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Hypertext Transfer Protocol Version 2 (HTTP/2)

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 perception of latency by introducing header field compression and allowing multiple concurrent exchanges on the same connection. It also introduces unsolicited push of representations from servers to clients.

This specification is an alternative to, but does not obsolete, the HTTP/1.1 message syntax. HTTP's existing semantics remain unchanged.

Discussion Venues

Discussion of this document takes place on the HTTPBIS Working Group mailing list (ietf-http-wg@w3.org), which is archived at <https://lists.w3.org/Archives/Public/ietf-http-wg/>.

This note is to be removed before publishing as an RFC.

Source for this draft and an issue tracker can be found at <https://github.com/httpwg/http2-spec>.

Status of This Memo

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1. Introduction

The Hypertext Transfer Protocol (HTTP) is a wildly successful protocol. However, the way HTTP/1.1 uses the underlying transport ([\[HTTP11\]](#)) has several characteristics that have a negative overall effect on application performance today.

In particular, HTTP/1.0 allowed only one request to be outstanding at a time on a given TCP connection. HTTP/1.1 added request pipelining, but this only partially addressed request concurrency and still suffers from head-of-line blocking. Therefore, HTTP/1.0 and HTTP/1.1 clients that need to make many requests use multiple connections to a server in order to achieve concurrency and thereby reduce latency.

Furthermore, HTTP header fields are often repetitive and verbose, causing unnecessary network traffic as well as causing the initial TCP [\[TCP\]](#) 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 request and response messages on the same connection and uses an efficient coding for HTTP header 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.

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

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.

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.

Flow control and prioritization ensure that it is possible to efficiently use multiplexed streams. [Flow control](#) ([Section 5.2](#)) helps to ensure that only data that can be used by a receiver is transmitted. [Prioritization](#) ([Section 5.3](#)) ensures that limited resources can be directed to the most important streams first.

HTTP/2 adds a new interaction mode whereby a server can [push responses to a client](#) ([Section 8.2](#)). Server push allows 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.

Because HTTP header 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.

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 the HTTP protocol and server push.

2.2. Conventions and Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [[RFC2119](#)].

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.

The following terms are used:

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

connection: A transport-layer connection between two endpoints.

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

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.

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

An HTTP/2 connection is an application-layer protocol running on top of a TCP connection ([\[TCP\]](#)). The client is the TCP connection initiator.

HTTP/2 uses the "http" and "https" URI schemes defined in [Section 4.2](#) of [\[HTTP\]](#). HTTP/2 shares the same default port numbers: 80 for "http" URIs and 443 for "https" URIs. As a result, implementations processing requests for target resource URIs like `http://example.org/foo` or `https://example.com/bar` are required to first discover whether the upstream server (the immediate peer to which the client wishes to establish a connection) supports HTTP/2.

The means by which support for HTTP/2 is determined is different for "http" and "https" URIs. Discovery for "http" URIs is described in [Section 3.2](#). Discovery for "https" URIs is described in [Section 3.3](#).

3.1. HTTP/2 Version Identification

The protocol defined in this document has two identifiers.

*The string "h2" identifies the protocol where HTTP/2 uses [Transport Layer Security \(TLS\)](#) [\[TLS13\]](#). 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 string "h2c" identifies the protocol where HTTP/2 is run over cleartext TCP. This identifier is used in the HTTP/1.1 Upgrade

header field and in any place where HTTP/2 over TCP is identified.

The "h2c" string is reserved from the ALPN identifier space but describes a protocol that does not use TLS.

Negotiating "h2" or "h2c" implies the use of the transport, security, framing, and message semantics described in this document.

3.2. Starting HTTP/2 for "http" URIs

A client that makes a request for an "http" URI without prior knowledge about support for HTTP/2 on the next hop uses the HTTP Upgrade mechanism ([Section 7.8](#) of [\[HTTP\]](#)). The client does so by making an HTTP/1.1 request that includes an Upgrade header field with the "h2c" token. Such an HTTP/1.1 request MUST include exactly one [HTTP2-Settings](#) ([Section 3.2.1](#)) header field.

For example:

```
GET / HTTP/1.1
Host: server.example.com
Connection: Upgrade, HTTP2-Settings
Upgrade: h2c
HTTP2-Settings: <base64url encoding of SETTINGS frame payload>
```

Requests that contain message content MUST be sent in their entirety before the client can send HTTP/2 frames. This means that a large request can block the use of the connection until it is completely sent.

If concurrency of an initial request with subsequent requests is important, an OPTIONS request can be used to perform the upgrade to HTTP/2, at the cost of an additional round trip.

A server that does not support HTTP/2 can respond to the request as though the Upgrade header field were absent:

```
HTTP/1.1 200 OK
Content-Length: 243
Content-Type: text/html
```

...

A server MUST ignore an "h2" token in an Upgrade header field. Presence of a token with "h2" implies HTTP/2 over TLS, which is instead negotiated as described in [Section 3.3](#).

A server that supports HTTP/2 accepts the upgrade with a 101 (Switching Protocols) response. After the empty line that terminates the 101 response, the server can begin sending HTTP/2 frames. These frames MUST include a response to the request that initiated the upgrade.

For example:

HTTP/1.1 101 Switching Protocols

Connection: Upgrade

Upgrade: h2c

[HTTP/2 connection ...

The first HTTP/2 frame sent by the server MUST be a server connection preface ([Section 3.5](#)) consisting of a [SETTINGS](#) frame ([Section 6.5](#)). Upon receiving the 101 response, the client MUST send a [connection preface](#) ([Section 3.5](#)), which includes a [SETTINGS](#) frame.

The HTTP/1.1 request that is sent prior to upgrade is assigned a stream identifier of 1 (see [Section 5.1.1](#)) with [default priority values](#) ([Section 5.3.5](#)). Stream 1 is implicitly "half-closed" from the client toward the server (see [Section 5.1](#)), since the request is completed as an HTTP/1.1 request. After commencing the HTTP/2 connection, stream 1 is used for the response.

3.2.1. HTTP2-Settings Header Field

A request that upgrades from HTTP/1.1 to HTTP/2 MUST include exactly one HTTP2-Settings header field. The HTTP2-Settings header field is a connection-specific header field that includes parameters that govern the HTTP/2 connection, provided in anticipation of the server accepting the request to upgrade.

HTTP2-Settings = token68

A server MUST NOT upgrade the connection to HTTP/2 if this header field is not present or if more than one is present. A server MUST NOT send this header field.

The content of the HTTP2-Settings header field is the frame payload of a [SETTINGS](#) frame ([Section 6.5](#)), encoded as a base64url string (that is, the URL- and filename-safe Base64 encoding described in [Section 5](#) of [[RFC4648](#)], with any trailing '=' characters omitted). The [ABNF](#) [[RFC5234](#)] production for token68 is defined in [Section 11.2](#) of [[HTTP](#)].

Since the upgrade is only intended to apply to the immediate connection, a client sending the HTTP2-Settings header field MUST also send HTTP2-Settings as a connection option in the Connection

header field to prevent it from being forwarded (see [Section 7.6.1](#) of [\[HTTP\]](#)).

A server decodes and interprets these values as it would any other [SETTINGS](#) frame. Explicit [acknowledgement of these settings](#) ([Section 6.5.3](#)) is not necessary, since a 101 response serves as implicit acknowledgement. Providing these values in the upgrade request gives a client an opportunity to provide parameters prior to receiving any frames from the server.

3.3. Starting HTTP/2 for "https" URIs

A client that makes a request to an "https" URI uses [TLS](#) [\[TLS13\]](#) with the [application-layer protocol negotiation \(ALPN\) 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 3.5](#)).

3.4. Starting HTTP/2 with Prior Knowledge

A client can learn that a particular server supports HTTP/2 by other means. For example, [\[ALT-SVC\]](#) describes a mechanism for advertising this capability.

A client MUST send the [connection preface](#) ([Section 3.5](#)) and then MAY immediately send HTTP/2 frames to such a server; servers can identify these connections by the presence of the connection preface. This only affects the establishment of HTTP/2 connections over cleartext TCP; implementations that support HTTP/2 over TLS MUST use [protocol negotiation in TLS](#) [\[TLS-ALPN\]](#).

Likewise, the server MUST send a [connection preface](#) ([Section 3.5](#)).

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.

3.5. 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 immediately upon receipt of a 101 (Switching Protocols) response (indicating a successful upgrade) or as the first application data octets of a TLS connection. If starting an HTTP/2 connection with prior knowledge of server support for the protocol, the client connection preface is sent upon connection establishment.

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 parameters 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 parameters 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.

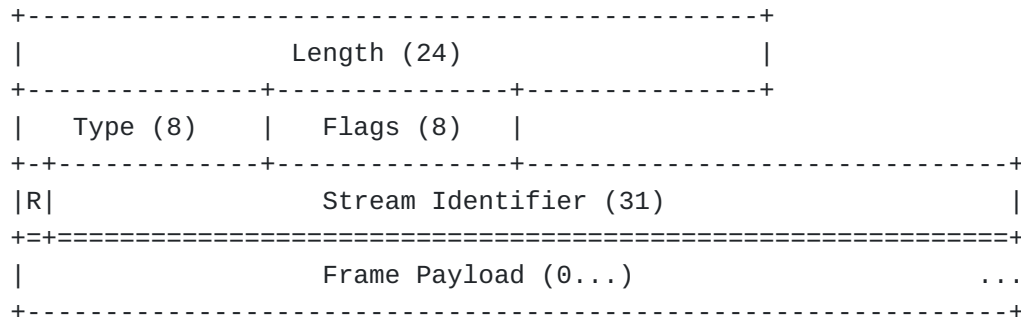


Figure 1: Frame Layout

The fields of the frame header are defined as:

Length: The length of the frame payload expressed as an unsigned 24-bit integer. 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. Implementations MUST ignore and discard any frame that has a type that is unknown.

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

Flags are assigned semantics specific to the indicated frame type. Flags that have no defined semantics for a particular frame type MUST be ignored and MUST be left unset (0x0) when sending.

R: A reserved 1-bit field. The semantics of this bit are undefined, and the bit MUST remain unset (0x0) when sending and MUST be ignored when receiving.

Stream Identifier: A stream identifier (see [Section 5.1.1](#)) expressed as an unsigned 31-bit integer. The value 0x0 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 is 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](#)), [SETTINGS](#), 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 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 is defined in [\[COMPRESSION\]](#), which, for historical reasons, refers to these processes as header compression and decompression.

Field blocks carry the compressed bytes of a field section, with header sections also carrying control data associated with the

message in the form of [pseudo-header fields](#) ([Section 8.1.2.1](#)) that use the same format as a field line.

Note: Previous versions of this specification 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 8.2](#)). 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 zero or more field lines. Each of the field lines in a field block carry a single value. The serialized field block is then divided into one or more octet sequences, called field block fragments, and 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.

The [Cookie header field](#) [[COOKIE](#)] is treated specially by the HTTP mapping (see [Section 8.1.2.5](#)).

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 cleared and one or more [CONTINUATION](#) frames, where the last [CONTINUATION](#) frame has the END_HEADERS flag set.

Field compression is stateful. One compression context and one decompression context are used for the entire connection. A decoding error in a field block MUST be treated as a [connection error](#) ([Section 5.4.1](#)) of type [COMPRESSION_ERROR](#).

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.

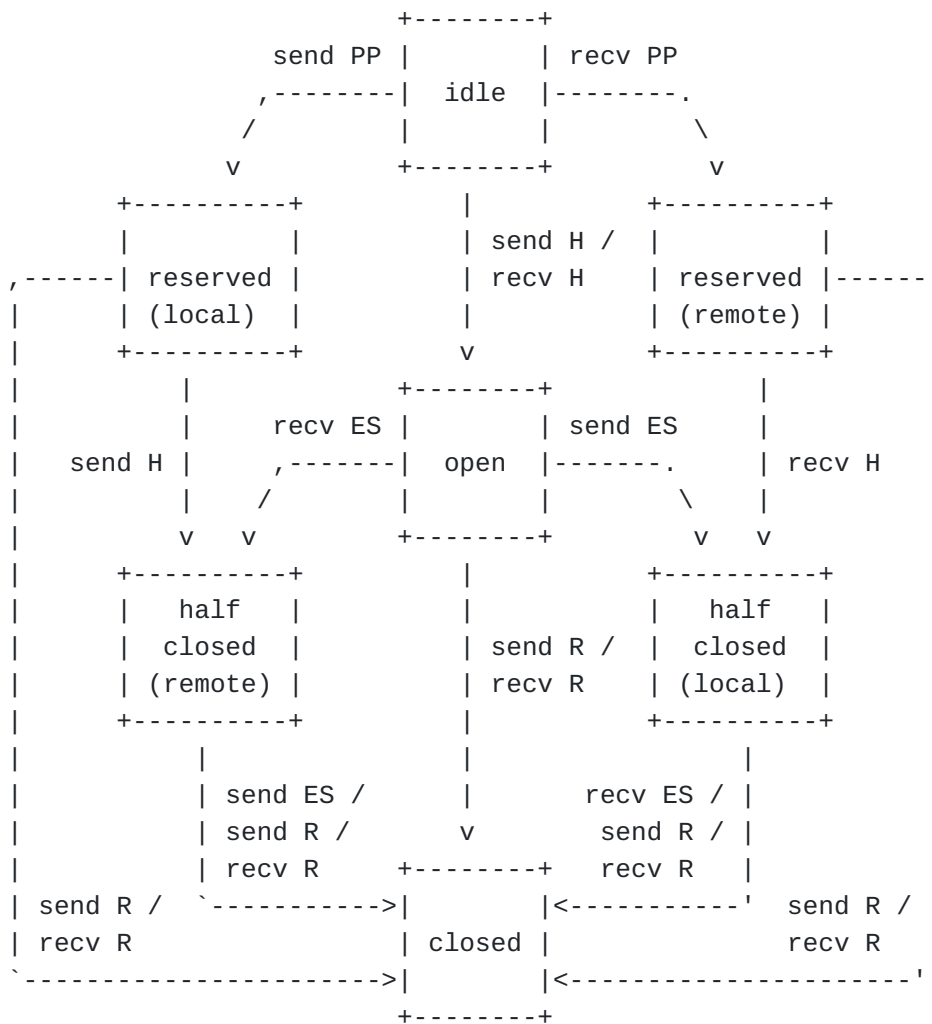
5. Streams and Multiplexing

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 the client or server.
- *Streams can be closed by either endpoint.
- *The order in which frames are sent on a stream 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](#).



send: endpoint sends this frame
recv: endpoint receives this frame

H: HEADERS frame (with implied CONTINUATIONS)

ES: END_STREAM flag

R: RST_STREAM frame

PP: PUSH_PROMISE frame (with implied CONTINUATIONS)

Note: State transitions are for the promised stream.

Figure 2: Stream States

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:

idle: All streams start in the "idle" state.

The following transitions are valid from this state:

- *Sending or receiving a [HEADERS](#) frame 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)".

- *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)".

- *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.

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](#).

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 8.2](#)).

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 MAY send a [PRIORITY](#) frame in this state to reprioritize the reserved stream. 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: A 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): A stream that is in the "half-closed (local)" state cannot be used for sending frames other than [WINDOW_UPDATE](#), [PRIORITY](#), and [RST_STREAM](#).

A stream transitions from this state to "closed" when a frame that contains an END_STREAM flag is received 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 bearing the END_STREAM flag is sent.

[PRIORITY](#) frames received in this state are used to reprioritize streams that depend on the identified stream.

half-closed (remote): A 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.

If an 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 that contains an END_STREAM flag or when either peer sends a [RST_STREAM](#) frame.

closed: The "closed" state is the terminal state.

An endpoint MUST NOT send frames other than [PRIORITY](#) on a closed stream. An endpoint that receives any frame other than [PRIORITY](#) after receiving a [RST_STREAM](#) MUST treat that as a [stream error](#) ([Section 5.4.2](#)) of type [STREAM_CLOSED](#). Similarly, an endpoint that receives any frames after receiving a frame with the END_STREAM flag set MUST treat that as a [connection error](#) ([Section 5.4.1](#)) of type [STREAM_CLOSED](#), unless the frame is permitted as described below.

[WINDOW_UPDATE](#) or [RST_STREAM](#) frames can be received in this state for a short period after a [DATA](#) or [HEADERS](#) frame containing an END_STREAM flag is sent. Until the remote peer receives and processes [RST_STREAM](#) or the frame bearing the END_STREAM flag, it might send frames of these types. Endpoints MUST ignore [WINDOW_UPDATE](#) or [RST_STREAM](#) frames received in this state, though endpoints MAY choose to treat frames that arrive a significant time after sending END_STREAM as a [connection error](#) ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

[PRIORITY](#) frames can be sent on closed streams to prioritize streams that are dependent on the closed stream. Endpoints SHOULD process [PRIORITY](#) frames, though they can be ignored if the stream has been removed from the dependency tree (see [Section 5.3.4](#)).

If this state is reached as a result of sending a [RST_STREAM](#) frame, the peer that receives the [RST_STREAM](#) might have already sent -- or enqueued for sending -- frames on the stream that cannot be withdrawn. An endpoint MUST ignore frames that it receives on closed streams after it has sent a [RST_STREAM](#) frame. An endpoint MAY choose to limit the period over which it ignores frames and treat frames that arrive after this time as being in error.

Flow-controlled frames (i.e., [DATA](#)) received after sending [RST_STREAM](#) are counted toward the connection flow-control window. Even though these frames might be ignored, because they are sent before the sender receives the [RST_STREAM](#), the sender will consider the frames to count against the flow-control window.

An endpoint might receive a [PUSH_PROMISE](#) frame after it sends [RST_STREAM](#). [PUSH_PROMISE](#) causes a stream to become "reserved" even if the associated stream has been reset. Therefore, a [RST_STREAM](#) is needed to close an unwanted promised stream.

In the absence of more specific guidance elsewhere in this document, 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. Frames of unknown types are ignored.

An example of the state transitions for an HTTP request/response exchange can be found in [Section 8.1](#). An example of the state transitions for server push can be found in [Sections 8.2.1](#) and [8.2.2](#).

5.1.1. Stream Identifiers

Streams are identified with 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 (0x0) is used for connection control messages; the stream identifier of zero cannot be used to establish a new stream.

HTTP/1.1 requests that are upgraded to HTTP/2 (see [Section 3.2](#)) are responded to with a stream identifier of one (0x1). After the upgrade completes, stream 0x1 is "half-closed (local)" to the

client. Therefore, stream 0x1 cannot be selected as a new stream identifier by a client that upgrades from HTTP/1.1.

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". When a stream transitions out of the "idle" state, all streams that might have been initiated by that peer with a lower-valued stream identifier are implicitly transitioned 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 8.1.4](#)) 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 for 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. Both types of flow control are 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. Flow control cannot be disabled.
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 managing how requests and responses are sent based on priority, 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. When using flow control, the receiver MUST read from the TCP receive buffer in a timely fashion. Failure to do so could lead to a deadlock when critical frames, such as [WINDOW_UPDATE](#), are not read and acted upon.

5.3. Stream Priority

A client can assign a priority for a new stream by including prioritization information in the [HEADERS frame](#) ([Section 6.2](#)) that

opens the stream. At any other time, the [PRIORITY frame](#) ([Section 6.3](#)) can be used to change the priority of a stream.

The purpose of prioritization is to allow an endpoint to express how it would prefer its peer to allocate resources when managing concurrent streams. Most importantly, priority can be used to select streams for transmitting frames when there is limited capacity for sending.

Streams can be prioritized by marking them as dependent on the completion of other streams ([Section 5.3.1](#)). Each dependency is assigned a relative weight, a number that is used to determine the relative proportion of available resources that are assigned to streams dependent on the same stream.

Explicitly setting the priority for a stream is input to a prioritization process. It does not guarantee any particular processing or transmission order for the stream relative to any other stream. An endpoint cannot force a peer to process concurrent streams in a particular order using priority. Expressing priority is therefore only a suggestion.

Prioritization information can be omitted from messages. Defaults are used prior to any explicit values being provided ([Section 5.3.5](#)).

The information that an endpoint maintains for stream priority is separate from other state. Importantly, this includes [stream states](#) ([Section 5.1](#)). A stream in any state can have its priority changed with a PRIORITY frame. The state of a stream is not changed as a result of changing its priority. The number of streams for which state is remembered is at the discretion of an endpoint, see [Section 5.3.4](#) for details.

5.3.1. Stream Dependencies

Each stream can be given an explicit dependency on another stream. Including a dependency expresses a preference to allocate resources to the identified stream rather than to the dependent stream.

A stream that is not dependent on any other stream is given a stream dependency of 0x0. In other words, the non-existent stream 0 forms the root of the tree.

A stream that depends on another stream is a dependent stream. The stream upon which a stream is dependent is a parent stream. A dependency on a stream that is not currently in the tree -- such as a stream in the "idle" state -- results in that stream being given a [default priority](#) ([Section 5.3.5](#)).

When assigning a dependency on another stream, the stream is added as a new dependency of the parent stream. Dependent streams that share the same parent are not ordered with respect to each other. For example, if streams B and C are dependent on stream A, and if stream D is created with a dependency on stream A, this results in a dependency order of A followed by B, C, and D in any order.



Figure 3: Example of Default Dependency Creation

An exclusive flag allows for the insertion of a new level of dependencies. The exclusive flag causes the stream to become the sole dependency of its parent stream, causing other dependencies to become dependent on the exclusive stream. In the previous example, if stream D is created with an exclusive dependency on stream A, this results in D becoming the dependency parent of B and C.



Figure 4: Example of Exclusive Dependency Creation

Inside the dependency tree, a dependent stream SHOULD only be allocated resources if either all of the streams that it depends on (the chain of parent streams up to 0x0) are closed or it is not possible to make progress on them.

A stream cannot depend on itself. An endpoint MUST treat this as a [stream error](#) ([Section 5.4.2](#)) of type [PROTOCOL_ERROR](#).

5.3.2. Dependency Weighting

All dependent streams are allocated an integer weight between 1 and 256 (inclusive).

Streams with the same parent SHOULD be allocated resources proportionally based on their weight. Thus, if stream B depends on stream A with weight 4, stream C depends on stream A with weight 12, and no progress can be made on stream A, stream B ideally receives one-third of the resources allocated to stream C.

5.3.3. Reprioritization

Stream priorities are changed using the [PRIORITY](#) frame. Setting a dependency causes a stream to become dependent on the identified parent stream.

Dependent streams move with their parent stream if the parent is reprioritized. Setting a dependency with the exclusive flag for a reprioritized stream causes all the dependencies of the new parent stream to become dependent on the reprioritized stream.

If a stream is made dependent on one of its own dependencies, the formerly dependent stream is first moved to be dependent on the reprioritized stream's previous parent. The moved dependency retains its weight.

For example, consider an original dependency tree where B and C depend on A, D and E depend on C, and F depends on D. If A is made dependent on D, then D takes the place of A. All other dependency relationships stay the same, except for F, which becomes dependent on A if the reprioritization is exclusive.

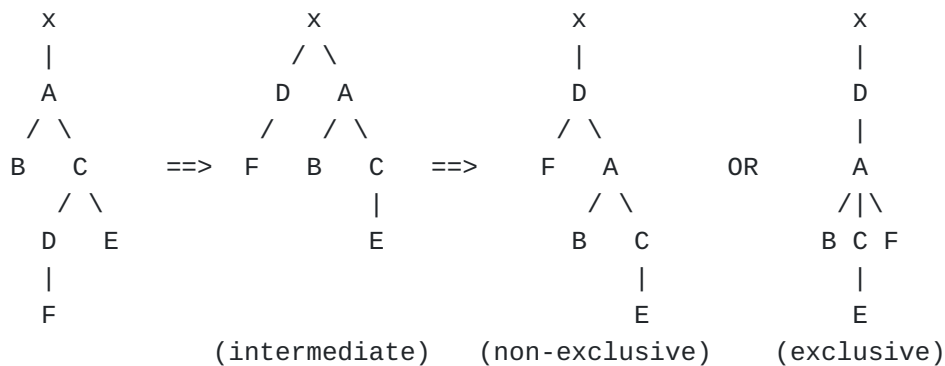


Figure 5: Example of Dependency Reordering

5.3.4. Prioritization State Management

When a stream is removed from the dependency tree, its dependencies can be moved to become dependent on the parent of the closed stream. The weights of new dependencies are recalculated by distributing the weight of the dependency of the closed stream proportionally based on the weights of its dependencies.

Streams that are removed from the dependency tree cause some prioritization information to be lost. Resources are shared between streams with the same parent stream, which means that if a stream in that set closes or becomes blocked, any spare capacity allocated to a stream is distributed to the immediate neighbors of the stream.

However, if the common dependency is removed from the tree, those streams share resources with streams at the next highest level.

For example, assume streams A and B share a parent, and streams C and D both depend on stream A. Prior to the removal of stream A, if streams A and D are unable to proceed, then stream C receives all the resources dedicated to stream A. If stream A is removed from the tree, the weight of stream A is divided between streams C and D. If stream D is still unable to proceed, this results in stream C receiving a reduced proportion of resources. For equal starting weights, C receives one third, rather than one half, of available resources.

It is possible for a stream to become closed while prioritization information that creates a dependency on that stream is in transit. If a stream identified in a dependency has no associated priority information, then the dependent stream is instead assigned a [default priority](#) ([Section 5.3.5](#)). This potentially creates suboptimal prioritization, since the stream could be given a priority that is different from what is intended.

To avoid these problems, an endpoint SHOULD retain stream prioritization state for a period after streams become closed. The longer state is retained, the lower the chance that streams are assigned incorrect or default priority values.

Similarly, streams that are in the "idle" state can be assigned priority or become a parent of other streams. This allows for the creation of a grouping node in the dependency tree, which enables more flexible expressions of priority. Idle streams begin with a [default priority](#) ([Section 5.3.5](#)).

The retention of priority information for streams that are not counted toward the limit set by [SETTINGS_MAX_CONCURRENT_STREAMS](#) could create a large state burden for an endpoint. Therefore, the amount of prioritization state that is retained MAY be limited.

The amount of additional state an endpoint maintains for prioritization could be dependent on load; under high load, prioritization state can be discarded to limit resource commitments. In extreme cases, an endpoint could even discard prioritization state for active or reserved streams. If a limit is applied, endpoints SHOULD maintain state for at least as many streams as allowed by their setting for [SETTINGS_MAX_CONCURRENT_STREAMS](#). Implementations SHOULD also attempt to retain state for streams that are in active use in the priority tree.

If it has retained enough state to do so, an endpoint receiving a [PRIORITY](#) frame that changes the priority of a closed stream SHOULD alter the dependencies of the streams that depend on it.

5.3.5. Default Priorities

All streams are initially assigned a non-exclusive dependency on stream 0x0. [Pushed streams](#) ([Section 8.2](#)) initially depend on their associated stream. In both cases, streams are assigned a default weight of 16.

5.4. Error Handling

HTTP/2 framing permits two classes of error:

- *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.

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 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 "open" or "half-closed" state, then the affected streams cannot be automatically retried (see [Section 8.1.4](#) 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 6.5.2](#)), or new [error codes](#) ([Section 7](#)). Registries are established for managing these extension points: [frame types](#) ([Section 11.2](#)), [settings](#) ([Section 11.3](#)), and [error codes](#) ([Section 11.4](#)).

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](#)), 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 elements 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 either of the connection as a whole or of 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 any given frame.

6.1. DATA

DATA frames (type=0x0) 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](#).

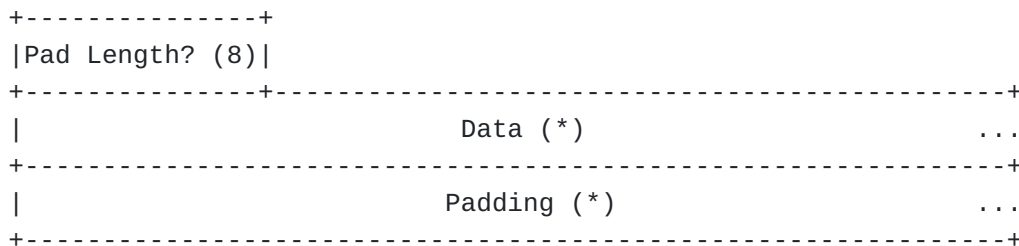


Figure 6: DATA Frame Payload

The DATA frame contains the following fields:

Pad Length: An 8-bit field containing the length of the frame padding in units of octets. This field is conditional (as signified by a "?" in the diagram) 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:

END_STREAM (0x1):

When set, bit 0 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](#)).

PADDED (0x8): When set, bit 3 indicates that the Pad Length field and any padding that it describes are present.

DATA frames MUST be associated with a stream. If a DATA frame is received whose stream identifier field is 0x0, 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 "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=0x1) 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.

```
+-----+
|Pad Length? (8)|
+-+-----+-----+
|E|           Stream Dependency? (31)           |
+-+-----+-----+
| Weight? (8) |
+-+-----+-----+
|           Field Block Fragment (*)           ...
+-+-----+-----+
|           Padding (*)                         ...
+-+-----+-----+
```


Figure 7: HEADERS Frame Payload

The HEADERS frame payload has the following fields:

Pad Length: 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.

E: A single-bit flag indicating that the stream dependency is exclusive (see [Section 5.3](#)). This field is only present if the PRIORITY flag is set.

Stream Dependency: A 31-bit stream identifier for the stream that this stream depends on (see [Section 5.3](#)). This field is only present if the PRIORITY flag is set.

Weight: An unsigned 8-bit integer representing a priority weight for the stream (see [Section 5.3](#)). Add one to the value to obtain a weight between 1 and 256. This field is only present if the PRIORITY flag is set.

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

Padding: Padding octets.

The HEADERS frame defines the following flags:

END_STREAM (0x1): When set, bit 0 indicates that the [field block](#) ([Section 4.3](#)) is the last that the endpoint will send for the identified stream.

A HEADERS frame carries the END_STREAM flag that 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.

END_HEADERS (0x4): When set, bit 2 indicates that this frame contains an entire [field block](#) ([Section 4.3](#)) and is not followed by any [CONTINUATION](#) frames.

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](#).

PADDED (0x8): When set, bit 3 indicates that the Pad Length field and any padding that it describes are present.

PRIORITY (0x20): When set, bit 5 indicates that the Exclusive Flag (E), Stream Dependency, and Weight fields are present; see [Section 5.3](#).

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 0x0, 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 HEADERS frame can include padding. Padding fields and flags are identical to those defined for [DATA frames](#) ([Section 6.1](#)). Padding that exceeds the size remaining for the header block fragment MUST be treated as a [PROTOCOL_ERROR](#).

Prioritization information in a HEADERS frame is logically equivalent to a separate [PRIORITY](#) frame, but inclusion in HEADERS avoids the potential for churn in stream prioritization when new streams are created. Prioritization fields in HEADERS frames subsequent to the first on a stream [reprioritize the stream](#) ([Section 5.3.3](#)).

6.3. PRIORITY

The PRIORITY frame (type=0x2) specifies the [sender-advised priority of a stream](#) ([Section 5.3](#)). It can be sent in any stream state, including idle or closed streams.

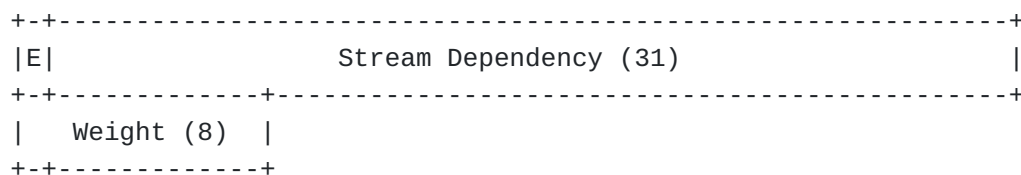


Figure 8: PRIORITY Frame Payload

The frame payload of a PRIORITY frame contains the following fields:

E:

A single-bit flag indicating that the stream dependency is exclusive (see [Section 5.3](#)).

Stream Dependency: A 31-bit stream identifier for the stream that this stream depends on (see [Section 5.3](#)).

Weight: An unsigned 8-bit integer representing a priority weight for the stream (see [Section 5.3](#)). Add one to the value to obtain a weight between 1 and 256.

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 0x0, 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](#)), only the priority of streams is altered.

The PRIORITY frame can be sent on a stream in any state, though it cannot be sent between consecutive frames that comprise a single [field block](#) ([Section 4.3](#)). Note that this frame could arrive after processing or frame sending has completed, which would cause it to have no effect on the identified stream. For a stream that is in the "half-closed (remote)" or "closed" state, this frame can only affect processing of the identified stream and its dependent streams; it does not affect frame transmission on that stream.

The PRIORITY frame can be sent for a stream in the "idle" or "closed" state. This allows for the reprioritization of a group of dependent streams by altering the priority of an unused or closed parent stream.

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=0x3) 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.

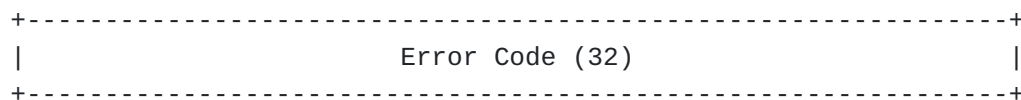


Figure 9: RST_STREAM Frame Payload

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, with the exception of [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 0x0, 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=0x4) 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 parameters. Individually, a SETTINGS parameter can also be referred to as a "setting".

SETTINGS parameters are not negotiated; they describe characteristics of the sending peer, which are used by the receiving peer. Different values for the same parameter 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 parameters defined by this specification.

Each parameter in a SETTINGS frame replaces any existing value for that parameter. Parameters 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 its parameters. Therefore, the value of a SETTINGS parameter is the last value that is seen by a receiver.

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

ACK (0x1): When set, bit 0 indicates that this frame acknowledges receipt and application of the peer's 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 (0x0). If an endpoint receives a SETTINGS frame whose stream identifier field is anything other than 0x0, 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 parameters, each consisting of an unsigned 16-bit setting identifier and an unsigned 32-bit value.

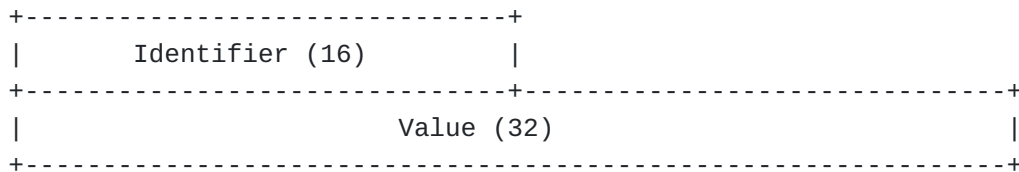


Figure 10: Setting Format

6.5.2. Defined SETTINGS Parameters

The following parameters are defined:

SETTINGS_HEADER_TABLE_SIZE (0x1): Allows the sender to inform the remote endpoint of the maximum size of the compression table used

to decode field blocks, in 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 (0x2): This setting can be used to disable [server push](#) ([Section 8.2](#)). An endpoint MUST NOT send a [PUSH_PROMISE](#) frame if it receives this parameter set to a value of 0. An endpoint 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 is 1, which indicates that server push is permitted. Any value other than 0 or 1 MUST be treated as a [connection error](#) ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

SETTINGS_MAX_CONCURRENT_STREAMS (0x3): 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 (0x4): Indicates the sender's initial window size (in 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 (0x5): Indicates the size of the largest frame payload that the sender is willing to receive, in 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 (0x6):

This advisory setting informs a peer of the maximum size of field section that the sender is prepared to accept, in octets. The value is based on the uncompressed size of field lines, including the length of the name and value in 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 parameters as soon as possible upon receipt.

The values in the SETTINGS frame MUST be processed in the order they appear, with no other frame processing between values. Unsupported parameters 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 parameters can rely on the setting having been applied.

If the sender of a SETTINGS frame does not receive an acknowledgement within a reasonable amount of time, it MAY issue a [connection error](#) ([Section 5.4.1](#)) of type [SETTINGS_TIMEOUT](#).

6.6. PUSH_PROMISE

The PUSH_PROMISE frame (type=0x5) 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 8.2](#) contains a thorough description of the use of PUSH_PROMISE frames.

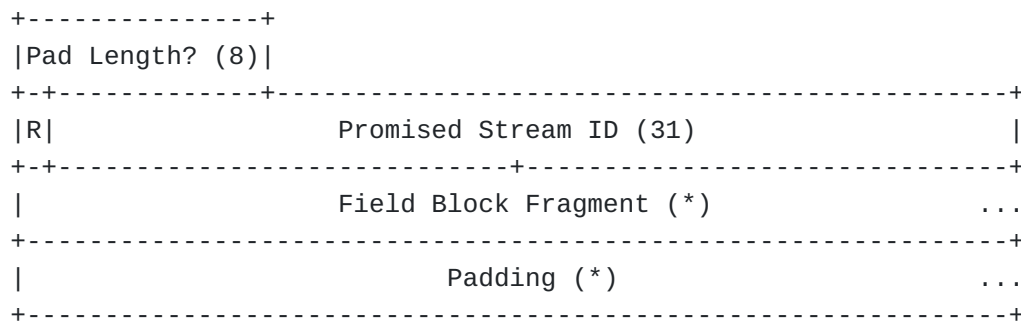


Figure 11: PUSH_PROMISE Frame Payload

The PUSH_PROMISE frame payload has the following fields:

Pad Length: 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.

R: A single reserved bit.

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

Field Block Fragment: A [field block fragment](#) ([Section 4.3](#)) containing request control data and header section.

Padding: Padding octets.

The PUSH_PROMISE frame defines the following flags:

END_HEADERS (0x4): When set, bit 2 indicates that this frame contains an entire [field block](#) ([Section 4.3](#)) and is not followed by any [CONTINUATION](#) frames.

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](#).

PADDED (0x8): When set, bit 3 indicates that the Pad Length field and any padding that it describes are present.

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

0x0, 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 acknowledgement 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" 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 PUSH_PROMISE frame can include padding. Padding fields and flags are identical to those defined for [DATA frames](#) ([Section 6.1](#)).

6.7. PING

The PING frame (type=0x6) 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.

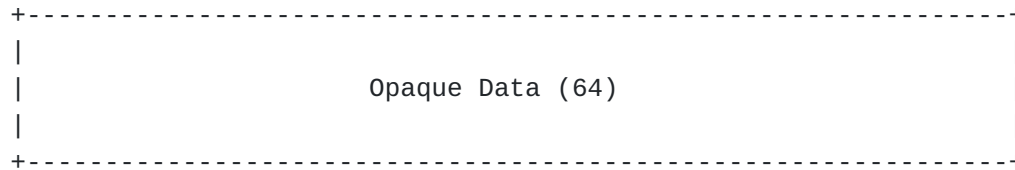


Figure 12: PING Frame Payload

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 (0x1): When set, bit 0 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 0x0, 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=0x7) 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 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 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.

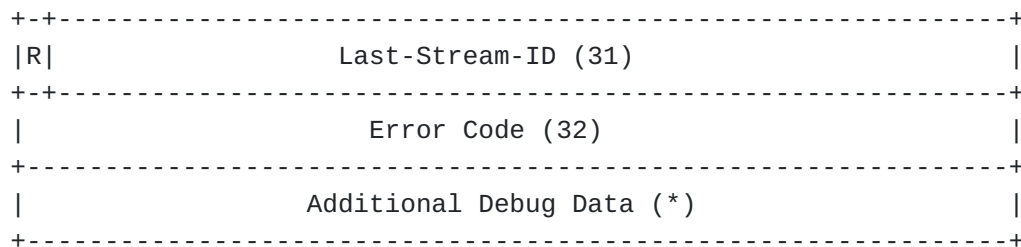


Figure 13: GOAWAY Frame Payload

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 0x0 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, with the exception of 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 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 can 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 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=0x8) 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.

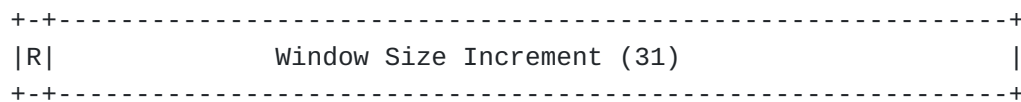


Figure 14: WINDOW_UPDATE Frame Payload

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 an 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 bearing the END_STREAM flag. This means that a receiver could receive a WINDOW_UPDATE frame on a "half-closed (remote)" or "closed" stream. 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.

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 that forms part of the connection preface. 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 to 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=0x9) 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.

```
+-----+
|               Field Block Fragment (*)               ...
+-----+
```

Figure 15: CONTINUATION Frame Payload

The CONTINUATION frame payload contains a [field block fragment](#) ([Section 4.3](#)).

The CONTINUATION frame defines the following flag:

END_HEADERS (0x4): When set, bit 2 indicates that this frame ends a [field block](#) ([Section 4.3](#)).

If the END_HEADERS bit 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 whose stream identifier field is 0x0, 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 (0x0): 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.

PROTOCOL_ERROR (0x1): The endpoint detected an unspecified protocol error. This error is for use when a more specific error code is not available.

INTERNAL_ERROR (0x2): The endpoint encountered an unexpected internal error.

FLOW_CONTROL_ERROR (0x3): The endpoint detected that its peer violated the flow-control protocol.

SETTINGS_TIMEOUT (0x4):

The endpoint sent a [SETTINGS](#) frame but did not receive a response in a timely manner. See [Section 6.5.3](#) ("Settings Synchronization").

STREAM_CLOSED (0x5): The endpoint received a frame after a stream was half-closed.

FRAME_SIZE_ERROR (0x6): The endpoint received a frame with an invalid size.

REFUSED_STREAM (0x7): The endpoint refused the stream prior to performing any application processing (see [Section 8.1.4](#) for details).

CANCEL (0x8): Used by the endpoint to indicate that the stream is no longer needed.

COMPRESSION_ERROR (0x9): The endpoint is unable to maintain the field section compression context for the connection.

CONNECT_ERROR (0xa): The connection established in response to a [CONNECT request](#) ([Section 8.3](#)) was reset or abnormally closed.

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

INADEQUATE_SECURITY (0xc): The underlying transport has properties that do not meet minimum security requirements (see [Section 9.2](#)).

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

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. HTTP Message Exchanges

HTTP/2 defines a framing 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-part, 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](#) frames (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 an END_STREAM flag that carries an informational status code is [malformed](#) ([Section 8.1.2.6](#)).

The last frame in the sequence bears an END_STREAM flag, noting that a [HEADERS](#) frame bearing the END_STREAM flag 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 [\[HTTP11\]](#) cannot be used in HTTP/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 8.1.2.1](#)). An endpoint that receives pseudo-header fields in trailers MUST treat the request or response as [malformed](#) ([Section 8.1.2.6](#)).

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 8.1.2.6](#)).

An HTTP request/response exchange fully consumes a single stream. A request starts with the [HEADERS](#) frame that puts the stream into an "open" state. The request ends with a frame bearing END_STREAM,

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 or 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). 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.

8.1.1.1. Upgrading from HTTP/2

HTTP/2 removes support for 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. Alternative protocols are able to use the same mechanisms that HTTP/2 uses to negotiate their use (see [Section 3](#)).

8.1.1.2. HTTP Fields

HTTP fields carry information as a series of field lines, which are key-value pairs. For a listing of registered HTTP fields, see the "Hypertext Transfer Protocol (HTTP) Field Name Registry" registry maintained at <https://www.iana.org/assignments/http-fields/>.

Just as in HTTP/1.x, field names are strings of ASCII characters that are compared in a case-insensitive fashion. Field names MUST be converted to lowercase prior to their encoding in HTTP/2. A request or response containing uppercase header field names MUST be treated as [malformed](#) ([Section 8.1.2.6](#)).

8.1.1.2.1. Pseudo-Header Fields

While HTTP/1.x used the message start-line (see [Section 2.1](#) of [\[HTTP11\]](#)) to convey control data, HTTP/2 uses special pseudo-header fields beginning with ':' character (ASCII 0x3a) for this purpose.

Pseudo-header fields are not HTTP header fields. Pseudo-header fields contain control data (see [Section 6.2](#) of [\[HTTP\]](#)). 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 8.1.2.6](#)).

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 8.1.2.6](#)).

8.1.2.2. Connection-Specific Header Fields

HTTP/2 does not use the Connection header field 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; any message containing connection-specific header fields MUST be treated as [malformed](#) ([Section 8.1.2.6](#)).

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 a 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 8.1.2.6](#)).

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.

8.1.2.3. 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 target URI ([Section 3.1](#) of [[RFC3986](#)]).

:scheme is not restricted to http and https schemes 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 includes the authority portion of the target URI ([Section 3.2](#) of [\[RFC3986\]](#)). The authority MUST NOT include the deprecated userinfo subcomponent for http or https schemes URIs.

To ensure that HTTP/1.1 control data can be reproduced accurately, this pseudo-header field MUST be omitted when translating from an HTTP/1.1 request that has a request target in origin or asterisk form (see [Section 3.2](#) of [\[HTTP11\]](#)). Clients that generate HTTP/2 requests directly SHOULD use the :authority pseudo-header field instead of the Host header field. An intermediary that converts an HTTP/2 request to HTTP/1.1 MUST create a Host header field if one is not present in a request by copying the value of the :authority pseudo-header field.

The :path pseudo-header field includes the path and query parts of the target URI (the path-absolute production and optionally a '?' character followed by the query production (see Sections 3.3 and 3.4 of [\[RFC3986\]](#)). A request in asterisk form 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 exception to this rule is 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 [\[HTTP\]](#)).

All HTTP/2 requests MUST include exactly one valid value for the :method, :scheme, and :path pseudo-header fields, unless it is a [CONNECT request](#) ([Section 8.3](#)). An HTTP request that omits mandatory pseudo-header fields is [malformed](#) ([Section 8.1.2.6](#)).

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

8.1.2.4. 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 8.1.2.6](#)).

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

8.1.2.5. Compressing the Cookie Header Field

The [Cookie header field](#) [COOKIE] uses a semi-colon (";") to delimit cookie-pairs (or "crumbs"). This header field contains multiple values, but does not use a COMMA (",") as a separator, which prevents 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
```

8.1.2.6. Malformed Requests and Responses

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 fields or pseudo-header fields, or the inclusion of uppercase field names.

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. A response that is defined to have no content, as described in [Section 6.4](#) of [HTTP], can 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. Note that 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.

8.1.3. Examples

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

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
		:path = /resource
		host = example.org
		accept = image/jpeg

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: "xyzzzy"	==>	+ END_STREAM
Expires: Thu, 23 Jan ...		+ END_HEADERS
		:status = 304
		etag = "xyzzzy"
		expires = Thu, 23 Jan ...

An HTTP POST request that includes control data and a request header and 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
		: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.

A response that includes control data and a response header and 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
		content-type = image/jpeg
		content-length = 123
{binary data}		
		DATA
		+ END_STREAM
		{binary data}

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-length = 123
123		content-type = image/jpeg
{binary data}		trailer = Foo
0		
Foo: bar		DATA
		- END_STREAM
		{binary data}
		HEADERS
		+ END_STREAM
		+ END_HEADERS
		foo = bar

8.1.4. Request Reliability Mechanisms in HTTP/2

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. 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 as 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.

8.2. Server Push

HTTP/2 allows a server to pre-emptively send (or "push") responses (along with corresponding "promised" requests) to a client in association with a previous client-initiated request. This can be useful when the server knows the client will need to have those responses available in order to fully process the response to the original request.

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 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 [\[CACHE\]](#)) 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 5.2.2.3](#) of [\[CACHE\]](#)) while the stream identified by the promised stream ID 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](#). Clients MUST reject any attempt to change the [SETTINGS_ENABLE_PUSH](#) setting to a value other than 0 by treating the message as a [connection error](#) ([Section 5.4.1](#)) of type [PROTOCOL_ERROR](#).

8.2.1. 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 8.1.2.3](#)). 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 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 responses referenced by the field block (for instance, in Link header fields), sending a [PUSH_PROMISE](#) before sending the header block 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 in response to 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.

8.2.2. Push Responses

After sending the [PUSH_PROMISE](#) frame, the server can begin delivering the pushed response as a [response](#) ([Section 8.1.2.4](#)) 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 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 disables server push by preventing the server from creating the necessary streams. This does not prohibit a server from sending [PUSH_PROMISE](#) frames; clients need to reset any promised streams that are not wanted.

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 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 bearing `END_STREAM`, which places the stream in the "closed" state.

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

8.3. The `CONNECT` Method

In HTTP/1.x, the pseudo-method `CONNECT` ([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 is used to establish a tunnel over a single HTTP/2 stream to a remote host for similar purposes. A `CONNECT` header section is constructed as defined in [Section 8.1.2.3](#) ("[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 [\[HTTP11\]](#)).

A `CONNECT` request that does not conform to these restrictions is [malformed](#) ([Section 8.1.2.6](#)).

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 bearing the END_STREAM flag. 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.

9. Additional HTTP Requirements/Considerations

This section outlines attributes of the HTTP protocol 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 8.3](#)), 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 \(SNI\)](#) [\[TLS-EXT\]](#) 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 [Section 9.2.1](#) and [Section 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 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) [[TLS13](#)] and 224 bits for cipher suites that use

ephemeral elliptic curve Diffie-Hellman (ECDHE) [[RFC4492](#)]. 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 cipher suites that are listed in the [list of prohibited cipher suites](#) ([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 causing 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 [[FIPS186](#)].

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

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 3.5](#)) contains a string that is designed to confuse HTTP/1.1 servers, but no special protection is offered for other protocols. A server that is willing to ignore parts of an HTTP/1.1 request containing an Upgrade header field in addition to the client connection preface could be exposed to a cross-protocol attack.

10.3. Intermediary Encapsulation Attacks

The HTTP/2 field block encoding allows the expression of names that are not valid field names in HTTP. Requests or responses containing invalid field names MUST be treated as [malformed](#) ([Section 8.1.2.6](#)). An intermediary therefore cannot translate an HTTP/2 request or response containing an invalid field name into an HTTP/1.1 message.

Similarly, HTTP/2 allows field values that are not valid. While most of the values that can be encoded will not alter header field parsing, carriage return (CR, ASCII 0xd), line feed (LF, ASCII 0xa), and the zero character (NUL, ASCII 0x0) might be exploited by an attacker if they are translated verbatim. Any request or response that contains a character not permitted in a field value MUST be treated as [malformed](#) ([Section 8.1.2.6](#)). Valid characters are defined by the field-content ABNF rule in [Section 5.5](#) of [\[HTTP\]](#).

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. The use of field section compression and flow control depend on a commitment of resources for storing 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](#)]. The following lists known ways that implementations might be subject to denial of service attack:

- *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.

- *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](#) parameters, setting multiple undefined parameters, 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 offers some opportunities to waste processing resources; see [Section 7](#) of [[COMPRESSION](#)] for more details on potential abuses.

- *Limits in [SETTINGS](#) parameters 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.

*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.

Most of the features that might be exploited for denial of service -- i.e., [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 having 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 an 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 value 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.

11. IANA Considerations

A string for identifying HTTP/2 is entered into the "Application-Layer Protocol Negotiation (ALPN) Protocol IDs" registry established in [[TLS-ALPN](#)].

This document establishes a registry for frame types, settings, and error codes. These new registries appear in the new "Hypertext Transfer Protocol version 2 (HTTP/2) Parameters" section.

This document registers the HTTP2-Settings header field for use in HTTP.

This document registers the PRI method for use in HTTP to avoid collisions with the [connection preface](#) ([Section 3.5](#)).

11.1. Registration of HTTP/2 Identification Strings

This document creates two registrations for the identification of HTTP/2 (see [Section 3.3](#)) in the "Application-Layer Protocol Negotiation (ALPN) Protocol IDs" registry established in [\[TLS-ALPN\]](#).

The "h2" string identifies HTTP/2 when used over TLS:

Protocol: HTTP/2 over TLS

Identification Sequence: 0x68 0x32 ("h2")

Specification: This document

The "h2c" string identifies HTTP/2 when used over cleartext TCP:

Protocol: HTTP/2 over TCP

Identification Sequence: 0x68 0x32 0x63 ("h2c")

Specification: This document

11.2. Frame Type Registry

This document establishes a registry for HTTP/2 frame type codes. The "HTTP/2 Frame Type" registry manages an 8-bit space. The "HTTP/2 Frame Type" registry operates under either of the ["IETF Review" or "IESG Approval" policies](#) [\[RFC5226\]](#) for values between 0x00 and 0xef, with values between 0xf0 and 0xff being reserved for Experimental Use.

New entries in this registry require the following information:

Frame Type: A name or label for the frame type.

Code: The 8-bit code assigned to the frame type.

Specification: A reference to a specification that includes a description of the frame layout, its semantics, and flags that the frame type uses, including any parts of the frame that are conditionally present based on the value of flags.

The entries in the following table are registered by this document.

Frame Type	Code	Section
DATA	0x0	Section 6.1
HEADERS	0x1	Section 6.2
PRIORITY	0x2	Section 6.3
RST_STREAM	0x3	Section 6.4
SETTINGS	0x4	Section 6.5

Frame Type	Code	Section
PUSH_PROMISE	0x5	Section 6.6
PING	0x6	Section 6.7
GOAWAY	0x7	Section 6.8
WINDOW_UPDATE	0x8	Section 6.9
CONTINUATION	0x9	Section 6.10

Table 1

11.3. Settings Registry

This document establishes a registry for HTTP/2 settings. The "HTTP/2 Settings" registry manages a 16-bit space. The "HTTP/2 Settings" registry operates under the ["Expert Review" policy](#) [RFC5226] for values in the range from 0x0000 to 0xffff, with values between and 0xf000 and 0xffff being reserved for Experimental Use.

New registrations are advised to provide the following information:

Name: A symbolic name for the setting. Specifying a setting name is optional.

Code: The 16-bit code assigned to the setting.

Initial Value: An initial value for the setting.

Specification: An optional reference to a specification that describes the use of the setting.

The entries in the following table are registered by this document.

Name	Code	Initial Value	Specification
HEADER_TABLE_SIZE	0x1	4096	Section 6.5.2
ENABLE_PUSH	0x2	1	Section 6.5.2
MAX_CONCURRENT_STREAMS	0x3	(infinite)	Section 6.5.2
INITIAL_WINDOW_SIZE	0x4	65535	Section 6.5.2
MAX_FRAME_SIZE	0x5	16384	Section 6.5.2
MAX_HEADER_LIST_SIZE	0x6	(infinite)	Section 6.5.2

Table 2

11.4. Error Code Registry

This document establishes a registry for HTTP/2 error codes. The "HTTP/2 Error Code" registry manages a 32-bit space. The "HTTP/2 Error Code" registry operates under the ["Expert Review" policy](#) [RFC5226].

Registrations for error codes are required to include a description of the error code. An expert reviewer is advised to examine new

registrations for possible duplication with existing error codes. Use of existing registrations is to be encouraged, but not mandated.

New registrations are advised to provide the following information:

Name: A name for the error code. Specifying an error code name is optional.

Code: The 32-bit error code value.

Description: A brief description of the error code semantics, longer if no detailed specification is provided.

Specification: An optional reference for a specification that defines the error code.

The entries in the following table are registered by this document.

Name	Code	Description	Specification
NO_ERROR	0x0	Graceful shutdown	Section 7
PROTOCOL_ERROR	0x1	Protocol error detected	Section 7
INTERNAL_ERROR	0x2	Implementation fault	Section 7
FLOW_CONTROL_ERROR	0x3	Flow-control limits exceeded	Section 7
SETTINGS_TIMEOUT	0x4	Settings not acknowledged	Section 7
STREAM_CLOSED	0x5	Frame received for closed stream	Section 7
FRAME_SIZE_ERROR	0x6	Frame size incorrect	Section 7
REFUSED_STREAM	0x7	Stream not processed	Section 7
CANCEL	0x8	Stream cancelled	Section 7
COMPRESSION_ERROR	0x9	Compression state not updated	Section 7
CONNECT_ERROR	0xa	TCP connection error for CONNECT method	Section 7
ENHANCE_YOUR_CALM	0xb	Processing capacity exceeded	Section 7
INADEQUATE_SECURITY	0xc	Negotiated TLS parameters not acceptable	Section 7
HTTP_1_1_REQUIRED	0xd	Use HTTP/1.1 for the request	Section 7

Table 3

11.5. HTTP2-Settings Header Field Registration

This section registers the HTTP2-Settings header field in the "Permanent Message Header Field Names" registry [[BCP90](#)].

Header field name:

HTTP2-Settings

Applicable protocol: http

Status: standard

Author/Change controller: IETF

Specification document(s): [Section 3.2.1](#) of this document

Related information: This header field is only used by an HTTP/2 client for Upgrade-based negotiation.

11.6. PRI Method Registration

This section registers the PRI method in the "HTTP Method Registry" ([Section 18.2](#) of [[HTTP](#)]).

Method Name: PRI

Safe: Yes

Idempotent: Yes

Specification document(s): [Section 3.5](#) of this document

Related information: This method is never used by an actual client. This method will appear to be used when an HTTP/1.1 server or intermediary attempts to parse an HTTP/2 connection preface.

11.7. The h2c Upgrade Token

This document registers the "h2c" upgrade token in the "HTTP Upgrade Tokens" registry ([Section 18.10](#) of [[HTTP](#)]).

Value: h2c

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

Expected Version Tokens: None

Reference: [Section 3.2](#) of this document

12. References

12.1. Normative References

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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
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*TLS_DHE_PSK_WITH_NULL_SHA384
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*TLS_RSA_PSK_WITH_AES_256_CBC_SHA384
*TLS_RSA_PSK_WITH_NULL_SHA256
*TLS_RSA_PSK_WITH_NULL_SHA384
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*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
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*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

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*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 at the time of writing. 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.

Appendix B. Changes from RFC 7540

This revision includes a number of editorial updates, plus the following substantive changes:

*Use of TLS 1.3 is defined based on RFC 8740, which this document obsoletes.

Contributors

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