promised stream

Note that this diagram shows stream state transitions and the frames and flags that affect those transitions only. In this regard, **CONTINUATION** frames do not result in state transitions; they are effectively part of the **HEADERS** or **PUSH_PROMISE** that they follow. For the purpose of state transitions, the **END_STREAM** flag

is processed as a separate event to the frame that bears it; a **HEADERS** frame with the **END_STREAM** flag set can cause two state transitions.

Both endpoints have a subjective view of the state of a stream that could be different when frames are in transit. Endpoints do not coordinate the creation of streams; they are created unilaterally by either endpoint. The negative consequences of a mismatch in states are limited to the "closed" state after sending **RST_STREAM**, where frames might be received for some time after closing.

Streams have the following states:

idleAll streams start in the "idle" state.

The following transitions are valid from this state:

- Sending a **HEADERS** frame as a client, or receiving a **HEADERS** frame as a server, causes the stream to become "open". The stream identifier is selected as described in [Section 5.1.1](#). The same **HEADERS** frame can also cause a stream to immediately become "half-closed".
- Sending a **PUSH_PROMISE** frame on another stream reserves the idle stream that is identified for later use. The stream state for the reserved stream transitions to "reserved (local)". Only a server may send **PUSH_PROMISE** frames.
- Receiving a **PUSH_PROMISE** frame on another stream reserves an idle stream that is identified for later use. The stream state for the reserved stream transitions to "reserved (remote)". Only a client may receive **PUSH_PROMISE** frames.
- Note that the **PUSH_PROMISE** frame is not sent on the idle stream but references the newly reserved stream in the Promised Stream ID field.
- Opening a stream with a higher-valued stream identifier causes the stream to transition immediately to a "closed" state; note that this transition is not shown in the diagram.

Receiving any frame other than **HEADERS** or **PRIORITY** on a stream in this state **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**. If this stream is initiated by the server, as described in [Section 5.1.1](#), then receiving a **HEADERS** frame **MUST** also be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

reserved (local)A stream in the "reserved (local)" state is one that has been promised by sending a **PUSH_PROMISE** frame. A **PUSH_PROMISE** frame reserves an idle stream by associating the stream with an open stream that was initiated by the remote peer (see [Section 8.4](#)).

In this state, only the following transitions are possible:

- The endpoint can send a **HEADERS** frame. This causes the stream to open in a "half-closed (remote)" state.
- Either endpoint can send a **RST_STREAM** frame to cause the stream to become "closed". This releases the stream reservation.

An endpoint **MUST NOT** send any type of frame other than **HEADERS**, **RST_STREAM**, or **PRIORITY** in this state.

A **PRIORITY** or **WINDOW_UPDATE** frame **MAY** be received in this state. Receiving any type of frame other than **RST_STREAM**, **PRIORITY**, or **WINDOW_UPDATE** on a stream in this state **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

reserved (remote)A stream in the "reserved (remote)" state has been reserved by a remote peer.

In this state, only the following transitions are possible:

- Receiving a **HEADERS** frame causes the stream to transition to "half-closed (local)".
- Either endpoint can send a **RST_STREAM** frame to cause the stream to become "closed". This releases the stream reservation.

An endpoint **MUST NOT** send any type of frame other than **RST_STREAM**, **WINDOW_UPDATE**, or **PRIORITY** in this state.

Receiving any type of frame other than **HEADERS**, **RST_STREAM**, or **PRIORITY** on a stream in this state **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

open stream in the "open" state may be used by both peers to send frames of any type. In this state, sending peers observe advertised stream-level flow-control limits (Section 5.2).

From this state, either endpoint can send a frame with an `END_STREAM` flag set, which causes the stream to transition into one of the "half-closed" states. An endpoint sending an `END_STREAM` flag causes the stream state to become "half-closed (local)"; an endpoint receiving an `END_STREAM` flag causes the stream state to become "half-closed (remote)".

Either endpoint can send a `RST_STREAM` frame from this state, causing it to transition immediately to "closed".

half-closed (local) stream that is in the "half-closed (local)" state cannot be used for sending frames other than `WINDOW_UPDATE`, `PRIORITY`, and `RST_STREAM`.

half-closed (local) stream transitions from this state to "closed" when a frame is received with the `END_STREAM` flag set or when either peer sends a `RST_STREAM` frame.

An endpoint can receive any type of frame in this state. Providing flow-control credit using `WINDOW_UPDATE` frames is necessary to continue receiving flow-controlled frames. In this state, a receiver can ignore `WINDOW_UPDATE` frames, which might arrive for a short period after a frame with the `END_STREAM` flag set is sent.

`PRIORITY` frames can be received in this state.

half-closed (remote) stream that is "half-closed (remote)" is no longer being used by the peer to send frames. In this state, an endpoint is no longer obligated to maintain a receiver flow-control window.

half-closed (remote) endpoint receives additional frames, other than `WINDOW_UPDATE`, `PRIORITY`, or `RST_STREAM`, for a stream that is in this state, it MUST respond with a stream error (Section 5.4.2) of type `STREAM_CLOSED`.

A stream that is "half-closed (remote)" can be used by the endpoint to send frames of any type. In this state, the endpoint continues to observe advertised stream-level flow-control limits (Section 5.2).

A stream can transition from this state to "closed" by sending a frame with the `END_STREAM` flag set or when either peer sends a `RST_STREAM` frame.

closed The "closed" state is the terminal state.

A stream enters the "closed" state after an endpoint both sends and receives a frame with an `END_STREAM` flag set. A stream also enters the "closed" state after an endpoint either sends or receives a `RST_STREAM` frame.

An endpoint MUST NOT send frames other than `PRIORITY` on a closed stream. An endpoint MAY treat receipt of any other type of frame on a closed stream as a connection error (Section 5.4.1) of type `STREAM_CLOSED`, except as noted below.

An endpoint that sends a frame with the `END_STREAM` flag set or a `RST_STREAM` frame might receive a `WINDOW_UPDATE` or `RST_STREAM` frame from its peer in the time before the peer receives and processes the frame that closes the stream.

An endpoint that sends a `RST_STREAM` frame on a stream that is in the "open" or "half-closed (local)" state could receive any type of frame. The peer might have sent or queued for sending these frames before processing the `RST_STREAM` frame. An endpoint MUST minimally process and then discard any frames it receives in this state. This means updating header compression state for `HEADERS` and `PUSH_PROMISE` frames. Receiving a `PUSH_PROMISE` frame also causes the promised stream to become "reserved (remote)", even when the `PUSH_PROMISE` frame is received on a closed stream. Additionally, the content of `DATA` frames counts toward the connection flow-control window.

An endpoint can perform this minimal processing for all streams that are in the "closed" state. Endpoints MAY use other signals to detect that a peer has received the frames that caused the stream to enter the "closed" state and treat receipt of any frame other than `PRIORITY` as a connection error (Section 5.4.1) of type `PROTOCOL_ERROR`. Endpoints can use frames that indicate that the peer has received the closing signal to drive this. Endpoints SHOULD NOT use timers for this purpose. For example, an endpoint that sends a `SETTINGS` frame after closing a stream can safely treat receipt of a `DATA` frame on that stream as an error after receiving an acknowledgment of the settings. Other things that might be used are `PING` frames, receiving data on streams that were created after closing the stream, or responses to requests created after closing the stream.

In the absence of more specific rules, implementations SHOULD treat the receipt of a frame that is not expressly permitted in the description of a state as a connection error (Section 5.4.1) of type `PROTOCOL_ERROR`. Note that `PRIORITY` can be sent and received in any stream state.

The rules in this section only apply to frames defined in this document. Receipt of frames for which the semantics are unknown cannot be treated as an error, as the conditions for sending and receiving those frames are also unknown; see Section 5.5.

An example of the state transitions for an HTTP request/response exchange can be found in Section 8.8. An example of the state transitions for server push can be found in Sections 8.4.1 and 8.4.2.

5.1.1. Stream Identifiers

Streams are identified by an unsigned 31-bit integer. Streams initiated by a client MUST use odd-numbered stream identifiers; those initiated by the server MUST use even-numbered stream identifiers. A stream identifier of zero (0x00) is used for connection control messages; the stream identifier of zero cannot be used to establish a new stream.

The identifier of a newly established stream MUST be numerically greater than all streams that the initiating endpoint has opened or reserved. This governs streams that are opened using a `HEADERS` frame and streams that are reserved using `PUSH_PROMISE`. An endpoint that receives an unexpected stream identifier MUST respond with a connection error (Section 5.4.1) of type `PROTOCOL_ERROR`.

A `HEADERS` frame will transition the client-initiated stream identified by the stream identifier in the frame header from "idle" to "open". A `PUSH_PROMISE` frame will transition the server-initiated stream identified by the Promised Stream ID field in the frame payload from "idle" to "reserved (local)" or "reserved (remote)". When a stream transitions out of the "idle" state, all streams in the "idle" state that might have been opened by the peer with a lower-valued stream identifier immediately transition to "closed". That is, an endpoint may skip a stream identifier, with the effect being that the skipped stream is immediately closed.

Stream identifiers cannot be reused. Long-lived connections can result in an endpoint exhausting the available range of stream identifiers. A client that is unable to establish a new stream identifier can establish a new connection for new streams. A server that is unable to establish a new stream identifier can send a `GOAWAY` frame so that the client is forced to open a new connection for new streams.

5.1.2. Stream Concurrency

A peer can limit the number of concurrently active streams using the `SETTINGS_MAX_CONCURRENT_STREAMS` parameter (see Section 6.5.2) within a `SETTINGS` frame. The maximum concurrent streams setting is specific to each endpoint and applies only to the peer that receives the setting. That is, clients specify the maximum number of concurrent streams the server can initiate, and servers specify the maximum number of concurrent streams the client can initiate.

Streams that are in the "open" state or in either of the "half-closed" states count toward the maximum number of streams that an endpoint is permitted to open. Streams in any of these three states count toward the limit advertised in the `SETTINGS_MAX_CONCURRENT_STREAMS` setting. Streams in either of the "reserved" states do not count toward the stream limit.

Endpoints MUST NOT exceed the limit set by their peer. An endpoint that receives a `HEADERS` frame that causes its advertised concurrent stream limit to be exceeded MUST treat this as a stream error (Section 5.4.2) of type `PROTOCOL_ERROR` or `REFUSED_STREAM`. The choice of error code determines whether the endpoint wishes to enable automatic retry (see Section 8.7 for details).

An endpoint that wishes to reduce the value of `SETTINGS_MAX_CONCURRENT_STREAMS` to a value that is below the current number of open streams can either close streams that exceed the new value or allow streams to complete.

5.2. Flow Control

Using streams for multiplexing introduces contention over use of the TCP connection, resulting in blocked streams. A flow-control scheme ensures that streams on the same connection do not destructively interfere with each other. Flow control is used for both individual streams and the connection as a whole.

HTTP/2 provides for flow control through use of the `WINDOW_UPDATE` frame (Section 6.9).

5.2.1. Flow-Control Principles

HTTP/2 stream flow control aims to allow a variety of flow-control algorithms to be used without requiring protocol changes. Flow control in HTTP/2 has the following characteristics:

1. Flow control is specific to a connection. HTTP/2 flow control operates between the endpoints of a single hop and not over the entire end-to-end path.
2. Flow control is based on `WINDOW_UPDATE` frames. Receivers advertise how many octets they are prepared to receive on a stream and for the entire connection. This is a credit-based scheme.
3. Flow control is directional with overall control provided by the receiver. A receiver MAY choose to set any window size that it desires for each stream and for the entire connection. A sender MUST respect flow-control limits imposed by a receiver. Clients, servers, and intermediaries all independently advertise their flow-control window as a receiver and abide by the flow-control limits set by their peer when sending.
4. The initial value for the flow-control window is 65,535 octets for both new streams and the overall connection.
5. The frame type determines whether flow control applies to a frame. Of the frames specified in this document, only `DATA` frames are subject to flow control; all other frame types do not consume space in the advertised flow-control window. This ensures that important control frames are not blocked by flow control.
6. An endpoint can choose to disable its own flow control, but an endpoint cannot ignore flow-control signals from its peer.
7. HTTP/2 defines only the format and semantics of the `WINDOW_UPDATE` frame (Section 6.9). This document does not stipulate how a receiver decides when to send this frame or the value that it sends, nor does it specify how a sender chooses to send packets. Implementations are able to select any algorithm that suits their needs.

Implementations are also responsible for prioritizing the sending of requests and responses, choosing how to avoid head-of-line blocking for requests, and managing the creation of new streams. Algorithm choices for these could interact with any flow-control algorithm.

5.2.2. Appropriate Use of Flow Control

Flow control is defined to protect endpoints that are operating under resource constraints. For example, a proxy needs to share memory between many connections and also might have a slow upstream connection and a fast downstream one. Flow control addresses cases where the receiver is unable to process data on one stream yet wants to continue to process other streams in the same connection.

Deployments that do not require this capability can advertise a flow-control window of the maximum size ($2^{31}-1$) and can maintain this window by sending a `WINDOW_UPDATE` frame when any data is received. This effectively disables flow control for that receiver. Conversely, a sender is always subject to the flow-control window advertised by the receiver.

Deployments with constrained resources (for example, memory) can employ flow control to limit the amount of memory a peer can consume. Note, however, that this can lead to suboptimal use of available network resources if flow control is enabled without knowledge of the bandwidth * delay product (see [RFC7323]).

Even with full awareness of the current bandwidth * delay product, implementation of flow control can be difficult. Endpoints MUST read and process HTTP/2 frames from the TCP receive buffer as soon as data is available. Failure to read promptly could lead to a deadlock when critical frames, such as

[WINDOW_UPDATE](#), are not read and acted upon. Reading frames promptly does not expose endpoints to resource exhaustion attacks, as HTTP/2 flow control limits resource commitments.

5.2.3. Flow-Control Performance

If an endpoint cannot ensure that its peer always has available flow-control window space that is greater than the peer's bandwidth * delay product on this connection, its receive throughput will be limited by HTTP/2 flow control. This will result in degraded performance.

Sending timely [WINDOW_UPDATE](#) frames can improve performance. Endpoints will want to balance the need to improve receive throughput with the need to manage resource exhaustion risks and should take careful note of [Section 10.5](#) in defining their strategy to manage window sizes.

5.3. Prioritization

In a multiplexed protocol like HTTP/2, prioritizing allocation of bandwidth and computation resources to streams can be critical to attaining good performance. A poor prioritization scheme can result in HTTP/2 providing poor performance. With no parallelism at the TCP layer, performance could be significantly worse than HTTP/1.1.

A good prioritization scheme benefits from the application of contextual knowledge such as the content of resources, how resources are interrelated, and how those resources will be used by a peer. In particular, clients can possess knowledge about the priority of requests that is relevant to server prioritization. In those cases, having clients provide priority information can improve performance.

5.3.1. Background on Priority in RFC 7540

RFC 7540 defined a rich system for signaling priority of requests. However, this system proved to be complex, and it was not uniformly implemented.

The flexible scheme meant that it was possible for clients to express priorities in very different ways, with little consistency in the approaches that were adopted. For servers, implementing generic support for the scheme was complex. Implementation of priorities was uneven in both clients and servers. Many server deployments ignored client signals when prioritizing their handling of requests.

In short, the prioritization signaling in [RFC 7540](#) [RFC7540] was not successful.

5.3.2. Priority Signaling in This Document

This update to HTTP/2 deprecates the priority signaling defined in [RFC 7540](#) [RFC7540]. The bulk of the text related to priority signals is not included in this document. The description of frame fields and some of the mandatory handling is retained to ensure that implementations of this document remain interoperable with implementations that use the priority signaling described in RFC 7540.

A thorough description of the RFC 7540 priority scheme remains in [Section 5.3](#) of [RFC7540].

Signaling priority information is necessary to attain good performance in many cases. Where signaling priority information is important, endpoints are encouraged to use an alternative scheme, such as the scheme described in [\[HTTP-PRIORITY\]](#).

Though the priority signaling from RFC 7540 was not widely adopted, the information it provides can still be useful in the absence of better information. Endpoints that receive priority signals in [HEADERS](#) or [PRIORITY](#) frames can benefit from applying that information. In particular, implementations that consume these signals would not benefit from discarding these priority signals in the absence of alternatives.

Servers SHOULD use other contextual information in determining priority of requests in the absence of any priority signals. Servers MAY interpret the complete absence of signals as an indication that the client has not implemented the feature. The defaults described in [Section 5.3.5](#) of [RFC7540] are known to have poor performance under most conditions, and their use is unlikely to be deliberate.

5.4. Error Handling

HTTP/2 framing permits two classes of errors:

- An error condition that renders the entire connection unusable is a connection error.
- An error in an individual stream is a stream error.

A list of error codes is included in [Section 7](#).

It is possible that an endpoint will encounter frames that would cause multiple errors. Implementations MAY discover multiple errors during processing, but they SHOULD report at most one stream and one connection error as a result.

The first stream error reported for a given stream prevents any other errors on that stream from being reported. In comparison, the protocol permits multiple [GOAWAY](#) frames, though an endpoint SHOULD report just one type of connection error unless an error is encountered during graceful shutdown. If this occurs, an endpoint MAY send an additional [GOAWAY](#) frame with the new error code, in addition to any prior [GOAWAY](#) that contained [NO_ERROR](#).

If an endpoint detects multiple different errors, it MAY choose to report any one of those errors. If a frame causes a connection error, that error MUST be reported. Additionally, an endpoint MAY use any applicable error code when it detects an error condition; a generic error code (such as [PROTOCOL_ERROR](#) or [INTERNAL_ERROR](#)) can always be used in place of more specific error codes.

5.4.1. Connection Error Handling

A connection error is any error that prevents further processing of the frame layer or corrupts any connection state.

An endpoint that encounters a connection error SHOULD first send a [GOAWAY](#) frame ([Section 6.8](#)) with the stream identifier of the last stream that it successfully received from its peer. The [GOAWAY](#) frame includes an error code ([Section 7](#)) that indicates why the connection is terminating. After sending the [GOAWAY](#) frame for an error condition, the endpoint MUST close the TCP connection.

It is possible that the [GOAWAY](#) will not be reliably received by the receiving endpoint. In the event of a connection error, [GOAWAY](#) only provides a best-effort attempt to communicate with the peer about why the connection is being terminated.

An endpoint can end a connection at any time. In particular, an endpoint MAY choose to treat a stream error as a connection error. Endpoints SHOULD send a [GOAWAY](#) frame when ending a connection, providing that circumstances permit it.

5.4.2. Stream Error Handling

A stream error is an error related to a specific stream that does not affect processing of other streams.

An endpoint that detects a stream error sends a [RST_STREAM](#) frame ([Section 6.4](#)) that contains the stream identifier of the stream where the error occurred. The [RST_STREAM](#) frame includes an error code that indicates the type of error.

A [RST_STREAM](#) is the last frame that an endpoint can send on a stream. The peer that sends the [RST_STREAM](#) frame MUST be prepared to receive any frames that were sent or enqueued for sending by the remote peer. These frames can be ignored, except where they modify connection state (such as the state maintained for field section compression ([Section 4.3](#)) or flow control).

Normally, an endpoint SHOULD NOT send more than one [RST_STREAM](#) frame for any stream. However, an endpoint MAY send additional [RST_STREAM](#) frames if it receives frames on a closed stream after more than a round-trip time. This behavior is permitted to deal with misbehaving implementations.

To avoid looping, an endpoint MUST NOT send a [RST_STREAM](#) in response to a [RST_STREAM](#) frame.

5.4.3. Connection Termination

If the TCP connection is closed or reset while streams remain in the "open" or "half-closed" states, then the affected streams cannot be automatically retried (see [Section 8.7](#) for details).

5.5. Extending HTTP/2

HTTP/2 permits extension of the protocol. Within the limitations described in this section, protocol extensions can be used to provide additional services or alter any aspect of the protocol. Extensions are effective only within the scope of a single HTTP/2 connection.

This applies to the protocol elements defined in this document. This does not affect the existing options for extending HTTP, such as defining new methods, status codes, or fields (see [Section 16](#) of [HTTP]).

Extensions are permitted to use new frame types ([Section 4.1](#)), new settings ([Section 6.5](#)), or new error codes ([Section 7](#)). Registries for managing these extension points are defined in [Section 11](#) of [RFC7540].

Implementations MUST ignore unknown or unsupported values in all extensible protocol elements. Implementations MUST discard frames that have unknown or unsupported types. This means that any of these extension points can be safely used by extensions without prior arrangement or negotiation. However, extension frames that appear in the middle of a field block ([Section 4.3](#)) are not permitted; these MUST be treated as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

Extensions SHOULD avoid changing protocol elements defined in this document or elements for which no extension mechanism is defined. This includes changes to the layout of frames, additions or changes to the way that frames are composed into HTTP messages ([Section 8.1](#)), the definition of pseudo-header fields, or changes to any protocol element that a compliant endpoint might treat as a connection error ([Section 5.4.1](#)).

An extension that changes existing protocol elements or state MUST be negotiated before being used. For example, an extension that changes the layout of the `HEADERS` frame cannot be used until the peer has given a positive signal that this is acceptable. In this case, it could also be necessary to coordinate when the revised layout comes into effect. For example, treating frames other than `DATA` frames as flow controlled requires a change in semantics that both endpoints need to understand, so this can only be done through negotiation.

This document doesn't mandate a specific method for negotiating the use of an extension but notes that a setting ([Section 6.5.2](#)) could be used for that purpose. If both peers set a value that indicates willingness to use the extension, then the extension can be used. If a setting is used for extension negotiation, the initial value MUST be defined in such a fashion that the extension is initially disabled.

6. Frame Definitions

This specification defines a number of frame types, each identified by a unique 8-bit type code. Each frame type serves a distinct purpose in the establishment and management of either the connection as a whole or individual streams.

The transmission of specific frame types can alter the state of a connection. If endpoints fail to maintain a synchronized view of the connection state, successful communication within the connection will no longer be possible. Therefore, it is important that endpoints have a shared comprehension of how the state is affected by the use of any given frame.

6.1. DATA

DATA frames (type=0x00) convey arbitrary, variable-length sequences of octets associated with a stream. One or more DATA frames are used, for instance, to carry HTTP request or response message contents.

DATA frames MAY also contain padding. Padding can be added to DATA frames to obscure the size of messages. Padding is a security feature; see [Section 10.7](#).

```
DATA Frame {
  Length (24),
  Type (8) = 0x00,

  Unused Flags (4),
  PADDED Flag (1),
  Unused Flags (2),
  END_STREAM Flag (1),

  Reserved (1),
  Stream Identifier (31),

  [Pad Length (8)],
  Data (..),
  Padding (..2040),
}
```

Figure 3: DATA Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The DATA frame contains the following additional fields:

Pad Length An 8-bit field containing the length of the frame padding in units of octets. This field is conditional and is only present if the PADDED flag is set.

Data Application data. The amount of data is the remainder of the frame payload after subtracting the length of the other fields that are present.

Padding Padding octets that contain no application semantic value. Padding octets MUST be set to zero when sending. A receiver is not obligated to verify padding but MAY treat non-zero padding as a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

The DATA frame defines the following flags:

PADDED When set, the PADDED flag indicates that the Pad Length field and any padding that it describes are present.

END_STREAM The END_STREAM flag indicates that this frame is the last that the endpoint will send for the identified stream. Setting this flag causes the stream to enter one of the "half-closed" states or the "closed" state ([Section 5.1](#)).

Note: An endpoint that learns of stream closure after sending all data can close a stream by sending a STREAM frame with a zero-length Data field and the END_STREAM flag set. This is only possible if the endpoint does not send trailers, as the END_STREAM flag appears on a HEADERS frame in that case; see [Section 8.1](#).

DATA frames MUST be associated with a stream. If a DATA frame is received whose Stream Identifier field is 0x00, the recipient MUST respond with a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

DATA frames are subject to flow control and can only be sent when a stream is in the "open" or "half-closed (remote)" state. The entire DATA frame payload is included in flow control, including the Pad Length and Padding fields if present. If a DATA frame is received whose stream is not in the "open" or "half-closed (local)" state, the recipient MUST respond with a stream error ([Section 5.4.2](#)) of type `STREAM_CLOSED`.

The total number of padding octets is determined by the value of the Pad Length field. If the length of the padding is the length of the frame payload or greater, the recipient MUST treat this as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

Note: A frame can be increased in size by one octet by including a Pad Length field with a value of zero.

6.2. HEADERS

The HEADERS frame (type=0x01) is used to open a stream ([Section 5.1](#)), and additionally carries a field block fragment. Despite the name, a HEADERS frame can carry a header section or a trailer section. HEADERS frames can be sent on a stream in the "idle", "reserved (local)", "open", or "half-closed (remote)" state.

```
HEADERS Frame {
  Length (24),
  Type (8) = 0x01,

  Unused Flags (2),
  PRIORITY Flag (1),
  Unused Flag (1),
  PADDED Flag (1),
  END_HEADERS Flag (1),
  Unused Flag (1),
  END_STREAM Flag (1),

  Reserved (1),
  Stream Identifier (31),

  [Pad Length (8)],
  [Exclusive (1)],
  [Stream Dependency (31)],
  [Weight (8)],
  Field Block Fragment (..),
  Padding (..2040),
}
```

Figure 4: HEADERS Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The HEADERS frame payload has the following additional fields:

Pad An 8-bit field containing the length of the frame padding in units of octets. This field is only present if the `PADDED` flag is set.

Exclusive A single-bit flag. This field is only present if the `PRIORITY` flag is set. Priority signals in HEADERS frames are deprecated; see [Section 5.3.2](#).

Stream Dependency A 31-bit stream identifier. This field is only present if the `PRIORITY` flag is set.

Weight: An unsigned 8-bit integer. This field is only present if the PRIORITY flag is set.

Field: A field block fragment ([Section 4.3](#)).

Block

Fragment:

Padding: Padding octets that contain no application semantic value. Padding octets MUST be set to zero when sending. A receiver is not obligated to verify padding but MAY treat non-zero padding as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

The HEADERS frame defines the following flags:

`PRIORITY`: If set, the PRIORITY flag indicates that the Exclusive, Stream Dependency, and Weight fields are present. (0x20)

`PADDED`: If set, the PADDED flag indicates that the Pad Length field and any padding that it describes are present. (0x08)

`END_HEADERS`: The `END_HEADERS` flag indicates that this frame contains an entire field block ([Section 4.3](#)) and is not followed by any `CONTINUATION` frames. (0x04)

A HEADERS frame without the `END_HEADERS` flag set MUST be followed by a `CONTINUATION` frame for the same stream. A receiver MUST treat the receipt of any other type of frame or a frame on a different stream as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

`END_STREAM`: The `END_STREAM` flag indicates that the field block ([Section 4.3](#)) is the last that the endpoint will send for the identified stream. (0x01)

A HEADERS frame with the `END_STREAM` flag set signals the end of a stream. However, a HEADERS frame with the `END_STREAM` flag set can be followed by `CONTINUATION` frames on the same stream. Logically, the `CONTINUATION` frames are part of the HEADERS frame.

The frame payload of a HEADERS frame contains a field block fragment ([Section 4.3](#)). A field block that does not fit within a HEADERS frame is continued in a `CONTINUATION` frame ([Section 6.10](#)).

HEADERS frames MUST be associated with a stream. If a HEADERS frame is received whose Stream Identifier field is 0x00, the recipient MUST respond with a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

The HEADERS frame changes the connection state as described in [Section 4.3](#).

The total number of padding octets is determined by the value of the Pad Length field. If the length of the padding is the length of the frame payload or greater, the recipient MUST treat this as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`.

Note: A frame can be increased in size by one octet by including a Pad Length field with a value of zero.

6.3. PRIORITY

The PRIORITY frame (type=0x02) is deprecated; see [Section 5.3.2](#). A PRIORITY frame can be sent in any stream state, including idle or closed streams.

```

PRIORITY Frame {
  Length (24) = 0x05,
  Type (8) = 0x02,

  Unused Flags (8),

  Reserved (1),
  Stream Identifier (31),

  Exclusive (1),
  Stream Dependency (31),
  Weight (8),
}

```

Figure 5: PRIORITY Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The frame payload of a PRIORITY frame contains the following additional fields:

Exclusive A single-bit flag.

Stream A 31-bit stream identifier.

Dependency:

Weight An unsigned 8-bit integer.

The PRIORITY frame does not define any flags.

The PRIORITY frame always identifies a stream. If a PRIORITY frame is received with a stream identifier of 0x00, the recipient **MUST** respond with a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

Sending or receiving a PRIORITY frame does not affect the state of any stream ([Section 5.1](#)). The PRIORITY frame can be sent on a stream in any state, including "idle" or "closed". A PRIORITY frame cannot be sent between consecutive frames that comprise a single field block ([Section 4.3](#)).

A PRIORITY frame with a length other than 5 octets **MUST** be treated as a stream error ([Section 5.4.2](#)) of type **FRAME_SIZE_ERROR**.

6.4. RST_STREAM

The RST_STREAM frame (type=0x03) allows for immediate termination of a stream. RST_STREAM is sent to request cancellation of a stream or to indicate that an error condition has occurred.

```

RST_STREAM Frame {
  Length (24) = 0x04,
  Type (8) = 0x03,

  Unused Flags (8),

  Reserved (1),
  Stream Identifier (31),

  Error Code (32),
}

```

Figure 6: RST_STREAM Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). Additionally, the RST_STREAM frame contains a single unsigned, 32-bit integer identifying the error code ([Section 7](#)). The error code indicates why the stream is being terminated.

The RST_STREAM frame does not define any flags.

The RST_STREAM frame fully terminates the referenced stream and causes it to enter the "closed" state. After receiving a RST_STREAM on a stream, the receiver MUST NOT send additional frames for that stream, except for [PRIORITY](#). However, after sending the RST_STREAM, the sending endpoint MUST be prepared to receive and process additional frames sent on the stream that might have been sent by the peer prior to the arrival of the RST_STREAM.

RST_STREAM frames MUST be associated with a stream. If a RST_STREAM frame is received with a stream identifier of 0x00, the recipient MUST treat this as a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

RST_STREAM frames MUST NOT be sent for a stream in the "idle" state. If a RST_STREAM frame identifying an idle stream is received, the recipient MUST treat this as a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

A RST_STREAM frame with a length other than 4 octets MUST be treated as a connection error ([Section 5.4.1](#)) of type [FRAME_SIZE_ERROR](#).

6.5. SETTINGS

The SETTINGS frame (type=0x04) conveys configuration parameters that affect how endpoints communicate, such as preferences and constraints on peer behavior. The SETTINGS frame is also used to acknowledge the receipt of those settings. Individually, a configuration parameter from a SETTINGS frame is referred to as a "setting".

Settings are not negotiated; they describe characteristics of the sending peer, which are used by the receiving peer. Different values for the same setting can be advertised by each peer. For example, a client might set a high initial flow-control window, whereas a server might set a lower value to conserve resources.

A SETTINGS frame MUST be sent by both endpoints at the start of a connection and MAY be sent at any other time by either endpoint over the lifetime of the connection. Implementations MUST support all of the settings defined by this specification.

Each parameter in a SETTINGS frame replaces any existing value for that parameter. Settings are processed in the order in which they appear, and a receiver of a SETTINGS frame does not need to maintain any state other than the current value of each setting. Therefore, the value of a SETTINGS parameter is the last value that is seen by a receiver.

SETTINGS frames are acknowledged by the receiving peer. To enable this, the SETTINGS frame defines the ACK flag:

When set, the ACK flag indicates that this frame acknowledges receipt and application of the peer's (0x04) SETTINGS frame. When this bit is set, the frame payload of the SETTINGS frame MUST be empty.

Receipt of a SETTINGS frame with the ACK flag set and a length field value other than 0 MUST be treated as a connection error ([Section 5.4.1](#)) of type [FRAME_SIZE_ERROR](#). For more information, see [Section 6.5.3](#) ("[Settings Synchronization](#)").

SETTINGS frames always apply to a connection, never a single stream. The stream identifier for a SETTINGS frame MUST be zero (0x00). If an endpoint receives a SETTINGS frame whose Stream Identifier field is anything other than 0x00, the endpoint MUST respond with a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

The SETTINGS frame affects connection state. A badly formed or incomplete SETTINGS frame MUST be treated as a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

A SETTINGS frame with a length other than a multiple of 6 octets MUST be treated as a connection error ([Section 5.4.1](#)) of type [FRAME_SIZE_ERROR](#).

6.5.1. SETTINGS Format

The frame payload of a SETTINGS frame consists of zero or more settings, each consisting of an unsigned 16-bit setting identifier and an unsigned 32-bit value.

```
SETTINGS Frame {
  Length (24),
  Type (8) = 0x04,

  Unused Flags (7),
  ACK Flag (1),

  Reserved (1),
  Stream Identifier (31) = 0,

  Setting (48) ...
}

Setting {
  Identifier (16),
  Value (32),
}
```

Figure 7: SETTINGS Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The frame payload of a SETTINGS frame contains any number of Setting fields, each of which consists of:

Identifier: A 16-bit setting identifier; see [Section 6.5.2](#).

Value: A 32-bit value for the setting.

6.5.2. Defined Settings

The following settings are defined:

SETTINGS_HEADER_TABLE_SIZE (0x01) Form the remote endpoint of the maximum size of the compression table used to decode field blocks, in units of octets. The encoder can select any size equal to or less than this value by using signaling specific to the compression format inside a field block (see [\[COMPRESSION\]](#)). The initial value is 4,096 octets.

SETTINGS_ENABLE_PUSH (0x02) enable or disable server push. A server **MUST NOT** send a **PUSH_PROMISE** frame if it receives this parameter set to a value of 0; see [Section 8.4](#). A client that has both set this parameter to 0 and had it acknowledged **MUST** treat the receipt of a **PUSH_PROMISE** frame as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**. The initial value of **SETTINGS_ENABLE_PUSH** is 1. For a client, this value indicates that it is willing to receive **PUSH_PROMISE** frames. For a server, this initial value has no effect, and is equivalent to the value 0. Any value other than 0 or 1 **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

A server **MUST NOT** explicitly set this value to 1. A server **MAY** choose to omit this setting when it sends a **SETTINGS** frame, but if a server does include a value, it **MUST** be 0. A client **MUST** treat receipt of a **SETTINGS** frame with **SETTINGS_ENABLE_PUSH** set to 1 as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

SETTINGS_MAX_CONCURRENT_STREAMS (0x03) This setting indicates the maximum number of concurrent streams that the sender will allow. This limit is directional: it applies to the number of streams that the sender permits the receiver to create. Initially, there is no limit to this value. It is recommended that this value be no smaller than 100, so as to not unnecessarily limit parallelism.

A value of 0 for **SETTINGS_MAX_CONCURRENT_STREAMS** **SHOULD NOT** be treated as special by endpoints. A zero value does prevent the creation of new streams; however, this can also happen for any

limit that is exhausted with active streams. Servers **SHOULD** only set a zero value for short durations; if a server does not wish to accept requests, closing the connection is more appropriate.

SETTINGS_INITIAL_WINDOW_SIZE (0x04) The initial window size (in units of octets) for stream-level flow control. The initial value is $2^{16}-1$ (65,535) octets.

This setting affects the window size of all streams (see [Section 6.9.2](#)).

Values above the maximum flow-control window size of $2^{31}-1$ **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **FLOW_CONTROL_ERROR**.

SETTINGS_MAX_FRAME_SIZE (0x05) The largest frame payload that the sender is willing to receive, in units of octets.

The initial value is 2^{14} (16,384) octets. The value advertised by an endpoint **MUST** be between this initial value and the maximum allowed frame size ($2^{24}-1$ or 16,777,215 octets), inclusive. Values outside this range **MUST** be treated as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

SETTINGS_MAX_HEADER_LIST_SIZE (0x06) The maximum field section size that the sender is prepared to accept, in units of octets. The value is based on the uncompressed size of field lines, including the length of the name and value in units of octets plus an overhead of 32 octets for each field line.

For any given request, a lower limit than what is advertised **MAY** be enforced. The initial value of this setting is unlimited.

An endpoint that receives a SETTINGS frame with any unknown or unsupported identifier **MUST** ignore that setting.

6.5.3. Settings Synchronization

Most values in SETTINGS benefit from or require an understanding of when the peer has received and applied the changed parameter values. In order to provide such synchronization timepoints, the recipient of a SETTINGS frame in which the ACK flag is not set **MUST** apply the updated settings as soon as possible upon receipt. SETTINGS frames are acknowledged in the order in which they are received.

The values in the SETTINGS frame **MUST** be processed in the order they appear, with no other frame processing between values. Unsupported settings **MUST** be ignored. Once all values have been processed, the recipient **MUST** immediately emit a SETTINGS frame with the ACK flag set. Upon receiving a SETTINGS frame with the ACK flag set, the sender of the altered settings can rely on the values from the oldest unacknowledged SETTINGS frame having been applied.

If the sender of a SETTINGS frame does not receive an acknowledgment within a reasonable amount of time, it **MAY** issue a connection error ([Section 5.4.1](#)) of type **SETTINGS_TIMEOUT**. In setting a timeout, some allowance needs to be made for processing delays at the peer; a timeout that is solely based on the round-trip time between endpoints might result in spurious errors.

6.6. PUSH_PROMISE

The PUSH_PROMISE frame (type=0x05) is used to notify the peer endpoint in advance of streams the sender intends to initiate. The PUSH_PROMISE frame includes the unsigned 31-bit identifier of the stream the endpoint plans to create along with a field section that provides additional context for the stream. [Section 8.4](#) contains a thorough description of the use of PUSH_PROMISE frames.

```

PUSH_PROMISE Frame {
  Length (24),
  Type (8) = 0x05,

  Unused Flags (4),
  PADDED Flag (1),
  END_HEADERS Flag (1),
  Unused Flags (2),

  Reserved (1),
  Stream Identifier (31),

  [Pad Length (8)],
  Reserved (1),
  Promised Stream ID (31),
  Field Block Fragment (...),
  Padding (...2040),
}

```

Figure 8: PUSH_PROMISE Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The PUSH_PROMISE frame payload has the following additional fields:

PadAn 8-bit field containing the length of the frame padding in units of octets. This field is only present if the **Length** **PADDED** flag is set.

Promised Stream IDA signed 31-bit integer that identifies the stream that is reserved by the PUSH_PROMISE. The Stream ID promised stream identifier **MUST** be a valid choice for the next stream sent by the sender (see "new stream ID: identifier" in [Section 5.1.1](#)).

Field Block FragmentA field block fragment ([Section 4.3](#)) containing the request control data and a header section.

Block

Fragment:

PaddingPadding octets that contain no application semantic value. Padding octets **MUST** be set to zero when sending. A receiver is not obligated to verify padding but **MAY** treat non-zero padding as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

The PUSH_PROMISE frame defines the following flags:

PADDEDWhen set, the PADDED flag indicates that the Pad Length field and any padding that it describes are present. (0x08)

END_HEADERSWhen set, the END_HEADERS flag indicates that this frame contains an entire field block ([Section 4.3](#)) and is not followed by any **CONTINUATION** frames. (0x04)

A PUSH_PROMISE frame without the END_HEADERS flag set **MUST** be followed by a CONTINUATION frame for the same stream. A receiver **MUST** treat the receipt of any other type of frame or a frame on a different stream as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

PUSH_PROMISE frames **MUST** only be sent on a peer-initiated stream that is in either the "open" or "half-closed (remote)" state. The stream identifier of a PUSH_PROMISE frame indicates the stream it is associated with. If the Stream Identifier field specifies the value 0x00, a recipient **MUST** respond with a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

Promised streams are not required to be used in the order they are promised. The PUSH_PROMISE only reserves stream identifiers for later use.

PUSH_PROMISE **MUST NOT** be sent if the **SETTINGS_ENABLE_PUSH** setting of the peer endpoint is set to 0. An endpoint that has set this setting and has received acknowledgment **MUST** treat the receipt of a PUSH_PROMISE frame as a connection error ([Section 5.4.1](#)) of type **PROTOCOL_ERROR**.

Recipients of PUSH_PROMISE frames can choose to reject promised streams by returning a RST_STREAM referencing the promised stream identifier back to the sender of the PUSH_PROMISE.

A PUSH_PROMISE frame modifies the connection state in two ways. First, the inclusion of a field block (Section 4.3) potentially modifies the state maintained for field section compression. Second, PUSH_PROMISE also reserves a stream for later use, causing the promised stream to enter the "reserved (local)" or "reserved (remote)" state. A sender MUST NOT send a PUSH_PROMISE on a stream unless that stream is either "open" or "half-closed (remote)"; the sender MUST ensure that the promised stream is a valid choice for a new stream identifier (Section 5.1.1) (that is, the promised stream MUST be in the "idle" state).

Since PUSH_PROMISE reserves a stream, ignoring a PUSH_PROMISE frame causes the stream state to become indeterminate. A receiver MUST treat the receipt of a PUSH_PROMISE on a stream that is neither "open" nor "half-closed (local)" as a connection error (Section 5.4.1) of type PROTOCOL_ERROR. However, an endpoint that has sent RST_STREAM on the associated stream MUST handle PUSH_PROMISE frames that might have been created before the RST_STREAM frame is received and processed.

A receiver MUST treat the receipt of a PUSH_PROMISE that promises an illegal stream identifier (Section 5.1.1) as a connection error (Section 5.4.1) of type PROTOCOL_ERROR. Note that an illegal stream identifier is an identifier for a stream that is not currently in the "idle" state.

The total number of padding octets is determined by the value of the Pad Length field. If the length of the padding is the length of the frame payload or greater, the recipient MUST treat this as a connection error (Section 5.4.1) of type PROTOCOL_ERROR.

Note: A frame can be increased in size by one octet by including a Pad Length field with a value of zero.

6.7. PING

The PING frame (type=0x06) is a mechanism for measuring a minimal round-trip time from the sender, as well as determining whether an idle connection is still functional. PING frames can be sent from any endpoint.

```
PING Frame {
  Length (24) = 0x08,
  Type (8) = 0x06,

  Unused Flags (7),
  ACK Flag (1),

  Reserved (1),
  Stream Identifier (31) = 0,

  Opaque Data (64),
}
```

Figure 9: PING Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in Section 4.

In addition to the frame header, PING frames MUST contain 8 octets of opaque data in the frame payload. A sender can include any value it chooses and use those octets in any fashion.

Receivers of a PING frame that does not include an ACK flag MUST send a PING frame with the ACK flag set in response, with an identical frame payload. PING responses SHOULD be given higher priority than any other frame.

The PING frame defines the following flags:

ACK When set, the ACK flag indicates that this PING frame is a PING response. An endpoint MUST set this flag in PING responses. An endpoint MUST NOT respond to PING frames containing this flag.

PING frames are not associated with any individual stream. If a PING frame is received with a Stream Identifier field value other than 0x00, the recipient **MUST** respond with a connection error (Section 5.4.1) of type `PROTOCOL_ERROR`.

Receipt of a PING frame with a length field value other than 8 **MUST** be treated as a connection error (Section 5.4.1) of type `FRAME_SIZE_ERROR`.

6.8. GOAWAY

The GOAWAY frame (type=0x07) is used to initiate shutdown of a connection or to signal serious error conditions. GOAWAY allows an endpoint to gracefully stop accepting new streams while still finishing processing of previously established streams. This enables administrative actions, like server maintenance.

There is an inherent race condition between an endpoint starting new streams and the remote peer sending a GOAWAY frame. To deal with this case, the GOAWAY contains the stream identifier of the last peer-initiated stream that was or might be processed on the sending endpoint in this connection. For instance, if the server sends a GOAWAY frame, the identified stream is the highest-numbered stream initiated by the client.

Once the GOAWAY is sent, the sender will ignore frames sent on streams initiated by the receiver if the stream has an identifier higher than the included last stream identifier. Receivers of a GOAWAY frame **MUST NOT** open additional streams on the connection, although a new connection can be established for new streams.

If the receiver of the GOAWAY has sent data on streams with a higher stream identifier than what is indicated in the GOAWAY frame, those streams are not or will not be processed. The receiver of the GOAWAY frame can treat the streams as though they had never been created at all, thereby allowing those streams to be retried later on a new connection.

Endpoints **SHOULD** always send a GOAWAY frame before closing a connection so that the remote peer can know whether a stream has been partially processed or not. For example, if an HTTP client sends a POST at the same time that a server closes a connection, the client cannot know if the server started to process that POST request if the server does not send a GOAWAY frame to indicate what streams it might have acted on.

An endpoint might choose to close a connection without sending a GOAWAY for misbehaving peers.

A GOAWAY frame might not immediately precede closing of the connection; a receiver of a GOAWAY that has no more use for the connection **SHOULD** still send a GOAWAY frame before terminating the connection.

```
GOAWAY Frame {
  Length (24),
  Type (8) = 0x07,

  Unused Flags (8),

  Reserved (1),
  Stream Identifier (31) = 0,

  Reserved (1),
  Last-Stream-ID (31),
  Error Code (32),
  Additional Debug Data (...),
}
```

Figure 10: GOAWAY Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in Section 4.

The GOAWAY frame does not define any flags.

The GOAWAY frame applies to the connection, not a specific stream. An endpoint **MUST** treat a GOAWAY frame with a stream identifier other than 0x00 as a connection error (Section 5.4.1) of type `PROTOCOL_ERROR`.

The last stream identifier in the GOAWAY frame contains the highest-numbered stream identifier for which the sender of the GOAWAY frame might have taken some action on or might yet take action on. All streams up to and including the identified stream might have been processed in some way. The last stream identifier can be set to 0 if no streams were processed.

Note: In this context, "processed" means that some data from the stream was passed to some higher layer of software that might have taken some action as a result.

If a connection terminates without a GOAWAY frame, the last stream identifier is effectively the highest possible stream identifier.

On streams with lower- or equal-numbered identifiers that were not closed completely prior to the connection being closed, reattempting requests, transactions, or any protocol activity is not possible, except for idempotent actions like HTTP GET, PUT, or DELETE. Any protocol activity that uses higher-numbered streams can be safely retried using a new connection.

Activity on streams numbered lower than or equal to the last stream identifier might still complete successfully. The sender of a GOAWAY frame might gracefully shut down a connection by sending a GOAWAY frame, maintaining the connection in an "open" state until all in-progress streams complete.

An endpoint MAY send multiple GOAWAY frames if circumstances change. For instance, an endpoint that sends GOAWAY with `NO_ERROR` during graceful shutdown could subsequently encounter a condition that requires immediate termination of the connection. The last stream identifier from the last GOAWAY frame received indicates which streams could have been acted upon. Endpoints MUST NOT increase the value they send in the last stream identifier, since the peers might already have retried unprocessed requests on another connection.

A client that is unable to retry requests loses all requests that are in flight when the server closes the connection. This is especially true for intermediaries that might not be serving clients using HTTP/2. A server that is attempting to gracefully shut down a connection SHOULD send an initial GOAWAY frame with the last stream identifier set to $2^{31}-1$ and a `NO_ERROR` code. This signals to the client that a shutdown is imminent and that initiating further requests is prohibited. After allowing time for any in-flight stream creation (at least one round-trip time), the server MAY send another GOAWAY frame with an updated last stream identifier. This ensures that a connection can be cleanly shut down without losing requests.

After sending a GOAWAY frame, the sender can discard frames for streams initiated by the receiver with identifiers higher than the identified last stream. However, any frames that alter connection state cannot be completely ignored. For instance, `HEADERS`, `PUSH_PROMISE`, and `CONTINUATION` frames MUST be minimally processed to ensure that the state maintained for field section compression is consistent (see [Section 4.3](#)); similarly, `DATA` frames MUST be counted toward the connection flow-control window. Failure to process these frames can cause flow control or field section compression state to become unsynchronized.

The GOAWAY frame also contains a 32-bit error code ([Section 7](#)) that contains the reason for closing the connection.

Endpoints MAY append opaque data to the frame payload of any GOAWAY frame. Additional debug data is intended for diagnostic purposes only and carries no semantic value. Debug information could contain security- or privacy-sensitive data. Logged or otherwise persistently stored debug data MUST have adequate safeguards to prevent unauthorized access.

6.9. WINDOW_UPDATE

The WINDOW_UPDATE frame (type=0x08) is used to implement flow control; see [Section 5.2](#) for an overview.

Flow control operates at two levels: on each individual stream and on the entire connection.

Both types of flow control are hop by hop, that is, only between the two endpoints. Intermediaries do not forward WINDOW_UPDATE frames between dependent connections. However, throttling of data transfer by any receiver can indirectly cause the propagation of flow-control information toward the original sender.

Flow control only applies to frames that are identified as being subject to flow control. Of the frame types defined in this document, this includes only [DATA](#) frames. Frames that are exempt from flow control **MUST** be accepted and processed, unless the receiver is unable to assign resources to handling the frame. A receiver **MAY** respond with a stream error ([Section 5.4.2](#)) or connection error ([Section 5.4.1](#)) of type [FLOW_CONTROL_ERROR](#) if it is unable to accept a frame.

```
WINDOW_UPDATE Frame {
  Length (24) = 0x04,
  Type (8) = 0x08,

  Unused Flags (8),

  Reserved (1),
  Stream Identifier (31),

  Reserved (1),
  Window Size Increment (31),
}
```

Figure 11: WINDOW_UPDATE Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The frame payload of a WINDOW_UPDATE frame is one reserved bit plus an unsigned 31-bit integer indicating the number of octets that the sender can transmit in addition to the existing flow-control window. The legal range for the increment to the flow-control window is 1 to $2^{31}-1$ (2,147,483,647) octets.

The WINDOW_UPDATE frame does not define any flags.

The WINDOW_UPDATE frame can be specific to a stream or to the entire connection. In the former case, the frame's stream identifier indicates the affected stream; in the latter, the value "0" indicates that the entire connection is the subject of the frame.

A receiver **MUST** treat the receipt of a WINDOW_UPDATE frame with a flow-control window increment of 0 as a stream error ([Section 5.4.2](#)) of type [PROTOCOL_ERROR](#); errors on the connection flow-control window **MUST** be treated as a connection error ([Section 5.4.1](#)).

WINDOW_UPDATE can be sent by a peer that has sent a frame with the END_STREAM flag set. This means that a receiver could receive a WINDOW_UPDATE frame on a stream in a "half-closed (remote)" or "closed" state. A receiver **MUST NOT** treat this as an error (see [Section 5.1](#)).

A receiver that receives a flow-controlled frame **MUST** always account for its contribution against the connection flow-control window, unless the receiver treats this as a connection error ([Section 5.4.1](#)). This is necessary even if the frame is in error. The sender counts the frame toward the flow-control window, but if the receiver does not, the flow-control window at the sender and receiver can become different.

A WINDOW_UPDATE frame with a length other than 4 octets **MUST** be treated as a connection error ([Section 5.4.1](#)) of type [FRAME_SIZE_ERROR](#).

6.9.1. The Flow-Control Window

Flow control in HTTP/2 is implemented using a window kept by each sender on every stream. The flow-control window is a simple integer value that indicates how many octets of data the sender is permitted to transmit; as such, its size is a measure of the buffering capacity of the receiver.

Two flow-control windows are applicable: the stream flow-control window and the connection flow-control window. The sender **MUST NOT** send a flow-controlled frame with a length that exceeds the space available in either of the flow-control windows advertised by the receiver. Frames with zero length with the END_STREAM flag set (that is, an empty [DATA](#) frame) **MAY** be sent if there is no available space in either flow-control window.

For flow-control calculations, the 9-octet frame header is not counted.

After sending a flow-controlled frame, the sender reduces the space available in both windows by the length of the transmitted frame.

The receiver of a frame sends a WINDOW_UPDATE frame as it consumes data and frees up space in flow-control windows. Separate WINDOW_UPDATE frames are sent for the stream- and connection-level flow-control windows. Receivers are advised to have mechanisms in place to avoid sending WINDOW_UPDATE frames with very small increments; see [Section 4.2.3.3](#) of [RFC1122].

A sender that receives a WINDOW_UPDATE frame updates the corresponding window by the amount specified in the frame.

A sender MUST NOT allow a flow-control window to exceed $2^{31}-1$ octets. If a sender receives a WINDOW_UPDATE that causes a flow-control window to exceed this maximum, it MUST terminate either the stream or the connection, as appropriate. For streams, the sender sends a RST_STREAM with an error code of FLOW_CONTROL_ERROR; for the connection, a GOAWAY frame with an error code of FLOW_CONTROL_ERROR is sent.

Flow-controlled frames from the sender and WINDOW_UPDATE frames from the receiver are completely asynchronous with respect to each other. This property allows a receiver to aggressively update the window size kept by the sender to prevent streams from stalling.

6.9.2. Initial Flow-Control Window Size

When an HTTP/2 connection is first established, new streams are created with an initial flow-control window size of 65,535 octets. The connection flow-control window is also 65,535 octets. Both endpoints can adjust the initial window size for new streams by including a value for SETTINGS_INITIAL_WINDOW_SIZE in the SETTINGS frame. The connection flow-control window can only be changed using WINDOW_UPDATE frames.

Prior to receiving a SETTINGS frame that sets a value for SETTINGS_INITIAL_WINDOW_SIZE, an endpoint can only use the default initial window size when sending flow-controlled frames. Similarly, the connection flow-control window is set based on the default initial window size until a WINDOW_UPDATE frame is received.

In addition to changing the flow-control window for streams that are not yet active, a SETTINGS frame can alter the initial flow-control window size for streams with active flow-control windows (that is, streams in the "open" or "half-closed (remote)" state). When the value of SETTINGS_INITIAL_WINDOW_SIZE changes, a receiver MUST adjust the size of all stream flow-control windows that it maintains by the difference between the new value and the old value.

A change to SETTINGS_INITIAL_WINDOW_SIZE can cause the available space in a flow-control window to become negative. A sender MUST track the negative flow-control window and MUST NOT send new flow-controlled frames until it receives WINDOW_UPDATE frames that cause the flow-control window to become positive.

For example, if the client sends 60 KB immediately on connection establishment and the server sets the initial window size to be 16 KB, the client will recalculate the available flow-control window to be -44 KB on receipt of the SETTINGS frame. The client retains a negative flow-control window until WINDOW_UPDATE frames restore the window to being positive, after which the client can resume sending.

A SETTINGS frame cannot alter the connection flow-control window.

An endpoint MUST treat a change to SETTINGS_INITIAL_WINDOW_SIZE that causes any flow-control window to exceed the maximum size as a connection error ([Section 5.4.1](#)) of type FLOW_CONTROL_ERROR.

6.9.3. Reducing the Stream Window Size

A receiver that wishes to use a smaller flow-control window than the current size can send a new [SETTINGS](#) frame. However, the receiver **MUST** be prepared to receive data that exceeds this window size, since the sender might send data that exceeds the lower limit prior to processing the [SETTINGS](#) frame.

After sending a [SETTINGS](#) frame that reduces the initial flow-control window size, a receiver **MAY** continue to process streams that exceed flow-control limits. Allowing streams to continue does not allow the receiver to immediately reduce the space it reserves for flow-control windows. Progress on these streams can also stall, since [WINDOW_UPDATE](#) frames are needed to allow the sender to resume sending. The receiver **MAY** instead send a [RST_STREAM](#) with an error code of [FLOW_CONTROL_ERROR](#) for the affected streams.

6.10. CONTINUATION

The CONTINUATION frame (type=0x09) is used to continue a sequence of field block fragments ([Section 4.3](#)). Any number of CONTINUATION frames can be sent, as long as the preceding frame is on the same stream and is a [HEADERS](#), [PUSH_PROMISE](#), or CONTINUATION frame without the [END_HEADERS](#) flag set.

```
CONTINUATION Frame {
  Length (24),
  Type (8) = 0x09,

  Unused Flags (5),
  END_HEADERS Flag (1),
  Unused Flags (2),

  Reserved (1),
  Stream Identifier (31),

  Field Block Fragment (..),
}
```

Figure 12: CONTINUATION Frame Format

The Length, Type, Unused Flag(s), Reserved, and Stream Identifier fields are described in [Section 4](#). The CONTINUATION frame payload contains a field block fragment ([Section 4.3](#)).

The CONTINUATION frame defines the following flag:

END_HEADERS END_HEADERS flag indicates that this frame ends a field block ([Section 4.3](#)).

If the END_HEADERS flag is not set, this frame **MUST** be followed by another CONTINUATION frame. A receiver **MUST** treat the receipt of any other type of frame or a frame on a different stream as a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

The CONTINUATION frame changes the connection state as defined in [Section 4.3](#).

CONTINUATION frames **MUST** be associated with a stream. If a CONTINUATION frame is received with a Stream Identifier field of 0x00, the recipient **MUST** respond with a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

A CONTINUATION frame **MUST** be preceded by a [HEADERS](#), [PUSH_PROMISE](#) or CONTINUATION frame without the [END_HEADERS](#) flag set. A recipient that observes violation of this rule **MUST** respond with a connection error ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

7. Error Codes

Error codes are 32-bit fields that are used in `RST_STREAM` and `GOAWAY` frames to convey the reasons for the stream or connection error.

Error codes share a common code space. Some error codes apply only to either streams or the entire connection and have no defined semantics in the other context.

The following error codes are defined:

`NO_ERROR` The associated condition is not a result of an error. For example, a `GOAWAY` might include this code to indicate graceful shutdown of a connection.
(0x00):

`PROTOCOL_ERROR` Detected an unspecified protocol error. This error is for use when a more specific error code is not available.
(0x01):

`INTERNAL_ERROR` Encountered an unexpected internal error.
(0x02):

`FLOW_CONTROL_ERROR` The endpoint or its peer violated the flow-control protocol.
(0x03):

`SETTINGS_TIMEOUT` A `SETTINGS` frame was received but did not receive a response in a timely manner. See [Section 6.5.3](#) ("Settings Synchronization").
(0x04):

`STREAM_CLOSED` Received a frame after a stream was half-closed.
(0x05):

`FRAME_SIZE_ERROR` Received a frame with an invalid size.
(0x06):

`REFUSED_STREAM` The endpoint refused the stream prior to performing any application processing (see [Section 8.7](#) for details).
(0x07):

`CANCELLED` The endpoint uses this error code to indicate that the stream is no longer needed.
(0x08):

`COMPRESSION_ERROR` The endpoint failed to maintain the field section compression context for the connection.
(0x09):

`CONNECT_ERROR` A `CONNECT` request ([Section 8.5](#)) was reset or abnormally closed.
(0x0a):

`ENHANCE_YOUR_CALM` The endpoint believes that its peer is exhibiting a behavior that might be generating excessive load.
(0x0b):

`INADEQUATE_SECURITY` The endpoint believes that the peer has properties that do not meet minimum security requirements (see [Section 9.2](#)).
(0x0c):

`HTTP_1_1_REQUIRED` The endpoint requires that HTTP/1.1 be used instead of HTTP/2.
(0x0d):

Unknown or unsupported error codes **MUST NOT** trigger any special behavior. These **MAY** be treated by an implementation as being equivalent to `INTERNAL_ERROR`.

8. Expressing HTTP Semantics in HTTP/2

HTTP/2 is an instantiation of the HTTP message abstraction ([Section 6](#) of [HTTP]).

8.1. HTTP Message Framing

A client sends an HTTP request on a new stream, using a previously unused stream identifier ([Section 5.1.1](#)). A server sends an HTTP response on the same stream as the request.

An HTTP message (request or response) consists of:

1. one **HEADERS** frame (followed by zero or more **CONTINUATION** frames) containing the header section (see [Section 6.3](#) of [HTTP]),
2. zero or more **DATA** frames containing the message content (see [Section 6.4](#) of [HTTP]), and
3. optionally, one **HEADERS** frame (followed by zero or more **CONTINUATION** frames) containing the trailer section, if present (see [Section 6.5](#) of [HTTP]).

For a response only, a server MAY send any number of interim responses before the **HEADERS** frame containing a final response. An interim response consists of a **HEADERS** frame (which might be followed by zero or more **CONTINUATION** frames) containing the control data and header section of an interim (1xx) HTTP response (see [Section 15](#) of [HTTP]). A **HEADERS** frame with the `END_STREAM` flag set that carries an informational status code is malformed ([Section 8.1.1](#)).

The last frame in the sequence bears an `END_STREAM` flag, noting that a **HEADERS** frame with the `END_STREAM` flag set can be followed by **CONTINUATION** frames that carry any remaining fragments of the field block.

Other frames (from any stream) MUST NOT occur between the **HEADERS** frame and any **CONTINUATION** frames that might follow.

HTTP/2 uses **DATA** frames to carry message content. The chunked transfer encoding defined in [Section 7.1](#) of [HTTP/1.1] cannot be used in HTTP/2; see [Section 8.2.2](#).

Trailer fields are carried in a field block that also terminates the stream. That is, trailer fields comprise a sequence starting with a **HEADERS** frame, followed by zero or more **CONTINUATION** frames, where the **HEADERS** frame bears an `END_STREAM` flag. Trailers MUST NOT include pseudo-header fields ([Section 8.3](#)). An endpoint that receives pseudo-header fields in trailers MUST treat the request or response as malformed ([Section 8.1.1](#)).

An endpoint that receives a **HEADERS** frame without the `END_STREAM` flag set after receiving the **HEADERS** frame that opens a request or after receiving a final (non-informational) status code MUST treat the corresponding request or response as malformed ([Section 8.1.1](#)).

An HTTP request/response exchange fully consumes a single stream. A request starts with the **HEADERS** frame that puts the stream into the "open" state. The request ends with a frame with the `END_STREAM` flag set, which causes the stream to become "half-closed (local)" for the client and "half-closed (remote)" for the server. A response stream starts with zero or more interim responses in **HEADERS** frames, followed by a **HEADERS** frame containing a final status code.

An HTTP response is complete after the server sends -- or the client receives -- a frame with the `END_STREAM` flag set (including any **CONTINUATION** frames needed to complete a field block). A server can send a complete response prior to the client sending an entire request if the response does not depend on any portion of the request that has not been sent and received. When this is true, a server MAY request that the client abort transmission of a request without error by sending a **RST_STREAM** with an error code of **NO_ERROR** after sending a complete response (i.e., a frame with the `END_STREAM` flag set). Clients MUST NOT discard responses as a result of receiving such a **RST_STREAM**, though clients can always discard responses at their discretion for other reasons.

8.1.1. Malformed Messages

A malformed request or response is one that is an otherwise valid sequence of HTTP/2 frames but is invalid due to the presence of extraneous frames, prohibited fields or pseudo-header fields, the absence of mandatory pseudo-header fields, the inclusion of uppercase field names, or invalid field names and/or values (in certain circumstances; see [Section 8.2](#)).

A request or response that includes message content can include a `content-length` header field. A request or response is also malformed if the value of a `content-length` header field does not equal the sum of the `DATA` frame payload lengths that form the content, unless the message is defined as having no content. For example, 204 or 304 responses contain no content, as does the response to a `HEAD` request. A response that is defined to have no content, as described in [Section 6.4.1](#) of [HTTP], MAY have a non-zero `content-length` header field, even though no content is included in `DATA` frames.

Intermediaries that process HTTP requests or responses (i.e., any intermediary not acting as a tunnel) MUST NOT forward a malformed request or response. Malformed requests or responses that are detected MUST be treated as a stream error ([Section 5.4.2](#)) of type `PROTOCOL_ERROR`.

For malformed requests, a server MAY send an HTTP response prior to closing or resetting the stream. Clients MUST NOT accept a malformed response.

Endpoints that progressively process messages might have performed some processing before identifying a request or response as malformed. For instance, it might be possible to generate an informational or 404 status code without having received a complete request. Similarly, intermediaries might forward incomplete messages before detecting errors. A server MAY generate a final response before receiving an entire request when the response does not depend on the remainder of the request being correct.

These requirements are intended to protect against several types of common attacks against HTTP; they are deliberately strict because being permissive can expose implementations to these vulnerabilities.

8.2. HTTP Fields

HTTP fields ([Section 5](#) of [HTTP]) are conveyed by HTTP/2 in the `HEADERS`, `CONTINUATION`, and `PUSH_PROMISE` frames, compressed with `HPACK` [COMPRESSION].

Field names MUST be converted to lowercase when constructing an HTTP/2 message.

8.2.1. Field Validity

The definitions of field names and values in HTTP prohibit some characters that `HPACK` might be able to convey. HTTP/2 implementations SHOULD validate field names and values according to their definitions in [Sections 5.1](#) and [5.5](#) of [HTTP], respectively, and treat messages that contain prohibited characters as malformed ([Section 8.1.1](#)).

Failure to validate fields can be exploited for request smuggling attacks. In particular, unvalidated fields might enable attacks when messages are forwarded using [HTTP/1.1](#) [HTTP/1.1], where characters such as carriage return (CR), line feed (LF), and COLON are used as delimiters. Implementations MUST perform the following minimal validation of field names and values:

- A field name MUST NOT contain characters in the ranges 0x00-0x20, 0x41-0x5a, or 0x7f-0xff (all ranges inclusive). This specifically excludes all non-visible ASCII characters, ASCII SP (0x20), and uppercase characters ('A' to 'Z', ASCII 0x41 to 0x5a).
- With the exception of pseudo-header fields ([Section 8.3](#)), which have a name that starts with a single colon, field names MUST NOT include a colon (ASCII COLON, 0x3a).
- A field value MUST NOT contain the zero value (ASCII NUL, 0x00), line feed (ASCII LF, 0x0a), or carriage return (ASCII CR, 0x0d) at any position.
- A field value MUST NOT start or end with an ASCII whitespace character (ASCII SP or HTAB, 0x20 or 0x09).

Note: An implementation that validates fields according to the definitions in Sections 5.1 and 5.5 of [HTTP] only needs an additional check that field names do not include uppercase characters.

A request or response that contains a field that violates any of these conditions MUST be treated as malformed (Section 8.1.1). In particular, an intermediary that does not process fields when forwarding messages MUST NOT forward fields that contain any of the values that are listed as prohibited above.

When a request message violates one of these requirements, an implementation SHOULD generate a 400 (Bad Request) status code (see Section 15.5.1 of [HTTP]), unless a more suitable status code is defined or the status code cannot be sent (e.g., because the error occurs in a trailer field).

Note: Field values that are not valid according to the definition of the corresponding field do not cause a request to be **malformed**; the requirements above only apply to the generic syntax for fields as defined in Section 5 of [HTTP].

8.2.2. Connection-Specific Header Fields

HTTP/2 does not use the `Connection` header field (Section 7.6.1 of [HTTP]) to indicate connection-specific header fields; in this protocol, connection-specific metadata is conveyed by other means. An endpoint MUST NOT generate an HTTP/2 message containing connection-specific header fields. This includes the `Connection` header field and those listed as having connection-specific semantics in Section 7.6.1 of [HTTP] (that is, `Proxy-Connection`, `Keep-Alive`, `Transfer-Encoding`, and `Upgrade`). Any message containing connection-specific header fields MUST be treated as malformed (Section 8.1.1).

The only exception to this is the `TE` header field, which MAY be present in an HTTP/2 request; when it is, it MUST NOT contain any value other than "trailers".

An intermediary transforming an HTTP/1.x message to HTTP/2 MUST remove connection-specific header fields as discussed in Section 7.6.1 of [HTTP], or their messages will be treated by other HTTP/2 endpoints as malformed (Section 8.1.1).

Note: HTTP/2 purposefully does not support upgrade to another protocol. The handshake methods described in Section 3 are believed sufficient to negotiate the use of alternative protocols.

8.2.3. Compressing the Cookie Header Field

The `Cookie` header field [COOKIE] uses a semicolon (";") to delimit cookie-pairs (or "crumbs"). This header field contains multiple values, but does not use a `COMMA` (",") as a separator, thereby preventing cookie-pairs from being sent on multiple field lines (see Section 5.2 of [HTTP]). This can significantly reduce compression efficiency, as updates to individual cookie-pairs would invalidate any field lines that are stored in the HPACK table.

To allow for better compression efficiency, the `Cookie` header field MAY be split into separate header fields, each with one or more cookie-pairs. If there are multiple `Cookie` header fields after decompression, these MUST be concatenated into a single octet string using the two-octet delimiter of 0x3b, 0x20 (the ASCII string "; ") before being passed into a non-HTTP/2 context, such as an HTTP/1.1 connection, or a generic HTTP server application.

Therefore, the following two lists of `Cookie` header fields are semantically equivalent.

```
cookie: a=b; c=d; e=f

cookie: a=b
cookie: c=d
cookie: e=f
```

8.3. HTTP Control Data

HTTP/2 uses special pseudo-header fields beginning with a ':' character (ASCII 0x3a) to convey message control data (see Section 6.2 of [HTTP]).

Pseudo-header fields are not HTTP header fields. Endpoints **MUST NOT** generate pseudo-header fields other than those defined in this document. Note that an extension could negotiate the use of additional pseudo-header fields; see [Section 5.5](#).

Pseudo-header fields are only valid in the context in which they are defined. Pseudo-header fields defined for requests **MUST NOT** appear in responses; pseudo-header fields defined for responses **MUST NOT** appear in requests. Pseudo-header fields **MUST NOT** appear in a trailer section. Endpoints **MUST** treat a request or response that contains undefined or invalid pseudo-header fields as malformed ([Section 8.1.1](#)).

All pseudo-header fields **MUST** appear in a field block before all regular field lines. Any request or response that contains a pseudo-header field that appears in a field block after a regular field line **MUST** be treated as malformed ([Section 8.1.1](#)).

The same pseudo-header field name **MUST NOT** appear more than once in a field block. A field block for an HTTP request or response that contains a repeated pseudo-header field name **MUST** be treated as malformed ([Section 8.1.1](#)).

8.3.1. Request Pseudo-Header Fields

The following pseudo-header fields are defined for HTTP/2 requests:

The `:method` pseudo-header field includes the HTTP method ([Section 9](#) of [HTTP]).

The `:scheme` pseudo-header field includes the scheme portion of the request target. The scheme is taken from the target URI ([Section 3.1](#) of [RFC3986]) when generating a request directly, or from the scheme of a translated request (for example, see [Section 3.3](#) of [HTTP/1.1]). Scheme is omitted for CONNECT requests ([Section 8.5](#)).

`:scheme` is not restricted to "http" and "https" schemed URIs. A proxy or gateway can translate requests for non-HTTP schemes, enabling the use of HTTP to interact with non-HTTP services.

The `:authority` pseudo-header field conveys the authority portion ([Section 3.2](#) of [RFC3986]) of the target URI ([Section 7.1](#) of [HTTP]). The recipient of an HTTP/2 request **MUST NOT** use the `Host` header field to determine the target URI if `:authority` is present.

Clients that generate HTTP/2 requests directly **MUST** use the `:authority` pseudo-header field to convey authority information, unless there is no authority information to convey (in which case it **MUST NOT** generate `:authority`).

Clients **MUST NOT** generate a request with a `Host` header field that differs from the `:authority` pseudo-header field. A server **SHOULD** treat a request as malformed if it contains a `Host` header field that identifies an entity that differs from the entity in the `:authority` pseudo-header field. The values of fields need to be normalized to compare them (see [Section 6.2](#) of [RFC3986]). An origin server can apply any normalization method, whereas other servers **MUST** perform scheme-based normalization (see [Section 6.2.3](#) of [RFC3986]) of the two fields.

An intermediary that forwards a request over HTTP/2 **MUST** construct an `:authority` pseudo-header field using the authority information from the control data of the original request, unless the original request's target URI does not contain authority information (in which case it **MUST NOT** generate `:authority`). Note that the `Host` header field is not the sole source of this information; see [Section 7.2](#) of [HTTP].

An intermediary that needs to generate a `Host` header field (which might be necessary to construct an HTTP/1.1 request) **MUST** use the value from the `:authority` pseudo-header field as the value of the `Host` field, unless the intermediary also changes the request target. This replaces any existing `Host` field to avoid potential vulnerabilities in HTTP routing.

An intermediary that forwards a request over HTTP/2 **MAY** retain any `Host` header field.

Note that request targets for CONNECT or asterisk-form OPTIONS requests never include authority information; see [Sections 7.1](#) and [7.2](#) of [HTTP].

`:authority` **MUST NOT** include the deprecated userinfo subcomponent for "http" or "https" schemed URIs.

The `:path` pseudo-header field includes the path and query parts of the target URI (the `absolute-path` production and, optionally, a `?` character followed by the `query` production; see [Section 4.1](#) of [HTTP]). A request in asterisk form (for OPTIONS) includes the value `*` for the `:path` pseudo-header field.

This pseudo-header field **MUST NOT** be empty for `http` or `https` URIs; `http` or `https` URIs that do not contain a path component **MUST** include a value of `/`. The exceptions to this rule are:

- an OPTIONS request for an `http` or `https` URI that does not include a path component; these **MUST** include a `:path` pseudo-header field with a value of `*` (see [Section 7.1](#) of [HTTP]).
- CONNECT requests ([Section 8.5](#)), where the `:path` pseudo-header field is omitted.

All HTTP/2 requests **MUST** include exactly one valid value for the `:method`, `:scheme`, and `:path` pseudo-header fields, unless they are CONNECT requests ([Section 8.5](#)). An HTTP request that omits mandatory pseudo-header fields is malformed ([Section 8.1.1](#)).

Individual HTTP/2 requests do not carry an explicit indicator of protocol version. All HTTP/2 requests implicitly have a protocol version of `"2.0"` (see [Section 6.2](#) of [HTTP]).

8.3.2. Response Pseudo-Header Fields

For HTTP/2 responses, a single `:status` pseudo-header field is defined that carries the HTTP status code field (see [Section 15](#) of [HTTP]). This pseudo-header field **MUST** be included in all responses, including interim responses; otherwise, the response is malformed ([Section 8.1.1](#)).

HTTP/2 responses implicitly have a protocol version of `"2.0"`.

8.4. Server Push

HTTP/2 allows a server to preemptively send (or "push") responses (along with corresponding "promised" requests) to a client in association with a previous client-initiated request.

Server push was designed to allow a server to improve client-perceived performance by predicting what requests will follow those that it receives, thereby removing a round trip for them. For example, a request for HTML is often followed by requests for stylesheets and scripts referenced by that page. When these requests are pushed, the client does not need to wait to receive the references to them in the HTML and issue separate requests.

In practice, server push is difficult to use effectively, because it requires the server to correctly anticipate the additional requests the client will make, taking into account factors such as caching, content negotiation, and user behavior. Errors in prediction can lead to performance degradation, due to the opportunity cost that the additional data on the wire represents. In particular, pushing any significant amount of data can cause contention issues with responses that are more important.

A client can request that server push be disabled, though this is negotiated for each hop independently. The `SETTINGS_ENABLE_PUSH` setting can be set to 0 to indicate that server push is disabled.

Promised requests **MUST** be safe (see [Section 9.2.1](#) of [HTTP]) and cacheable (see [Section 9.2.3](#) of [HTTP]). Promised requests cannot include any content or a trailer section. Clients that receive a promised request that is not cacheable, that is not known to be safe, or that indicates the presence of request content **MUST** reset the promised stream with a stream error ([Section 5.4.2](#)) of type `PROTOCOL_ERROR`. Note that this could result in the promised stream being reset if the client does not recognize a newly defined method as being safe.

Pushed responses that are cacheable (see [Section 3](#) of [CACHING]) can be stored by the client, if it implements an HTTP cache. Pushed responses are considered successfully validated on the origin server (e.g., if the "no-cache" cache response directive is present; see [Section 5.2.2.4](#) of [CACHING]) while the stream identified by the promised stream identifier is still open.

Pushed responses that are not cacheable **MUST NOT** be stored by any HTTP cache. They **MAY** be made available to the application separately.

The server **MUST** include a value in the `:authority` pseudo-header field for which the server is authoritative (see [Section 10.1](#)). A client **MUST** treat a `PUSH_PROMISE` for which the server is not authoritative as a stream error ([Section 5.4.2](#)) of type `PROTOCOL_ERROR`.

An intermediary can receive pushes from the server and choose not to forward them on to the client. In other words, how to make use of the pushed information is up to that intermediary. Equally, the intermediary might choose to make additional pushes to the client, without any action taken by the server.

A client cannot push. Thus, servers **MUST** treat the receipt of a `PUSH_PROMISE` frame as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`. A server cannot set the `SETTINGS_ENABLE_PUSH` setting to a value other than 0 (see [Section 6.5.2](#)).

8.4.1. Push Requests

Server push is semantically equivalent to a server responding to a request; however, in this case, that request is also sent by the server, as a `PUSH_PROMISE` frame.

The `PUSH_PROMISE` frame includes a field block that contains control data and a complete set of request header fields that the server attributes to the request. It is not possible to push a response to a request that includes message content.

Promised requests are always associated with an explicit request from the client. The `PUSH_PROMISE` frames sent by the server are sent on that explicit request's stream. The `PUSH_PROMISE` frame also includes a promised stream identifier, chosen from the stream identifiers available to the server (see [Section 5.1.1](#)).

The header fields in `PUSH_PROMISE` and any subsequent `CONTINUATION` frames **MUST** be a valid and complete set of request header fields ([Section 8.3.1](#)). The server **MUST** include a method in the `:method` pseudo-header field that is safe and cacheable. If a client receives a `PUSH_PROMISE` that does not include a complete and valid set of header fields or the `:method` pseudo-header field identifies a method that is not safe, it **MUST** respond on the promised stream with a stream error ([Section 5.4.2](#)) of type `PROTOCOL_ERROR`.

The server **SHOULD** send `PUSH_PROMISE` ([Section 6.6](#)) frames prior to sending any frames that reference the promised responses. This avoids a race where clients issue requests prior to receiving any `PUSH_PROMISE` frames.

For example, if the server receives a request for a document containing embedded links to multiple image files and the server chooses to push those additional images to the client, sending `PUSH_PROMISE` frames before the `DATA` frames that contain the image links ensures that the client is able to see that a resource will be pushed before discovering embedded links. Similarly, if the server pushes resources referenced by the field block (for instance, in Link header fields), sending a `PUSH_PROMISE` before sending the header ensures that clients do not request those resources.

`PUSH_PROMISE` frames **MUST NOT** be sent by the client.

`PUSH_PROMISE` frames can be sent by the server on any client-initiated stream, but the stream **MUST** be in either the "open" or "half-closed (remote)" state with respect to the server. `PUSH_PROMISE` frames are interspersed with the frames that comprise a response, though they cannot be interspersed with `HEADERS` and `CONTINUATION` frames that comprise a single field block.

Sending a `PUSH_PROMISE` frame creates a new stream and puts the stream into the "reserved (local)" state for the server and the "reserved (remote)" state for the client.

8.4.2. Push Responses

After sending the `PUSH_PROMISE` frame, the server can begin delivering the pushed response as a response ([Section 8.3.2](#)) on a server-initiated stream that uses the promised stream identifier. The server uses this stream to transmit an HTTP response, using the same sequence of frames as that defined in [Section 8.1](#). This stream becomes "half-closed" to the client ([Section 5.1](#)) after the initial `HEADERS` frame is sent.

Once a client receives a **PUSH_PROMISE** frame and chooses to accept the pushed response, the client **SHOULD NOT** issue any requests for the promised response until after the promised stream has closed.

If the client determines, for any reason, that it does not wish to receive the pushed response from the server or if the server takes too long to begin sending the promised response, the client can send a **RST_STREAM** frame, using either the **CANCEL** or **REFUSED_STREAM** code and referencing the pushed stream's identifier.

A client can use the **SETTINGS_MAX_CONCURRENT_STREAMS** setting to limit the number of responses that can be concurrently pushed by a server. Advertising a **SETTINGS_MAX_CONCURRENT_STREAMS** value of zero prevents the server from opening the streams necessary to push responses. However, this does not prevent the server from reserving streams using **PUSH_PROMISE** frames, because reserved streams do not count toward the concurrent stream limit. Clients that do not wish to receive pushed resources need to reset any unwanted reserved streams or set **SETTINGS_ENABLE_PUSH** to 0.

Clients receiving a pushed response **MUST** validate that either the server is authoritative (see [Section 10.1](#)) or the proxy that provided the pushed response is configured for the corresponding request. For example, a server that offers a certificate for only the `example.com` DNS-ID (see [\[RFC6125\]](#)) is not permitted to push a response for `<https://www.example.org/doc>`.

The response for a **PUSH_PROMISE** stream begins with a **HEADERS** frame, which immediately puts the stream into the "half-closed (remote)" state for the server and "half-closed (local)" state for the client, and ends with a frame with the **END_STREAM** flag set, which places the stream in the "closed" state.

Note: The client never sends a frame with the **END_STREAM** flag set for a server push.

8.5. The CONNECT Method

The **CONNECT** method ([Section 9.3.6](#) of [\[HTTP\]](#)) is used to convert an HTTP connection into a tunnel to a remote host. **CONNECT** is primarily used with HTTP proxies to establish a TLS session with an origin server for the purposes of interacting with "https" resources.

In HTTP/2, the **CONNECT** method establishes a tunnel over a single HTTP/2 stream to a remote host, rather than converting the entire connection to a tunnel. A **CONNECT** header section is constructed as defined in [Section 8.3.1](#) ("Request Pseudo-Header Fields"), with a few differences. Specifically:

- The `:method` pseudo-header field is set to **CONNECT**.
- The `:scheme` and `:path` pseudo-header fields **MUST** be omitted.
- The `:authority` pseudo-header field contains the host and port to connect to (equivalent to the authority-form of the request-target of **CONNECT** requests; see [Section 3.2.3](#) of [\[HTTP/1.1\]](#)).

A **CONNECT** request that does not conform to these restrictions is malformed ([Section 8.1.1](#)).

A proxy that supports **CONNECT** establishes a **TCP connection** [TCP] to the host and port identified in the `:authority` pseudo-header field. Once this connection is successfully established, the proxy sends a **HEADERS** frame containing a 2xx-series status code to the client, as defined in [Section 9.3.6](#) of [\[HTTP\]](#).

After the initial **HEADERS** frame sent by each peer, all subsequent **DATA** frames correspond to data sent on the TCP connection. The frame payload of any **DATA** frames sent by the client is transmitted by the proxy to the TCP server; data received from the TCP server is assembled into **DATA** frames by the proxy. Frame types other than **DATA** or stream management frames (**RST_STREAM**, **WINDOW_UPDATE**, and **PRIORITY**) **MUST NOT** be sent on a connected stream and **MUST** be treated as a stream error ([Section 5.4.2](#)) if received.

The TCP connection can be closed by either peer. The **END_STREAM** flag on a **DATA** frame is treated as being equivalent to the TCP FIN bit. A client is expected to send a **DATA** frame with the **END_STREAM** flag set after receiving a frame with the **END_STREAM** flag set. A proxy that receives a **DATA** frame with the **END_STREAM** flag set sends the attached data with the FIN bit set on the last TCP segment. A proxy that receives a TCP segment with the FIN bit set sends a **DATA** frame with the **END_STREAM** flag set. Note that the final TCP segment or **DATA** frame could be empty.

A TCP connection error is signaled with [RST_STREAM](#). A proxy treats any error in the TCP connection, which includes receiving a TCP segment with the RST bit set, as a stream error ([Section 5.4.2](#)) of type [CONNECT_ERROR](#). Correspondingly, a proxy **MUST** send a TCP segment with the RST bit set if it detects an error with the stream or the HTTP/2 connection.

8.6. The Upgrade Header Field

HTTP/2 does not support the 101 (Switching Protocols) informational status code ([Section 15.2.2](#) of [HTTP]).

The semantics of 101 (Switching Protocols) aren't applicable to a multiplexed protocol. Similar functionality might be enabled through the use of [extended CONNECT](#) [RFC8441], and other protocols are able to use the same mechanisms that HTTP/2 uses to negotiate their use (see [Section 3](#)).

8.7. Request Reliability

In general, an HTTP client is unable to retry a non-idempotent request when an error occurs because there is no means to determine the nature of the error (see [Section 9.2.2](#) of [HTTP]). It is possible that some server processing occurred prior to the error, which could result in undesirable effects if the request were reattempted.

HTTP/2 provides two mechanisms for providing a guarantee to a client that a request has not been processed:

- The [GOAWAY](#) frame indicates the highest stream number that might have been processed. Requests on streams with higher numbers are therefore guaranteed to be safe to retry.
- The [REFUSED_STREAM](#) error code can be included in a [RST_STREAM](#) frame to indicate that the stream is being closed prior to any processing having occurred. Any request that was sent on the reset stream can be safely retried.

Requests that have not been processed have not failed; clients **MAY** automatically retry them, even those with non-idempotent methods.

A server **MUST NOT** indicate that a stream has not been processed unless it can guarantee that fact. If frames that are on a stream are passed to the application layer for any stream, then [REFUSED_STREAM](#) **MUST NOT** be used for that stream, and a [GOAWAY](#) frame **MUST** include a stream identifier that is greater than or equal to the given stream identifier.

In addition to these mechanisms, the [PING](#) frame provides a way for a client to easily test a connection. Connections that remain idle can become broken, because some middleboxes (for instance, network address translators or load balancers) silently discard connection bindings. The [PING](#) frame allows a client to safely test whether a connection is still active without sending a request.

8.8. Examples

This section shows HTTP/1.1 requests and responses, with illustrations of equivalent HTTP/2 requests and responses.

8.8.1. Simple Request

An HTTP GET request includes control data and a request header with no message content and is therefore transmitted as a single [HEADERS](#) frame, followed by zero or more [CONTINUATION](#) frames containing the serialized block of request header fields. The [HEADERS](#) frame in the following has both the [END_HEADERS](#) and [END_STREAM](#) flags set; no [CONTINUATION](#) frames are sent.

```

GET /resource HTTP/1.1           HEADERS
Host: example.org                ==>  + END_STREAM
Accept: image/jpeg               + END_HEADERS
                                 :method = GET
                                 :scheme = https
                                 :authority = example.org
                                 :path = /resource
                                 host = example.org
                                 accept = image/jpeg

```

8.8.2. Simple Response

Similarly, a response that includes only control data and a response header is transmitted as a [HEADERS](#) frame (again, followed by zero or more [CONTINUATION](#) frames) containing the serialized block of response header fields.

```

HTTP/1.1 304 Not Modified        HEADERS
ETag: "xyzzy"                   ==>  + END_STREAM
Expires: Thu, 23 Jan ...         + END_HEADERS
                                 :status = 304
                                 etag = "xyzzy"
                                 expires = Thu, 23 Jan ...

```

8.8.3. Complex Request

An HTTP POST request that includes control data and a request header with message content is transmitted as one [HEADERS](#) frame, followed by zero or more [CONTINUATION](#) frames containing the request header, followed by one or more [DATA](#) frames, with the last [CONTINUATION](#) (or [HEADERS](#)) frame having the `END_HEADERS` flag set and the final [DATA](#) frame having the `END_STREAM` flag set:

```

POST /resource HTTP/1.1         HEADERS
Host: example.org               ==>  - END_STREAM
Content-Type: image/jpeg        - END_HEADERS
Content-Length: 123             :method = POST
                                 :authority = example.org
                                 :path = /resource
                                 :scheme = https

{binary data}

CONTINUATION
+ END_HEADERS
content-type = image/jpeg
host = example.org
content-length = 123

DATA
+ END_STREAM
{binary data}

```

Note that data contributing to any given field line could be spread between field block fragments. The allocation of field lines to frames in this example is illustrative only.

8.8.4. Response with Body

A response that includes control data and a response header with message content is transmitted as a [HEADERS](#) frame, followed by zero or more [CONTINUATION](#) frames, followed by one or more [DATA](#) frames, with the last [DATA](#) frame in the sequence having the `END_STREAM` flag set:

```

HTTP/1.1 200 OK                                HEADERS
Content-Type: image/jpeg ==>                 - END_STREAM
Content-Length: 123                             + END_HEADERS
                                                :status = 200
{binary data}                                  content-type = image/jpeg
                                                content-length = 123

                                                DATA
                                                + END_STREAM
{binary data}

```

8.8.5. Informational Responses

An informational response using a 1xx status code other than 101 is transmitted as a [HEADERS](#) frame, followed by zero or more [CONTINUATION](#) frames.

A trailer section is sent as a field block after both the request or response field block and all the [DATA](#) frames have been sent. The [HEADERS](#) frame starting the field block that comprises the trailer section has the `END_STREAM` flag set.

The following example includes both a 100 (Continue) status code, which is sent in response to a request containing a "100-continue" token in the Expect header field, and a trailer section:

```

HTTP/1.1 100 Continue                          HEADERS
Extension-Field: bar ==>                     - END_STREAM
                                                + END_HEADERS
                                                :status = 100
                                                extension-field = bar

HTTP/1.1 200 OK                                HEADERS
Content-Type: image/jpeg ==>                 - END_STREAM
Transfer-Encoding: chunked                     + END_HEADERS
Trailer: Foo                                   :status = 200
                                                content-type = image/jpeg
123                                             trailer = Foo
{binary data}
0
Foo: bar                                         DATA
                                                - END_STREAM
                                                {binary data}

                                                HEADERS
                                                + END_STREAM
                                                + END_HEADERS
                                                foo = bar

```

9. HTTP/2 Connections

This section outlines attributes of HTTP that improve interoperability, reduce exposure to known security vulnerabilities, or reduce the potential for implementation variation.

9.1. Connection Management

HTTP/2 connections are persistent. For best performance, it is expected that clients will not close connections until it is determined that no further communication with a server is necessary (for example, when a user navigates away from a particular web page) or until the server closes the connection.

Clients SHOULD NOT open more than one HTTP/2 connection to a given host and port pair, where the host is derived from a URI, a selected [alternative service](#) [ALT-SVC], or a configured proxy.

A client can create additional connections as replacements, either to replace connections that are near to exhausting the available stream identifier space ([Section 5.1.1](#)), to refresh the keying material for a TLS connection, or to replace connections that have encountered errors ([Section 5.4.1](#)).

A client MAY open multiple connections to the same IP address and TCP port using different [Server Name Indication](#) [TLS-EXT] values or to provide different TLS client certificates but SHOULD avoid creating multiple connections with the same configuration.

Servers are encouraged to maintain open connections for as long as possible but are permitted to terminate idle connections if necessary. When either endpoint chooses to close the transport-layer TCP connection, the terminating endpoint SHOULD first send a [GOAWAY](#) ([Section 6.8](#)) frame so that both endpoints can reliably determine whether previously sent frames have been processed and gracefully complete or terminate any necessary remaining tasks.

9.1.1. Connection Reuse

Connections that are made to an origin server, either directly or through a tunnel created using the CONNECT method ([Section 8.5](#)), MAY be reused for requests with multiple different URI authority components. A connection can be reused as long as the origin server is authoritative ([Section 10.1](#)). For TCP connections without TLS, this depends on the host having resolved to the same IP address.

For "https" resources, connection reuse additionally depends on having a certificate that is valid for the host in the URI. The certificate presented by the server MUST satisfy any checks that the client would perform when forming a new TLS connection for the host in the URI. A single certificate can be used to establish authority for multiple origins. [Section 4.3](#) of [HTTP] describes how a client determines whether a server is authoritative for a URI.

In some deployments, reusing a connection for multiple origins can result in requests being directed to the wrong origin server. For example, TLS termination might be performed by a middlebox that uses the TLS [Server Name Indication](#) [TLS-EXT] extension to select an origin server. This means that it is possible for clients to send requests to servers that might not be the intended target for the request, even though the server is otherwise authoritative.

A server that does not wish clients to reuse connections can indicate that it is not authoritative for a request by sending a 421 (Misdirected Request) status code in response to the request (see [Section 15.5.20](#) of [HTTP]).

A client that is configured to use a proxy over HTTP/2 directs requests to that proxy through a single connection. That is, all requests sent via a proxy reuse the connection to the proxy.

9.2. Use of TLS Features

Implementations of HTTP/2 MUST use [TLS version 1.2](#) [TLS12] or higher for HTTP/2 over TLS. The general TLS usage guidance in [TLSBCP] SHOULD be followed, with some additional restrictions that are specific to HTTP/2.

The TLS implementation **MUST** support the [Server Name Indication \(SNI\)](#) [TLS-EXT] extension to TLS. If the server is identified by a [domain name](#) [DNS-TERMS], clients **MUST** send the `server_name` TLS extension unless an alternative mechanism to indicate the target host is used.

Requirements for deployments of HTTP/2 that negotiate [TLS 1.3](#) [TLS13] are included in [Section 9.2.3](#). Deployments of TLS 1.2 are subject to the requirements in [Sections 9.2.1](#) and [9.2.2](#). Implementations are encouraged to provide defaults that comply, but it is recognized that deployments are ultimately responsible for compliance.

9.2.1. TLS 1.2 Features

This section describes restrictions on the TLS 1.2 feature set that can be used with HTTP/2. Due to deployment limitations, it might not be possible to fail TLS negotiation when these restrictions are not met. An endpoint **MAY** immediately terminate an HTTP/2 connection that does not meet these TLS requirements with a connection error ([Section 5.4.1](#)) of type `INADEQUATE_SECURITY`.

A deployment of HTTP/2 over TLS 1.2 **MUST** disable compression. TLS compression can lead to the exposure of information that would not otherwise be revealed [[RFC3749](#)]. Generic compression is unnecessary, since HTTP/2 provides compression features that are more aware of context and therefore likely to be more appropriate for use for performance, security, or other reasons.

A deployment of HTTP/2 over TLS 1.2 **MUST** disable renegotiation. An endpoint **MUST** treat a TLS renegotiation as a connection error ([Section 5.4.1](#)) of type `PROTOCOL_ERROR`. Note that disabling renegotiation can result in long-lived connections becoming unusable due to limits on the number of messages the underlying cipher suite can encipher.

An endpoint **MAY** use renegotiation to provide confidentiality protection for client credentials offered in the handshake, but any renegotiation **MUST** occur prior to sending the connection preface. A server **SHOULD** request a client certificate if it sees a renegotiation request immediately after establishing a connection.

This effectively prevents the use of renegotiation in response to a request for a specific protected resource. A future specification might provide a way to support this use case. Alternatively, a server might use an error ([Section 5.4](#)) of type `HTTP_1_1_REQUIRED` to request that the client use a protocol that supports renegotiation.

Implementations **MUST** support ephemeral key exchange sizes of at least 2048 bits for cipher suites that use ephemeral finite field Diffie-Hellman (DHE) ([Section 8.1.2](#) of [TLS12]) and 224 bits for cipher suites that use ephemeral elliptic curve Diffie-Hellman (ECDHE) [[RFC8422](#)]. Clients **MUST** accept DHE sizes of up to 4096 bits. Endpoints **MAY** treat negotiation of key sizes smaller than the lower limits as a connection error ([Section 5.4.1](#)) of type `INADEQUATE_SECURITY`.

9.2.2. TLS 1.2 Cipher Suites

A deployment of HTTP/2 over TLS 1.2 **SHOULD NOT** use any of the prohibited cipher suites listed in [Appendix A](#).

Endpoints **MAY** choose to generate a connection error ([Section 5.4.1](#)) of type `INADEQUATE_SECURITY` if one of the prohibited cipher suites is negotiated. A deployment that chooses to use a prohibited cipher suite risks triggering a connection error unless the set of potential peers is known to accept that cipher suite.

Implementations **MUST NOT** generate this error in reaction to the negotiation of a cipher suite that is not prohibited. Consequently, when clients offer a cipher suite that is not prohibited, they have to be prepared to use that cipher suite with HTTP/2.

The list of prohibited cipher suites includes the cipher suite that TLS 1.2 makes mandatory, which means that TLS 1.2 deployments could have non-intersecting sets of permitted cipher suites. To avoid this problem, which causes TLS handshake failures, deployments of HTTP/2 that use TLS 1.2 **MUST** support `TLS_ECDHE_RSA_WITH_AES_128_GCM_SHA256` [TLS-ECDHE] with the P-256 elliptic curve [[RFC8422](#)].

Note that clients might advertise support of cipher suites that are prohibited in order to allow for connection to servers that do not support HTTP/2. This allows servers to select HTTP/1.1 with a cipher suite that is prohibited in HTTP/2. However, this can result in HTTP/2 being negotiated with a prohibited cipher suite if the application protocol and cipher suite are independently selected.

9.2.3. TLS 1.3 Features

TLS 1.3 includes a number of features not available in earlier versions. This section discusses the use of these features.

HTTP/2 servers **MUST NOT** send post-handshake TLS 1.3 CertificateRequest messages. HTTP/2 clients **MUST** treat a TLS post-handshake CertificateRequest message as a connection error (Section 5.4.1) of type **PROTOCOL_ERROR**.

The prohibition on post-handshake authentication applies even if the client offered the "post_handshake_auth" TLS extension. Post-handshake authentication support might be advertised independently of **ALPN** [TLS-ALPN]. Clients might offer the capability for use in other protocols, but inclusion of the extension cannot imply support within HTTP/2.

[TLS13] defines other post-handshake messages, NewSessionTicket and KeyUpdate, which can be used as they have no direct interaction with HTTP/2. Unless the use of a new type of TLS message depends on an interaction with the application-layer protocol, that TLS message can be sent after the handshake completes.

TLS early data **MAY** be used to send requests, provided that the guidance in [RFC8470] is observed. Clients send requests in early data assuming initial values for all server settings.

10. Security Considerations

The use of TLS is necessary to provide many of the security properties of this protocol. Many of the claims in this section do not hold unless TLS is used as described in [Section 9.2](#).

10.1. Server Authority

HTTP/2 relies on the HTTP definition of authority for determining whether a server is authoritative in providing a given response (see [Section 4.3](#) of [HTTP]). This relies on local name resolution for the "http" URI scheme and the authenticated server identity for the "https" scheme.

10.2. Cross-Protocol Attacks

In a cross-protocol attack, an attacker causes a client to initiate a transaction in one protocol toward a server that understands a different protocol. An attacker might be able to cause the transaction to appear as a valid transaction in the second protocol. In combination with the capabilities of the web context, this can be used to interact with poorly protected servers in private networks.

Completing a TLS handshake with an ALPN identifier for HTTP/2 can be considered sufficient protection against cross-protocol attacks. ALPN provides a positive indication that a server is willing to proceed with HTTP/2, which prevents attacks on other TLS-based protocols.

The encryption in TLS makes it difficult for attackers to control the data that could be used in a cross-protocol attack on a cleartext protocol.

The cleartext version of HTTP/2 has minimal protection against cross-protocol attacks. The connection preface ([Section 3.4](#)) contains a string that is designed to confuse HTTP/1.1 servers, but no special protection is offered for other protocols.

10.3. Intermediary Encapsulation Attacks

HPACK permits encoding of field names and values that might be treated as delimiters in other HTTP versions. An intermediary that translates an HTTP/2 request or response MUST validate fields according to the rules in [Section 8.2](#) before translating a message to another HTTP version. Translating a field that includes invalid delimiters could be used to cause recipients to incorrectly interpret a message, which could be exploited by an attacker.

[Section 8.2](#) does not include specific rules for validation of pseudo-header fields. If the values of these fields are used, additional validation is necessary. This is particularly important where ":scheme", ":authority", and ":path" are combined to form a single URI string [RFC3986]. Similar problems might occur when that URI or just ":path" is combined with ":method" to construct a request line (as in [Section 3](#) of [HTTP/1.1]). Simple concatenation is not secure unless the input values are fully validated.

An intermediary can reject fields that contain invalid field names or values for other reasons -- in particular, those fields that do not conform to the HTTP ABNF grammar from [Section 5](#) of [HTTP]. Intermediaries that do not perform any validation of fields other than the minimum required by [Section 8.2](#) could forward messages that contain invalid field names or values.

An intermediary that receives any fields that require removal before forwarding (see [Section 7.6.1](#) of [HTTP]) MUST remove or replace those header fields when forwarding messages. Additionally, intermediaries should take care when forwarding messages containing Content-Length fields to ensure that the message is well-formed ([Section 8.1.1](#)). This ensures that if the message is translated into HTTP/1.1 at any point, the framing will be correct.

10.4. Cacheability of Pushed Responses

Pushed responses do not have an explicit request from the client; the request is provided by the server in the PUSH_PROMISE frame.

Caching responses that are pushed is possible based on the guidance provided by the origin server in the Cache-Control header field. However, this can cause issues if a single server hosts more than one tenant. For example, a server might offer multiple users each a small portion of its URI space.

Where multiple tenants share space on the same server, that server **MUST** ensure that tenants are not able to push representations of resources that they do not have authority over. Failure to enforce this would allow a tenant to provide a representation that would be served out of cache, overriding the actual representation that the authoritative tenant provides.

Pushed responses for which an origin server is not authoritative (see [Section 10.1](#)) **MUST NOT** be used or cached.

10.5. Denial-of-Service Considerations

An HTTP/2 connection can demand a greater commitment of resources to operate than an HTTP/1.1 connection. Both field section compression and flow control depend on a commitment of a greater amount of state. Settings for these features ensure that memory commitments for these features are strictly bounded.

The number of **PUSH_PROMISE** frames is not constrained in the same fashion. A client that accepts server push **SHOULD** limit the number of streams it allows to be in the "reserved (remote)" state. An excessive number of server push streams can be treated as a stream error ([Section 5.4.2](#)) of type **ENHANCE_YOUR_CALM**.

A number of HTTP/2 implementations were found to be vulnerable to denial of service [[NFLX-2019-002](#)]. Below is a list of known ways that implementations might be subject to denial-of-service attacks:

Inefficient tracking of outstanding outbound frames can lead to overload if an adversary can cause large numbers of frames to be enqueued for sending. A peer could use one of several techniques to cause large numbers of frames to be generated:

- Providing tiny increments to flow control in **WINDOW_UPDATE** frames can cause a sender to generate a large number of **DATA** frames.
- An endpoint is required to respond to a **PING** frame.
- Each **SETTINGS** frame requires acknowledgment.
- An invalid request (or server push) can cause a peer to send **RST_STREAM** frames in response.
- An attacker can provide large amounts of flow-control credit at the HTTP/2 layer but withhold credit at the TCP layer, preventing frames from being sent. An endpoint that constructs and remembers frames for sending without considering TCP limits might be subject to resource exhaustion.
- Large numbers of small or empty frames can be abused to cause a peer to expend time processing frame headers. Caution is required here as some uses of small frames are entirely legitimate, such as the sending of an empty **DATA** or **CONTINUATION** frame at the end of a stream.
- The **SETTINGS** frame might also be abused to cause a peer to expend additional processing time. This might be done by pointlessly changing settings, sending multiple undefined settings, or changing the same setting multiple times in the same frame.
- Handling reprioritization with **PRIORITY** frames can require significant processing time and can lead to overload if many **PRIORITY** frames are sent.
- Field section compression also provides opportunities for an attacker to waste processing resources; see [Section 7](#) of [[COMPRESSION](#)] for more details on potential abuses.
- Limits in **SETTINGS** cannot be reduced instantaneously, which leaves an endpoint exposed to behavior from a peer that could exceed the new limits. In particular, immediately after establishing a connection, limits set by a server are not known to clients and could be exceeded without being an obvious protocol violation.

Most of the features that might be exploited for denial of service -- such as **SETTINGS** changes, small frames, field section compression -- have legitimate uses. These features become a burden only when they are used unnecessarily or to excess.

An endpoint that doesn't monitor use of these features exposes itself to a risk of denial of service. Implementations SHOULD track the use of these features and set limits on their use. An endpoint MAY treat activity that is suspicious as a connection error (Section 5.4.1) of type `ENHANCE_YOUR_CALM`.

10.5.1. Limits on Field Block Size

A large field block (Section 4.3) can cause an implementation to commit a large amount of state. Field lines that are critical for routing can appear toward the end of a field block, which prevents streaming of fields to their ultimate destination. This ordering and other reasons, such as ensuring cache correctness, mean that an endpoint might need to buffer the entire field block. Since there is no hard limit to the size of a field block, some endpoints could be forced to commit a large amount of available memory for field blocks.

An endpoint can use the `SETTINGS_MAX_HEADER_LIST_SIZE` to advise peers of limits that might apply on the size of uncompressed field blocks. This setting is only advisory, so endpoints MAY choose to send field blocks that exceed this limit and risk the request or response being treated as malformed. This setting is specific to a connection, so any request or response could encounter a hop with a lower, unknown limit. An intermediary can attempt to avoid this problem by passing on values presented by different peers, but they are not obliged to do so.

A server that receives a larger field block than it is willing to handle can send an HTTP 431 (Request Header Fields Too Large) status code [RFC6585]. A client can discard responses that it cannot process. The field block MUST be processed to ensure a consistent connection state, unless the connection is closed.

10.5.2. CONNECT Issues

The `CONNECT` method can be used to create disproportionate load on a proxy, since stream creation is relatively inexpensive when compared to the creation and maintenance of a TCP connection. A proxy might also maintain some resources for a TCP connection beyond the closing of the stream that carries the `CONNECT` request, since the outgoing TCP connection remains in the `TIME_WAIT` state. Therefore, a proxy cannot rely on `SETTINGS_MAX_CONCURRENT_STREAMS` alone to limit the resources consumed by `CONNECT` requests.

10.6. Use of Compression

Compression can allow an attacker to recover secret data when it is compressed in the same context as data under attacker control. HTTP/2 enables compression of field lines (Section 4.3); the following concerns also apply to the use of HTTP compressed content-codings (Section 8.4.1 of [HTTP]).

There are demonstrable attacks on compression that exploit the characteristics of the Web (e.g., [BREACH]). The attacker induces multiple requests containing varying plaintext, observing the length of the resulting ciphertext in each, which reveals a shorter length when a guess about the secret is correct.

Implementations communicating on a secure channel MUST NOT compress content that includes both confidential and attacker-controlled data unless separate compression dictionaries are used for each source of data. Compression MUST NOT be used if the source of data cannot be reliably determined. Generic stream compression, such as that provided by TLS, MUST NOT be used with HTTP/2 (see Section 9.2).

Further considerations regarding the compression of header fields are described in [COMPRESSION].

10.7. Use of Padding

Padding within HTTP/2 is not intended as a replacement for general purpose padding, such as that provided by TLS [TLS13]. Redundant padding could even be counterproductive. Correct application can depend on having specific knowledge of the data that is being padded.

To mitigate attacks that rely on compression, disabling or limiting compression might be preferable to padding as a countermeasure.

Padding can be used to obscure the exact size of frame content and is provided to mitigate specific attacks within HTTP -- for example, attacks where compressed content includes both attacker-controlled plaintext and secret data (e.g., [\[BREACH\]](#)).

Use of padding can result in less protection than might seem immediately obvious. At best, padding only makes it more difficult for an attacker to infer length information by increasing the number of frames an attacker has to observe. Incorrectly implemented padding schemes can be easily defeated. In particular, randomized padding with a predictable distribution provides very little protection; similarly, padding frame payloads to a fixed size exposes information as frame payload sizes cross the fixed-sized boundary, which could be possible if an attacker can control plaintext.

Intermediaries SHOULD retain padding for [DATA](#) frames but MAY drop padding for [HEADERS](#) and [PUSH_PROMISE](#) frames. A valid reason for an intermediary to change the amount of padding of frames is to improve the protections that padding provides.

10.8. Privacy Considerations

Several characteristics of HTTP/2 provide an observer an opportunity to correlate actions of a single client or server over time. These include the values of settings, the manner in which flow-control windows are managed, the way priorities are allocated to streams, the timing of reactions to stimulus, and the handling of any features that are controlled by settings.

As far as these create observable differences in behavior, they could be used as a basis for fingerprinting a specific client, as defined in [Section 3.2](#) of [\[PRIVACY\]](#).

HTTP/2's preference for using a single TCP connection allows correlation of a user's activity on a site. Reusing connections for different origins allows tracking across those origins.

Because the [PING](#) and [SETTINGS](#) frames solicit immediate responses, they can be used by an endpoint to measure latency to their peer. This might have privacy implications in certain scenarios.

10.9. Remote Timing Attacks

Remote timing attacks extract secrets from servers by observing variations in the time that servers take when processing requests that use secrets. HTTP/2 enables concurrent request creation and processing, which can give attackers better control over when request processing commences. Multiple HTTP/2 requests can be included in the same IP packet or TLS record. HTTP/2 can therefore make remote timing attacks more efficient by eliminating variability in request delivery, leaving only request order and the delivery of responses as sources of timing variability.

Ensuring that processing time is not dependent on the value of a secret is the best defense against any form of timing attack.

11. IANA Considerations

This revision of HTTP/2 marks the `HTTP2-Settings` header field and the `h2c` upgrade token, both defined in [RFC7540], as obsolete.

[Section 11](#) of [RFC7540] registered the `h2` and `h2c` ALPN identifiers along with the `PR1` HTTP method. RFC 7540 also established a registry for frame types, settings, and error codes. These registrations and registries apply to HTTP/2, but are not redefined in this document.

IANA has updated references to RFC 7540 in the following registries to refer to this document: "TLS Application-Layer Protocol Negotiation (ALPN) Protocol IDs", "HTTP/2 Frame Type", "HTTP/2 Settings", "HTTP/2 Error Code", and "HTTP Method Registry". The registration of the `PR1` method has been updated to refer to [Section 3.4](#); all other section numbers have not changed.

IANA has changed the policy on those portions of the "HTTP/2 Frame Type" and "HTTP/2 Settings" registries that were reserved for Experimental Use in RFC 7540. These portions of the registries shall operate on the same policy as the remainder of each registry.

11.1. HTTP2-Settings Header Field Registration

This section marks the `HTTP2-Settings` header field registered by [Section 11.5](#) of [RFC7540] in the "Hypertext Transfer Protocol (HTTP) Field Name Registry" as obsolete. This capability has been removed: see [Section 3.1](#). The registration is updated to include the details as required by [Section 18.4](#) of [HTTP]:

Field Name: `HTTP2-Settings`

Name:

Status: `obsolete`

Reference: [Section 3.2.1](#) of [RFC7540]

Comments: `obsolete`; see [Section 11.1](#) of this document.

11.2. The `h2c` Upgrade Token

This section records the `h2c` upgrade token registered by [Section 11.8](#) of [RFC7540] in the "Hypertext Transfer Protocol (HTTP) Upgrade Token Registry" as obsolete. This capability has been removed: see [Section 3.1](#). The registration is updated as follows:

Value: `h2c`

Description: `(OBSOLETE) Hypertext Transfer Protocol version 2 (HTTP/2)`

Experimental: `None`

Version:

Tokens:

Reference: [Section 3.1](#) of this document

12. References

12.1. Normative References

- [CACHING] Fielding, R., Ed., Nottingham, M., Ed., and J. Reschke, Ed., "[HTTP Caching](#)", [STD 98](#), RFC 9111, [DOI 10.17487/RFC9111](#), June 2022, <<https://www.rfc-editor.org/info/rfc9111>>.
- [COMPRESSION] Peon, R. and H. Ruellan, "[HPACK: Header Compression for HTTP/2](#)", RFC 7541, [DOI 10.17487/RFC7541](#), May 2015, <<https://www.rfc-editor.org/info/rfc7541>>.
- [COOKIE] Barth, A., "[HTTP State Management Mechanism](#)", RFC 6265, [DOI 10.17487/RFC6265](#), April 2011, <<https://www.rfc-editor.org/info/rfc6265>>.
- [HTTP] Fielding, R., Ed., Nottingham, M., Ed., and J. Reschke, Ed., "[HTTP Semantics](#)", [STD 97](#), RFC 9110, [DOI 10.17487/RFC9110](#), June 2022, <<https://www.rfc-editor.org/info/rfc9110>>.
- [QUIC] Iyengar, J., Ed. and M. Thomson, Ed., "[QUIC: A UDP-Based Multiplexed and Secure Transport](#)", RFC 9000, [DOI 10.17487/RFC9000](#), May 2021, <<https://www.rfc-editor.org/info/rfc9000>>.
- [RFC2119] Bradner, S., "[Key words for use in RFCs to Indicate Requirement Levels](#)", [BCP 14](#), RFC 2119, [DOI 10.17487/RFC2119](#), March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC3986] Berners-Lee, T., Fielding, R., and L. Masinter, "[Uniform Resource Identifier \(URI\): Generic Syntax](#)", [STD 66](#), RFC 3986, [DOI 10.17487/RFC3986](#), January 2005, <<https://www.rfc-editor.org/info/rfc3986>>.
- [RFC8174] Leiba, B., "[Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words](#)", [BCP 14](#), RFC 8174, [DOI 10.17487/RFC8174](#), May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [RFC8422] Nir, Y., Josefsson, S., and M. Pegourie-Gonnard, "[Elliptic Curve Cryptography \(ECC\) Cipher Suites for Transport Layer Security \(TLS\) Versions 1.2 and Earlier](#)", RFC 8422, [DOI 10.17487/RFC8422](#), August 2018, <<https://www.rfc-editor.org/info/rfc8422>>.
- [RFC8470] Thomson, M., Nottingham, M., and W. Tareau, "[Using Early Data in HTTP](#)", RFC 8470, [DOI 10.17487/RFC8470](#), September 2018, <<https://www.rfc-editor.org/info/rfc8470>>.
- [TCP] Postel, J., "[Transmission Control Protocol](#)", [STD 7](#), RFC 793, [DOI 10.17487/RFC0793](#), September 1981, <<https://www.rfc-editor.org/info/rfc793>>.
- [TLS-ALPN] Friedl, S., Popov, A., Langley, A., and E. Stephan, "[Transport Layer Security \(TLS\) Application-Layer Protocol Negotiation Extension](#)", RFC 7301, [DOI 10.17487/RFC7301](#), July 2014, <<https://www.rfc-editor.org/info/rfc7301>>.
- [TLS-ECDHE] Rescorla, E., "[TLS Elliptic Curve Cipher Suites with SHA-256/384 and AES Galois Counter Mode \(GCM\)](#)", RFC 5289, [DOI 10.17487/RFC5289](#), August 2008, <<https://www.rfc-editor.org/info/rfc5289>>.
- [TLS-EXT] Eastlake 3rd, D., "[Transport Layer Security \(TLS\) Extensions: Extension Definitions](#)", RFC 6066, [DOI 10.17487/RFC6066](#), January 2011, <<https://www.rfc-editor.org/info/rfc6066>>.
- [TLS12] Dierks, T. and E. Rescorla, "[The Transport Layer Security \(TLS\) Protocol Version 1.2](#)", RFC 5246, [DOI 10.17487/RFC5246](#), August 2008, <<https://www.rfc-editor.org/info/rfc5246>>.
- [TLS13] Rescorla, E., "[The Transport Layer Security \(TLS\) Protocol Version 1.3](#)", RFC 8446, [DOI 10.17487/RFC8446](#), August 2018, <<https://www.rfc-editor.org/info/rfc8446>>.

[TLSBCP] Sheffer, Y., Holz, R., and P. Saint-Andre, "[Recommendations for Secure Use of Transport Layer Security \(TLS\) and Datagram Transport Layer Security \(DTLS\)](#)", [BCP 195](#), RFC 7525, [DOI 10.17487/RFC7525](#), May 2015, <<https://www.rfc-editor.org/info/rfc7525>>.

12.2. Informative References

- [ALT-SVC] Nottingham, M., McManus, P., and J. Reschke, "[HTTP Alternative Services](#)", RFC 7838, [DOI 10.17487/RFC7838](#), April 2016, <<https://www.rfc-editor.org/info/rfc7838>>.
- [BREACH] Gluck, Y., Harris, N., and A. Prado, "[BREACH: Reviving the CRIME Attack](#)", July 2013, <<https://breachattack.com/resources/BREACH%20-%20SSL,%20gone%20in%2030%20seconds.pdf>>.
- [DNS-TERMS] Hoffman, P., Sullivan, A., and K. Fujiwara, "[DNS Terminology](#)", [BCP 219](#), RFC 8499, [DOI 10.17487/RFC8499](#), January 2019, <<https://www.rfc-editor.org/info/rfc8499>>.
- [HTTP-PRIORITY] Oku, K. and L. Pardue, "[Extensible Prioritization Scheme for HTTP](#)", RFC 9218, [DOI 10.17487/RFC9218](#), June 2022, <<https://www.rfc-editor.org/info/rfc9218>>.
- [HTTP/1.1] Fielding, R., Ed., Nottingham, M., Ed., and J. Reschke, Ed., "[HTTP/1.1](#)", [STD 99](#), RFC 9112, [DOI 10.17487/RFC9112](#), June 2022, <<https://www.rfc-editor.org/info/rfc9112>>.
- [NFLX-2019-002] Netflix, "[HTTP/2 Denial of Service Advisory](#)", August 2019, <<https://github.com/Netflix/security-bulletins/blob/master/advisories/third-party/2019-002.md>>.
- [PRIVACY] Cooper, A., Tschofenig, H., Aboba, B., Peterson, J., Morris, J., Hansen, M., and R. Smith, "[Privacy Considerations for Internet Protocols](#)", RFC 6973, [DOI 10.17487/RFC6973](#), July 2013, <<https://www.rfc-editor.org/info/rfc6973>>.
- [RFC1122] Braden, R., Ed., "[Requirements for Internet Hosts - Communication Layers](#)", [STD 3](#), RFC 1122, [DOI 10.17487/RFC1122](#), October 1989, <<https://www.rfc-editor.org/info/rfc1122>>.
- [RFC3749] Hollenbeck, S., "[Transport Layer Security Protocol Compression Methods](#)", RFC 3749, [DOI 10.17487/RFC3749](#), May 2004, <<https://www.rfc-editor.org/info/rfc3749>>.
- [RFC6125] Saint-Andre, P. and J. Hodges, "[Representation and Verification of Domain-Based Application Service Identity within Internet Public Key Infrastructure Using X.509 \(PKIX\) Certificates in the Context of Transport Layer Security \(TLS\)](#)", RFC 6125, [DOI 10.17487/RFC6125](#), March 2011, <<https://www.rfc-editor.org/info/rfc6125>>.
- [RFC6585] Nottingham, M. and R. Fielding, "[Additional HTTP Status Codes](#)", RFC 6585, [DOI 10.17487/RFC6585](#), April 2012, <<https://www.rfc-editor.org/info/rfc6585>>.
- [RFC7323] Borman, D., Braden, B., Jacobson, V., and R. Scheffenegger, Ed., "[TCP Extensions for High Performance](#)", RFC 7323, [DOI 10.17487/RFC7323](#), September 2014, <<https://www.rfc-editor.org/info/rfc7323>>.
- [RFC7540] Belshe, M., Peon, R., and M. Thomson, Ed., "[Hypertext Transfer Protocol Version 2 \(HTTP/2\)](#)", RFC 7540, [DOI 10.17487/RFC7540](#), May 2015, <<https://www.rfc-editor.org/info/rfc7540>>.
- [RFC8441] McManus, P., "[Bootstrapping WebSockets with HTTP/2](#)", RFC 8441, [DOI 10.17487/RFC8441](#), September 2018, <<https://www.rfc-editor.org/info/rfc8441>>.
- [RFC8740] Benjamin, D., "[Using TLS 1.3 with HTTP/2](#)", RFC 8740, [DOI 10.17487/RFC8740](#), February 2020, <<https://www.rfc-editor.org/info/rfc8740>>.
- [TALKING] Huang, L., Chen, E., Barth, A., Rescorla, E., and C. Jackson, "[Talking to Yourself for Fun and Profit](#)", 2011, <<https://www.adambarth.com/papers/2011/huang-chen-barth-rescorla-jackson.pdf>>.

Appendix A. Prohibited TLS 1.2 Cipher Suites

An HTTP/2 implementation MAY treat the negotiation of any of the following cipher suites with TLS 1.2 as a connection error (Section 5.4.1) of type `INADEQUATE_SECURITY`:

- `TLS_NULL_WITH_NULL_NULL`
- `TLS_RSA_WITH_NULL_MD5`
- `TLS_RSA_WITH_NULL_SHA`
- `TLS_RSA_EXPORT_WITH_RC4_40_MD5`
- `TLS_RSA_WITH_RC4_128_MD5`
- `TLS_RSA_WITH_RC4_128_SHA`
- `TLS_RSA_EXPORT_WITH_RC2_CBC_40_MD5`
- `TLS_RSA_WITH_IDEA_CBC_SHA`
- `TLS_RSA_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_RSA_WITH_DES_CBC_SHA`
- `TLS_RSA_WITH_3DES_EDE_CBC_SHA`
- `TLS_DH_DSS_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_DH_DSS_WITH_DES_CBC_SHA`
- `TLS_DH_DSS_WITH_3DES_EDE_CBC_SHA`
- `TLS_DH_RSA_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_DH_RSA_WITH_DES_CBC_SHA`
- `TLS_DH_RSA_WITH_3DES_EDE_CBC_SHA`
- `TLS_DHE_DSS_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_DHE_DSS_WITH_DES_CBC_SHA`
- `TLS_DHE_DSS_WITH_3DES_EDE_CBC_SHA`
- `TLS_DHE_RSA_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_DHE_RSA_WITH_DES_CBC_SHA`
- `TLS_DHE_RSA_WITH_3DES_EDE_CBC_SHA`
- `TLS_DH_anon_EXPORT_WITH_RC4_40_MD5`
- `TLS_DH_anon_WITH_RC4_128_MD5`
- `TLS_DH_anon_EXPORT_WITH_DES40_CBC_SHA`
- `TLS_DH_anon_WITH_DES_CBC_SHA`
- `TLS_DH_anon_WITH_3DES_EDE_CBC_SHA`
- `TLS_KRB5_WITH_DES_CBC_SHA`
- `TLS_KRB5_WITH_3DES_EDE_CBC_SHA`
- `TLS_KRB5_WITH_RC4_128_SHA`
- `TLS_KRB5_WITH_IDEA_CBC_SHA`
- `TLS_KRB5_WITH_DES_CBC_MD5`
- `TLS_KRB5_WITH_3DES_EDE_CBC_MD5`
- `TLS_KRB5_WITH_RC4_128_MD5`
- `TLS_KRB5_WITH_IDEA_CBC_MD5`
- `TLS_KRB5_EXPORT_WITH_DES_CBC_40_SHA`
- `TLS_KRB5_EXPORT_WITH_RC2_CBC_40_SHA`
- `TLS_KRB5_EXPORT_WITH_RC4_40_SHA`
- `TLS_KRB5_EXPORT_WITH_DES_CBC_40_MD5`
- `TLS_KRB5_EXPORT_WITH_RC2_CBC_40_MD5`

- TLS_KRB5_EXPORT_WITH_RC4_40_MD5
- TLS_PSK_WITH_NULL_SHA
- TLS_DHE_PSK_WITH_NULL_SHA
- TLS_RSA_PSK_WITH_NULL_SHA
- TLS_RSA_WITH_AES_128_CBC_SHA
- TLS_DH_DSS_WITH_AES_128_CBC_SHA
- TLS_DH_RSA_WITH_AES_128_CBC_SHA
- TLS_DHE_DSS_WITH_AES_128_CBC_SHA
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA
- TLS_DH_anon_WITH_AES_128_CBC_SHA
- TLS_RSA_WITH_AES_256_CBC_SHA
- TLS_DH_DSS_WITH_AES_256_CBC_SHA
- TLS_DH_RSA_WITH_AES_256_CBC_SHA
- TLS_DHE_DSS_WITH_AES_256_CBC_SHA
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA
- TLS_DH_anon_WITH_AES_256_CBC_SHA
- TLS_RSA_WITH_NULL_SHA256
- TLS_RSA_WITH_AES_128_CBC_SHA256
- TLS_RSA_WITH_AES_256_CBC_SHA256
- TLS_DH_DSS_WITH_AES_128_CBC_SHA256
- TLS_DH_RSA_WITH_AES_128_CBC_SHA256
- TLS_DHE_DSS_WITH_AES_128_CBC_SHA256
- TLS_RSA_WITH_CAMELLIA_128_CBC_SHA
- TLS_DH_DSS_WITH_CAMELLIA_128_CBC_SHA
- TLS_DH_RSA_WITH_CAMELLIA_128_CBC_SHA
- TLS_DHE_DSS_WITH_CAMELLIA_128_CBC_SHA
- TLS_DHE_RSA_WITH_CAMELLIA_128_CBC_SHA
- TLS_DH_anon_WITH_CAMELLIA_128_CBC_SHA
- TLS_DHE_RSA_WITH_AES_128_CBC_SHA256
- TLS_DH_DSS_WITH_AES_256_CBC_SHA256
- TLS_DH_RSA_WITH_AES_256_CBC_SHA256
- TLS_DHE_DSS_WITH_AES_256_CBC_SHA256
- TLS_DHE_RSA_WITH_AES_256_CBC_SHA256
- TLS_DH_anon_WITH_AES_128_CBC_SHA256
- TLS_DH_anon_WITH_AES_256_CBC_SHA256
- TLS_RSA_WITH_CAMELLIA_256_CBC_SHA
- TLS_DH_DSS_WITH_CAMELLIA_256_CBC_SHA
- TLS_DH_RSA_WITH_CAMELLIA_256_CBC_SHA
- TLS_DHE_DSS_WITH_CAMELLIA_256_CBC_SHA
- TLS_DHE_RSA_WITH_CAMELLIA_256_CBC_SHA
- TLS_DH_anon_WITH_CAMELLIA_256_CBC_SHA
- TLS_PSK_WITH_RC4_128_SHA
- TLS_PSK_WITH_3DES_EDE_CBC_SHA
- TLS_PSK_WITH_AES_128_CBC_SHA

- TLS_PSK_WITH_AES_256_CBC_SHA
- TLS_DHE_PSK_WITH_RC4_128_SHA
- TLS_DHE_PSK_WITH_3DES_EDE_CBC_SHA
- TLS_DHE_PSK_WITH_AES_128_CBC_SHA
- TLS_DHE_PSK_WITH_AES_256_CBC_SHA
- TLS_RSA_PSK_WITH_RC4_128_SHA
- TLS_RSA_PSK_WITH_3DES_EDE_CBC_SHA
- TLS_RSA_PSK_WITH_AES_128_CBC_SHA
- TLS_RSA_PSK_WITH_AES_256_CBC_SHA
- TLS_RSA_WITH_SEED_CBC_SHA
- TLS_DH_DSS_WITH_SEED_CBC_SHA
- TLS_DH_RSA_WITH_SEED_CBC_SHA
- TLS_DHE_DSS_WITH_SEED_CBC_SHA
- TLS_DHE_RSA_WITH_SEED_CBC_SHA
- TLS_DH_anon_WITH_SEED_CBC_SHA
- TLS_RSA_WITH_AES_128_GCM_SHA256
- TLS_RSA_WITH_AES_256_GCM_SHA384
- TLS_DH_RSA_WITH_AES_128_GCM_SHA256
- TLS_DH_RSA_WITH_AES_256_GCM_SHA384
- TLS_DH_DSS_WITH_AES_128_GCM_SHA256
- TLS_DH_DSS_WITH_AES_256_GCM_SHA384
- TLS_DH_anon_WITH_AES_128_GCM_SHA256
- TLS_DH_anon_WITH_AES_256_GCM_SHA384
- TLS_PSK_WITH_AES_128_GCM_SHA256
- TLS_PSK_WITH_AES_256_GCM_SHA384
- TLS_RSA_PSK_WITH_AES_128_GCM_SHA256
- TLS_RSA_PSK_WITH_AES_256_GCM_SHA384
- TLS_PSK_WITH_AES_128_CBC_SHA256
- TLS_PSK_WITH_AES_256_CBC_SHA384
- TLS_PSK_WITH_NULL_SHA256
- TLS_PSK_WITH_NULL_SHA384
- TLS_DHE_PSK_WITH_AES_128_CBC_SHA256
- TLS_DHE_PSK_WITH_AES_256_CBC_SHA384
- TLS_DHE_PSK_WITH_NULL_SHA256
- TLS_DHE_PSK_WITH_NULL_SHA384
- TLS_RSA_PSK_WITH_AES_128_CBC_SHA256
- TLS_RSA_PSK_WITH_AES_256_CBC_SHA384
- TLS_RSA_PSK_WITH_NULL_SHA256
- TLS_RSA_PSK_WITH_NULL_SHA384
- TLS_RSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_DH_DSS_WITH_CAMELLIA_128_CBC_SHA256
- TLS_DH_RSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_DHE_DSS_WITH_CAMELLIA_128_CBC_SHA256
- TLS_DHE_RSA_WITH_CAMELLIA_128_CBC_SHA256

- TLS_DH_anon_WITH_CAMELLIA_128_CBC_SHA256
- TLS_RSA_WITH_CAMELLIA_256_CBC_SHA256
- TLS_DH_DSS_WITH_CAMELLIA_256_CBC_SHA256
- TLS_DH_RSA_WITH_CAMELLIA_256_CBC_SHA256
- TLS_DHE_DSS_WITH_CAMELLIA_256_CBC_SHA256
- TLS_DHE_RSA_WITH_CAMELLIA_256_CBC_SHA256
- TLS_DH_anon_WITH_CAMELLIA_256_CBC_SHA256
- TLS_EMPTY_RENEGOTIATION_INFO_SCSV
- TLS_ECDH_ECDSA_WITH_NULL_SHA
- TLS_ECDH_ECDSA_WITH_RC4_128_SHA
- TLS_ECDH_ECDSA_WITH_3DES_EDE_CBC_SHA
- TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA
- TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA
- TLS_ECDHE_ECDSA_WITH_NULL_SHA
- TLS_ECDHE_ECDSA_WITH_RC4_128_SHA
- TLS_ECDHE_ECDSA_WITH_3DES_EDE_CBC_SHA
- TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA
- TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA
- TLS_ECDH_RSA_WITH_NULL_SHA
- TLS_ECDH_RSA_WITH_RC4_128_SHA
- TLS_ECDH_RSA_WITH_3DES_EDE_CBC_SHA
- TLS_ECDH_RSA_WITH_AES_128_CBC_SHA
- TLS_ECDH_RSA_WITH_AES_256_CBC_SHA
- TLS_ECDHE_RSA_WITH_NULL_SHA
- TLS_ECDHE_RSA_WITH_RC4_128_SHA
- TLS_ECDHE_RSA_WITH_3DES_EDE_CBC_SHA
- TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA
- TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA
- TLS_ECDH_anon_WITH_NULL_SHA
- TLS_ECDH_anon_WITH_RC4_128_SHA
- TLS_ECDH_anon_WITH_3DES_EDE_CBC_SHA
- TLS_ECDH_anon_WITH_AES_128_CBC_SHA
- TLS_ECDH_anon_WITH_AES_256_CBC_SHA
- TLS_SRP_SHA_WITH_3DES_EDE_CBC_SHA
- TLS_SRP_SHA_RSA_WITH_3DES_EDE_CBC_SHA
- TLS_SRP_SHA_DSS_WITH_3DES_EDE_CBC_SHA
- TLS_SRP_SHA_WITH_AES_128_CBC_SHA
- TLS_SRP_SHA_RSA_WITH_AES_128_CBC_SHA
- TLS_SRP_SHA_DSS_WITH_AES_128_CBC_SHA
- TLS_SRP_SHA_WITH_AES_256_CBC_SHA
- TLS_SRP_SHA_RSA_WITH_AES_256_CBC_SHA
- TLS_SRP_SHA_DSS_WITH_AES_256_CBC_SHA
- TLS_ECDHE_ECDSA_WITH_AES_128_CBC_SHA256
- TLS_ECDHE_ECDSA_WITH_AES_256_CBC_SHA384

- TLS_ECDH_ECDSA_WITH_AES_128_CBC_SHA256
- TLS_ECDH_ECDSA_WITH_AES_256_CBC_SHA384
- TLS_ECDHE_RSA_WITH_AES_128_CBC_SHA256
- TLS_ECDHE_RSA_WITH_AES_256_CBC_SHA384
- TLS_ECDH_RSA_WITH_AES_128_CBC_SHA256
- TLS_ECDH_RSA_WITH_AES_256_CBC_SHA384
- TLS_ECDH_ECDSA_WITH_AES_128_GCM_SHA256
- TLS_ECDH_ECDSA_WITH_AES_256_GCM_SHA384
- TLS_ECDH_RSA_WITH_AES_128_GCM_SHA256
- TLS_ECDH_RSA_WITH_AES_256_GCM_SHA384
- TLS_ECDHE_PSK_WITH_RC4_128_SHA
- TLS_ECDHE_PSK_WITH_3DES_EDE_CBC_SHA
- TLS_ECDHE_PSK_WITH_AES_128_CBC_SHA
- TLS_ECDHE_PSK_WITH_AES_256_CBC_SHA
- TLS_ECDHE_PSK_WITH_AES_128_CBC_SHA256
- TLS_ECDHE_PSK_WITH_AES_256_CBC_SHA384
- TLS_ECDHE_PSK_WITH_NULL_SHA
- TLS_ECDHE_PSK_WITH_NULL_SHA256
- TLS_ECDHE_PSK_WITH_NULL_SHA384
- TLS_RSA_WITH_ARIA_128_CBC_SHA256
- TLS_RSA_WITH_ARIA_256_CBC_SHA384
- TLS_DH_DSS_WITH_ARIA_128_CBC_SHA256
- TLS_DH_DSS_WITH_ARIA_256_CBC_SHA384
- TLS_DH_RSA_WITH_ARIA_128_CBC_SHA256
- TLS_DH_RSA_WITH_ARIA_256_CBC_SHA384
- TLS_DHE_DSS_WITH_ARIA_128_CBC_SHA256
- TLS_DHE_DSS_WITH_ARIA_256_CBC_SHA384
- TLS_DHE_RSA_WITH_ARIA_128_CBC_SHA256
- TLS_DHE_RSA_WITH_ARIA_256_CBC_SHA384
- TLS_DH_anon_WITH_ARIA_128_CBC_SHA256
- TLS_DH_anon_WITH_ARIA_256_CBC_SHA384
- TLS_ECDHE_ECDSA_WITH_ARIA_128_CBC_SHA256
- TLS_ECDHE_ECDSA_WITH_ARIA_256_CBC_SHA384
- TLS_ECDH_ECDSA_WITH_ARIA_128_CBC_SHA256
- TLS_ECDH_ECDSA_WITH_ARIA_256_CBC_SHA384
- TLS_ECDHE_RSA_WITH_ARIA_128_CBC_SHA256
- TLS_ECDHE_RSA_WITH_ARIA_256_CBC_SHA384
- TLS_ECDH_RSA_WITH_ARIA_128_CBC_SHA256
- TLS_ECDH_RSA_WITH_ARIA_256_CBC_SHA384
- TLS_RSA_WITH_ARIA_128_GCM_SHA256
- TLS_RSA_WITH_ARIA_256_GCM_SHA384
- TLS_DH_RSA_WITH_ARIA_128_GCM_SHA256
- TLS_DH_RSA_WITH_ARIA_256_GCM_SHA384
- TLS_DH_DSS_WITH_ARIA_128_GCM_SHA256

- TLS_DH_DSS_WITH_ARIA_256_GCM_SHA384
- TLS_DH_anon_WITH_ARIA_128_GCM_SHA256
- TLS_DH_anon_WITH_ARIA_256_GCM_SHA384
- TLS_ECDH_ECDSA_WITH_ARIA_128_GCM_SHA256
- TLS_ECDH_ECDSA_WITH_ARIA_256_GCM_SHA384
- TLS_ECDH_RSA_WITH_ARIA_128_GCM_SHA256
- TLS_ECDH_RSA_WITH_ARIA_256_GCM_SHA384
- TLS_PSK_WITH_ARIA_128_CBC_SHA256
- TLS_PSK_WITH_ARIA_256_CBC_SHA384
- TLS_DHE_PSK_WITH_ARIA_128_CBC_SHA256
- TLS_DHE_PSK_WITH_ARIA_256_CBC_SHA384
- TLS_RSA_PSK_WITH_ARIA_128_CBC_SHA256
- TLS_RSA_PSK_WITH_ARIA_256_CBC_SHA384
- TLS_PSK_WITH_ARIA_128_GCM_SHA256
- TLS_PSK_WITH_ARIA_256_GCM_SHA384
- TLS_RSA_PSK_WITH_ARIA_128_GCM_SHA256
- TLS_RSA_PSK_WITH_ARIA_256_GCM_SHA384
- TLS_ECDHE_PSK_WITH_ARIA_128_CBC_SHA256
- TLS_ECDHE_PSK_WITH_ARIA_256_CBC_SHA384
- TLS_ECDHE_ECDSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_ECDHE_ECDSA_WITH_CAMELLIA_256_CBC_SHA384
- TLS_ECDH_ECDSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_ECDH_ECDSA_WITH_CAMELLIA_256_CBC_SHA384
- TLS_ECDHE_RSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_ECDHE_RSA_WITH_CAMELLIA_256_CBC_SHA384
- TLS_ECDH_RSA_WITH_CAMELLIA_128_CBC_SHA256
- TLS_ECDH_RSA_WITH_CAMELLIA_256_CBC_SHA384
- TLS_RSA_WITH_CAMELLIA_128_GCM_SHA256
- TLS_RSA_WITH_CAMELLIA_256_GCM_SHA384
- TLS_DH_RSA_WITH_CAMELLIA_128_GCM_SHA256
- TLS_DH_RSA_WITH_CAMELLIA_256_GCM_SHA384
- TLS_DH_DSS_WITH_CAMELLIA_128_GCM_SHA256
- TLS_DH_DSS_WITH_CAMELLIA_256_GCM_SHA384
- TLS_DH_anon_WITH_CAMELLIA_128_GCM_SHA256
- TLS_DH_anon_WITH_CAMELLIA_256_GCM_SHA384
- TLS_ECDH_ECDSA_WITH_CAMELLIA_128_GCM_SHA256
- TLS_ECDH_ECDSA_WITH_CAMELLIA_256_GCM_SHA384
- TLS_ECDH_RSA_WITH_CAMELLIA_128_GCM_SHA256
- TLS_ECDH_RSA_WITH_CAMELLIA_256_GCM_SHA384
- TLS_PSK_WITH_CAMELLIA_128_GCM_SHA256
- TLS_PSK_WITH_CAMELLIA_256_GCM_SHA384
- TLS_RSA_PSK_WITH_CAMELLIA_128_GCM_SHA256
- TLS_RSA_PSK_WITH_CAMELLIA_256_GCM_SHA384
- TLS_PSK_WITH_CAMELLIA_128_CBC_SHA256

- TLS_PSK_WITH_CAMELLIA_256_CBC_SHA384
- TLS_DHE_PSK_WITH_CAMELLIA_128_CBC_SHA256
- TLS_DHE_PSK_WITH_CAMELLIA_256_CBC_SHA384
- TLS_RSA_PSK_WITH_CAMELLIA_128_CBC_SHA256
- TLS_RSA_PSK_WITH_CAMELLIA_256_CBC_SHA384
- TLS_ECDHE_PSK_WITH_CAMELLIA_128_CBC_SHA256
- TLS_ECDHE_PSK_WITH_CAMELLIA_256_CBC_SHA384
- TLS_RSA_WITH_AES_128_CCM
- TLS_RSA_WITH_AES_256_CCM
- TLS_RSA_WITH_AES_128_CCM_8
- TLS_RSA_WITH_AES_256_CCM_8
- TLS_PSK_WITH_AES_128_CCM
- TLS_PSK_WITH_AES_256_CCM
- TLS_PSK_WITH_AES_128_CCM_8
- TLS_PSK_WITH_AES_256_CCM_8

Note: This list was assembled from the set of registered TLS cipher suites when [\[RFC7540\]](#) was developed. This list includes those cipher suites that do not offer an ephemeral key exchange and those that are based on the TLS null, stream, or block cipher type (as defined in [Section 6.2.3](#) of [\[TLS12\]](#)). Additional cipher suites with these properties could be defined; these would not be explicitly prohibited.

For more details, see [Section 9.2.2](#).

Appendix B. Changes from RFC 7540

This revision includes the following substantive changes:

- Use of TLS 1.3 was defined based on [\[RFC8740\]](#), which this document obsoletes.
- The priority scheme defined in RFC 7540 is deprecated. Definitions for the format of the **PRIORITY** frame and the priority fields in the **HEADERS** frame have been retained, plus the rules governing when **PRIORITY** frames can be sent and received, but the semantics of these fields are only described in RFC 7540. The priority signaling scheme from RFC 7540 was not successful. Using the simpler signaling in [\[HTTP-PRIORITY\]](#) is recommended.
- The HTTP/1.1 Upgrade mechanism is deprecated and no longer specified in this document. It was never widely deployed, with plaintext HTTP/2 users choosing to use the prior-knowledge implementation instead.
- Validation for field names and values has been narrowed. The validation that is mandatory for intermediaries is precisely defined, and error reporting for requests has been amended to encourage sending 400-series status codes.
- The ranges of codepoints for settings and frame types that were reserved for Experimental Use are now available for general use.
- Connection-specific header fields -- which are prohibited -- are more precisely and comprehensively identified.
- Host and ":authority" are no longer permitted to disagree.
- Rules for sending Dynamic Table Size Update instructions after changes in settings have been clarified in [Section 4.3.1](#).

Editorial changes are also included. In particular, changes to terminology and document structure are in response to updates to [core HTTP semantics](#) [HTTP]. Those documents now include some concepts that were first defined in RFC 7540, such as the 421 status code or connection coalescing.

Acknowledgments

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