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TLS Encrypted Client Hello
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Abstract

This document describes a mechanism in Transport Layer Security (TLS) for encrypting a ClientHello message under a server public key.

Discussion Venues

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/tlswg/draft-ietf-tls-esni> (<https://github.com/tlswg/draft-ietf-tls-esni>).

Status of This Memo

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

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1. Introduction

DISCLAIMER: This draft is work-in-progress and has not yet seen significant (or really any) security analysis. It should not be used as a basis for building production systems. This published version of the draft has been designated an "implementation draft" for testing and interop purposes.

Although TLS 1.3 [RFC8446] encrypts most of the handshake, including the server certificate, there are several ways in which an on-path attacker can learn private information about the connection. The plaintext Server Name Indication (SNI) extension in ClientHello messages, which leaks the target domain for a given connection, is perhaps the most sensitive, unencrypted information in TLS 1.3.

This document specifies a new TLS extension, called Encrypted Client Hello (ECH), that allows clients to encrypt their ClientHello to such a deployment. This protects the SNI and other potentially sensitive fields, such as the ALPN list [RFC7301]. Co-located servers with consistent externally visible TLS configurations and behavior, including supported versions and cipher suites and how they respond to incoming client connections, form an anonymity set. (Note that implementation-specific choices, such as extension ordering within TLS messages or division of data into record-layer boundaries, can result in different externally visible behavior, even for servers with consistent TLS configurations.) Usage of this mechanism reveals that a client is connecting to a particular service provider, but does not reveal which server from the anonymity set terminates the connection. Deployment implications of this feature are discussed in Section 8.

ECH is not in itself sufficient to protect the identity of the server. The target domain may also be visible through other channels, such as plaintext client DNS queries or visible server IP addresses. However, DoH [RFC8484] and DPRIVE [RFC7858] [RFC8094] provide mechanisms for clients to conceal DNS lookups from network inspection, and many TLS servers host multiple domains on the same IP address. Private origins may also be deployed behind a common provider, such as a reverse proxy. In such environments, the SNI remains the primary explicit signal used to determine the server's identity.

ECH is supported in TLS 1.3 [RFC8446], DTLS 1.3 [RFC9147], and newer versions of the TLS and DTLS protocols.

2. Conventions and Definitions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here. All TLS notation comes from [RFC8446], Section 3.

3. Overview

This protocol is designed to operate in one of two topologies illustrated below, which we call "Shared Mode" and "Split Mode". These modes are described in the following section.

3.1. Topologies

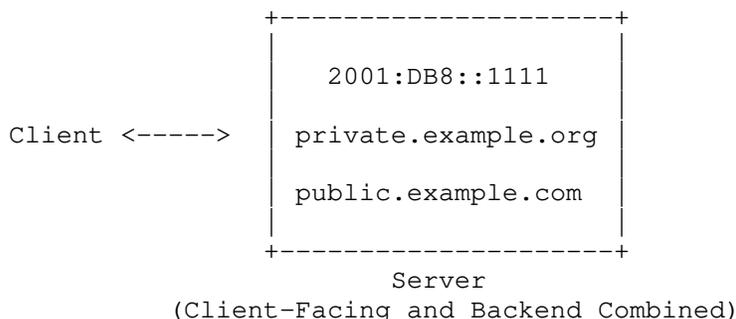


Figure 1: Shared Mode Topology

In Shared Mode, the provider is the origin server for all the domains whose DNS records point to it. In this mode, the TLS connection is terminated by the provider.

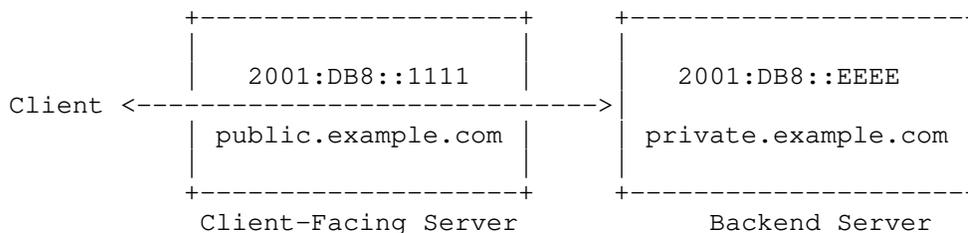


Figure 2: Split Mode Topology

In Split Mode, the provider is not the origin server for private domains. Rather, the DNS records for private domains point to the provider, and the provider's server relays the connection back to the origin server, who terminates the TLS connection with the client. Importantly, the service provider does not have access to the plaintext of the connection beyond the unencrypted portions of the handshake.

In the remainder of this document, we will refer to the ECH-service provider as the "client-facing server" and to the TLS terminator as the "backend server". These are the same entity in Shared Mode, but in Split Mode, the client-facing and backend servers are physically separated.

See Section 10 for more discussion about the ECH threat model and how it relates to the client, client-facing server, and backend server.

3.2. Encrypted ClientHello (ECH)

A client-facing server enables ECH by publishing an ECH configuration, which is an encryption public key and associated metadata. The server must publish this for all the domains it serves via Shared or Split Mode. This document defines the ECH configuration's format, but delegates DNS publication details to [HTTPS-RR]. See [ECH-IN-DNS] for specifics about how ECH configurations are advertised in HTTPS records. Other delivery mechanisms are also possible. For example, the client may have the ECH configuration preconfigured.

When a client wants to establish a TLS session with some backend server, it constructs a private ClientHello, referred to as the ClientHelloInner. The client then constructs a public ClientHello, referred to as the ClientHelloOuter. The ClientHelloOuter contains innocuous values for sensitive extensions and an "encrypted_client_hello" extension (Section 5), which carries the encrypted ClientHelloInner. Finally, the client sends ClientHelloOuter to the server.

The server takes one of the following actions:

1. If it does not support ECH or cannot decrypt the extension, it completes the handshake with ClientHelloOuter. This is referred to as rejecting ECH.
2. If it successfully decrypts the extension, it forwards the ClientHelloInner to the backend server, which completes the handshake. This is referred to as accepting ECH.

Upon receiving the server's response, the client determines whether or not ECH was accepted (Section 6.1.4) and proceeds with the handshake accordingly. When ECH is rejected, the resulting connection is not usable by the client for application data. Instead, ECH rejection allows the client to retry with up-to-date configuration (Section 6.1.6).

The primary goal of ECH is to ensure that connections to servers in the same anonymity set are indistinguishable from one another. Moreover, it should achieve this goal without affecting any existing security properties of TLS 1.3. See Section 10.1 for more details about the ECH security and privacy goals.

4. Encrypted ClientHello Configuration

ECH uses HPKE for public key encryption [HPKE]. The ECH configuration is defined by the following ECHConfig structure.

```
opaque HpkePublicKey<1..2^16-1>;
uint16 HpkeKemId;           // Defined in RFC9180
uint16 HpkeKdfId;          // Defined in RFC9180
uint16 HpkeAeadId;         // Defined in RFC9180
uint16 ECHConfigExtensionType; // Defined in Section 11.3

struct {
    HpkeKdfId kdf_id;
    HpkeAeadId aead_id;
} HpkeSymmetricCipherSuite;

struct {
    uint8 config_id;
    HpkeKemId kem_id;
    HpkePublicKey public_key;
    HpkeSymmetricCipherSuite cipher_suites<4..2^16-4>;
} HpkeKeyConfig;

struct {
    ECHConfigExtensionType type;
    opaque data<0..2^16-1>;
} ECHConfigExtension;

struct {
    HpkeKeyConfig key_config;
    uint8 maximum_name_length;
    opaque public_name<1..255>;
    ECHConfigExtension extensions<0..2^16-1>;
} ECHConfigContents;

struct {
    uint16 version;
    uint16 length;
    select (ECHConfig.version) {
        case 0xfe0d: ECHConfigContents contents;
    }
} ECHConfig;
```

The structure contains the following fields:

version The version of ECH for which this configuration is used. Beginning with draft-08, the version is the same as the code point for the "encrypted_client_hello" extension. Clients MUST ignore any ECHConfig structure with a version they do not support.

length The length, in bytes, of the next field. This length field allows implementations to skip over the elements in such a list where they cannot parse the specific version of ECHConfig.

contents An opaque byte string whose contents depend on the version. For this specification, the contents are an ECHConfigContents structure.

The ECHConfigContents structure contains the following fields:

key_config A HpkeKeyConfig structure carrying the configuration information associated with the HPKE public key. Note that this structure contains the config_id field, which applies to the entire ECHConfigContents.

maximum_name_length The longest name of a backend server, if known. If not known, this value can be set to zero. It is used to compute padding (Section 6.1.3) and does not constrain server name lengths. Names may exceed this length if, e.g., the server uses wildcard names or added new names to the anonymity set.

public_name The DNS name of the client-facing server, i.e., the entity trusted to update the ECH configuration. This is used to correct misconfigured clients, as described in Section 6.1.6.

Clients MUST ignore any ECHConfig structure whose public_name is not parsable as a dot-separated sequence of LDH labels, as defined in [RFC5890], Section 2.3.1 or which begins or end with an ASCII dot. Clients additionally SHOULD ignore the structure if the final LDH label either consists of all ASCII digits (i.e. '0' through '9') or is "0x" or "0X" followed by some, possibly empty, sequence of ASCII hexadecimal digits (i.e. '0' through '9', 'a' through 'f', and 'A' through 'F'). This avoids public_name values that may be interpreted as IPv4 literals. Additionally, clients MAY ignore the ECHConfig if the length of any label in the DNS name is longer than 63 octets, as this is the maximum length of a DNS label.

See Section 6.1.7 for how the client interprets and validates the public_name.

extensions A list of ECHConfigExtension values that the client must take into consideration when generating a ClientHello message. Each ECHConfigExtension has a 2-octet type and opaque data value, where the data value is encoded with a 2-octet integer representing the length of the data, in network byte order. ECHConfigExtension values are described below (Section 4.2).

The HpkeKeyConfig structure contains the following fields:

config_id A one-byte identifier for the given HPKE key

configuration. This is used by clients to indicate the key used for ClientHello encryption. Section 4.1 describes how client-facing servers allocate this value.

kem_id The HPKE KEM identifier corresponding to **public_key**. Clients MUST ignore any ECHConfig structure with a key using a KEM they do not support.

public_key The HPKE public key used by the client to encrypt ClientHelloInner.

cipher_suites The list of HPKE KDF and AEAD identifier pairs clients can use for encrypting ClientHelloInner. See Section 6.1 for how clients choose from this list.

The client-facing server advertises a sequence of ECH configurations to clients, serialized as follows.

```
ECHConfig ECHConfigList<1..216-1>;
```

The ECHConfigList structure contains one or more ECHConfig structures in decreasing order of preference. This allows a server to support multiple versions of ECH and multiple sets of ECH parameters.

4.1. Configuration Identifiers

A client-facing server has a set of known ECHConfig values, with corresponding private keys. This set SHOULD contain the currently published values, as well as previous values that may still be in use, since clients may cache DNS records up to a TTL or longer.

Section 7.1 describes a trial decryption process for decrypting the ClientHello. This can impact performance when the client-facing server maintains many known ECHConfig values. To avoid this, the client-facing server SHOULD allocate distinct config_id values for each ECHConfig in its known set. The RECOMMENDED strategy is via rejection sampling, i.e., to randomly select config_id repeatedly until it does not match any known ECHConfig.

It is not necessary for config_id values across different client-facing servers to be distinct. A backend server may be hosted behind two different client-facing servers with colliding config_id values without any performance impact. Values may also be reused if the previous ECHConfig is no longer in the known set.

4.2. Configuration Extensions

ECH configuration extensions are used to provide room for additional functionality as needed. See Appendix A for guidance on which types of extensions are appropriate for this structure.

The format is as defined in Section 4 and mirrors Section 4.2 of [RFC8446]. However, ECH configuration extension types are maintained by IANA as described in Section 11.3. ECH configuration extensions follow the same interpretation rules as TLS extensions: extensions MAY appear in any order, but there MUST NOT be more than one extension of the same type in the extensions block. Unlike TLS extensions, an extension can be tagged as mandatory by using an extension type codepoint with the high order bit set to 1.

Clients MUST parse the extension list and check for unsupported mandatory extensions. If an unsupported mandatory extension is present, clients MUST ignore the ECHConfig.

5. The "encrypted_client_hello" Extension

To offer ECH, the client sends an "encrypted_client_hello" extension in the ClientHelloOuter. When it does, it MUST also send the extension in ClientHelloInner.

```
enum {
    encrypted_client_hello(0xfe0d), (65535)
} ExtensionType;
```

The payload of the extension has the following structure:

```
enum { outer(0), inner(1) } ECHClientHelloType;

struct {
    ECHClientHelloType type;
    select (ECHClientHello.type) {
        case outer:
            HpkeSymmetricCipherSuite cipher_suite;
            uint8 config_id;
            opaque enc<0..2^16-1>;
            opaque payload<1..2^16-1>;
        case inner:
            Empty;
    };
} ECHClientHello;
```

The outer extension uses the outer variant and the inner extension uses the inner variant. The inner extension has an empty payload, which is included because TLS servers are not allowed to provide extensions in ServerHello which were not included in ClientHello. The outer extension has the following fields:

`config_id` The `ECHConfigContents.key_config.config_id` for the chosen `ECHConfig`.

`cipher_suite` The cipher suite used to encrypt `ClientHelloInner`. This **MUST** match a value provided in the corresponding `ECHConfigContents.cipher_suites` list.

`enc` The HPKE encapsulated key, used by servers to decrypt the corresponding payload field. This field is empty in a `ClientHelloOuter` sent in response to `HelloRetryRequest`.

`payload` The serialized and encrypted `EncodedClientHelloInner` structure, encrypted using HPKE as described in Section 6.1.

When a client offers the outer version of an "encrypted_client_hello" extension, the server **MAY** include an "encrypted_client_hello" extension in its `EncryptedExtensions` message, as described in Section 7.1, with the following payload:

```
struct {
    ECHConfigList retry_configs;
} ECHEncryptedExtensions;
```

The response is valid only when the server used the `ClientHelloOuter`. If the server sent this extension in response to the inner variant, then the client **MUST** abort with an "unsupported_extension" alert.

`retry_configs` An `ECHConfigList` structure containing one or more `ECHConfig` structures, in decreasing order of preference, to be used by the client as described in Section 6.1.6. These are known as the server's "retry configurations".

Finally, when the client offers the "encrypted_client_hello", if the payload is the inner variant and the server responds with `HelloRetryRequest`, it **MUST** include an "encrypted_client_hello" extension with the following payload:

```
struct {
    opaque confirmation[8];
} ECHHelloRetryRequest;
```

The value of `ECHHelloRetryRequest.confirmation` is set to `hrr_accept_confirmation` as described in Section 7.2.1.

This document also defines the "ech_required" alert, which the client MUST send when it offered an "encrypted_client_hello" extension that was not accepted by the server. (See Section 11.2.)

5.1. Encoding the ClientHelloInner

Before encrypting, the client pads and optionally compresses `ClientHelloInner` into a `EncodedClientHelloInner` structure, defined below:

```
struct {
    ClientHello client_hello;
    uint8 zeros[length_of_padding];
} EncodedClientHelloInner;
```

The `client_hello` field is computed by first making a copy of `ClientHelloInner` and setting the `legacy_session_id` field to the empty string. Note this field uses the `ClientHello` structure, defined in Section 4.1.2 of [RFC8446] which does not include the Handshake structure's four byte header. The `zeros` field MUST be all zeroes.

Repeating large extensions, such as "key_share" with post-quantum algorithms, between `ClientHelloInner` and `ClientHelloOuter` can lead to excessive size. To reduce the size impact, the client MAY substitute extensions which it knows will be duplicated in `ClientHelloOuter`. It does so by removing and replacing extensions from `EncodedClientHelloInner` with a single "ech_outer_extensions" extension, defined as follows:

```
enum {
    ech_outer_extensions(0xfd00), (65535)
} ExtensionType;
```

```
ExtensionType OuterExtensions<2..254>;
```

`OuterExtensions` contains the removed `ExtensionType` values. Each value references the matching extension in `ClientHelloOuter`. The values MUST be ordered contiguously in `ClientHelloInner`, and the "ech_outer_extensions" extension MUST be inserted in the corresponding position in `EncodedClientHelloInner`. Additionally, the extensions MUST appear in `ClientHelloOuter` in the same relative order. However, there is no requirement that they be contiguous. For example, `OuterExtensions` may contain extensions A, B, C, while `ClientHelloOuter` contains extensions A, D, B, C, E, F.

The "ech_outer_extensions" extension can only be included in EncodedClientHelloInner, and MUST NOT appear in either ClientHelloOuter or ClientHelloInner.

Finally, the client pads the message by setting the zeros field to a byte string whose contents are all zeros and whose length is the amount of padding to add. Section 6.1.3 describes a recommended padding scheme.

The client-facing server computes ClientHelloInner by reversing this process. First it parses EncodedClientHelloInner, interpreting all bytes after client_hello as padding. If any padding byte is non-zero, the server MUST abort the connection with an "illegal_parameter" alert.

Next it makes a copy of the client_hello field and copies the legacy_session_id field from ClientHelloOuter. It then looks for an "ech_outer_extensions" extension. If found, it replaces the extension with the corresponding sequence of extensions in the ClientHelloOuter. The server MUST abort the connection with an "illegal_parameter" alert if any of the following are true:

- * Any referenced extension is missing in ClientHelloOuter.
- * Any extension is referenced in OuterExtensions more than once.
- * "encrypted_client_hello" is referenced in OuterExtensions.
- * The extensions in ClientHelloOuter corresponding to those in OuterExtensions do not occur in the same order.

These requirements prevent an attacker from performing a packet amplification attack, by crafting a ClientHelloOuter which decompresses to a much larger ClientHelloInner. This is discussed further in Section 10.12.4.

Implementations SHOULD construct the ClientHelloInner in linear time. Quadratic time implementations (such as may happen via naive copying) create a denial of service risk. Appendix B describes a linear-time procedure that may be used for this purpose.

5.2. Authenticating the ClientHelloOuter

To prevent a network attacker from modifying the ClientHelloOuter while keeping the same encrypted ClientHelloInner (see Section 10.12.3), ECH authenticates ClientHelloOuter by passing ClientHelloOuterAAD as the associated data for HPKE sealing and opening operations. The ClientHelloOuterAAD is a serialized ClientHello structure, defined in Section 4.1.2 of [RFC8446], which matches the ClientHelloOuter except that the payload field of the "encrypted_client_hello" is replaced with a byte string of the same length but whose contents are zeros. This value does not include the four-byte header from the Handshake structure.

6. Client Behavior

Clients that implement the ECH extension behave in one of two ways: either they offer a real ECH extension, as described in Section 6.1; or they send a GREASE ECH extension, as described in Section 6.2. Clients of the latter type do not negotiate ECH. Instead, they generate a dummy ECH extension that is ignored by the server. (See Section 10.10.4 for an explanation.) The client offers ECH if it is in possession of a compatible ECH configuration and sends GREASE ECH otherwise.

6.1. Offering ECH

To offer ECH, the client first chooses a suitable ECHConfig from the server's ECHConfigList. To determine if a given ECHConfig is suitable, it checks that it supports the KEM algorithm identified by ECHConfig.contents.kem_id, at least one KDF/AEAD algorithm identified by ECHConfig.contents.cipher_suites, and the version of ECH indicated by ECHConfig.contents.version. Once a suitable configuration is found, the client selects the cipher suite it will use for encryption. It MUST NOT choose a cipher suite or version not advertised by the configuration. If no compatible configuration is found, then the client SHOULD proceed as described in Section 6.2.

Next, the client constructs the ClientHelloInner message just as it does a standard ClientHello, with the exception of the following rules:

1. It MUST NOT offer to negotiate TLS 1.2 or below. This is necessary to ensure the backend server does not negotiate a TLS version that is incompatible with ECH.
2. It MUST NOT offer to resume any session for TLS 1.2 and below.

3. If it intends to compress any extensions (see Section 5.1), it MUST order those extensions consecutively.
4. It MUST include the "encrypted_client_hello" extension of type inner as described in Section 5. (This requirement is not applicable when the "encrypted_client_hello" extension is generated as described in Section 6.2.)

The client then constructs EncodedClientHelloInner as described in Section 5.1. It also computes an HPKE encryption context and enc value as:

```
pkR = DeserializePublicKey(ECHConfig.contents.public_key)
enc, context = SetupBaseS(pkR,
                          "tls ech" || 0x00 || ECHConfig)
```

Next, it constructs a partial ClientHelloOuterAAD as it does a standard ClientHello, with the exception of the following rules:

1. It MUST offer to negotiate TLS 1.3 or above.
2. If it compressed any extensions in EncodedClientHelloInner, it MUST copy the corresponding extensions from ClientHelloInner. The copied extensions additionally MUST be in the same relative order as in ClientHelloInner.
3. It MUST copy the legacy_session_id field from ClientHelloInner. This allows the server to echo the correct session ID for TLS 1.3's compatibility mode (see Appendix D.4 of [RFC8446]) when ECH is negotiated.
4. It MAY copy any other field from the ClientHelloInner except ClientHelloInner.random. Instead, It MUST generate a fresh ClientHelloOuter.random using a secure random number generator. (See Section 10.12.1.)
5. It SHOULD place the value of ECHConfig.contents.public_name in the "server_name" extension. Clients that do not follow this step, or place a different value in the "server_name" extension, risk breaking the retry mechanism described in Section 6.1.6 or failing to interoperate with servers that require this step to be done; see Section 7.1.
6. When the client offers the "pre_shared_key" extension in ClientHelloInner, it SHOULD also include a GREASE "pre_shared_key" extension in ClientHelloOuter, generated in the manner described in Section 6.1.2. The client MUST NOT use this extension to advertise a PSK to the client-facing server. (See

Section 10.12.3.) When the client includes a GREASE "pre_shared_key" extension, it MUST also copy the "psk_key_exchange_modes" from the ClientHelloInner into the ClientHelloOuter.

7. When the client offers the "early_data" extension in ClientHelloInner, it MUST also include the "early_data" extension in ClientHelloOuter. This allows servers that reject ECH and use ClientHelloOuter to safely ignore any early data sent by the client per [RFC8446], Section 4.2.10.

Note that these rules may change in the presence of an application profile specifying otherwise.

The client might duplicate non-sensitive extensions in both messages. However, implementations need to take care to ensure that sensitive extensions are not offered in the ClientHelloOuter. See Section 10.5 for additional guidance.

Finally, the client encrypts the EncodedClientHelloInner with the above values, as described in Section 6.1.1, to construct a ClientHelloOuter. It sends this to the server, and processes the response as described in Section 6.1.4.

6.1.1. Encrypting the ClientHello

Given an EncodedClientHelloInner, an HPKE encryption context and enc value, and a partial ClientHelloOuterAAD, the client constructs a ClientHelloOuter as follows.

First, the client determines the length L of encrypting EncodedClientHelloInner with the selected HPKE AEAD. This is typically the sum of the plaintext length and the AEAD tag length. The client then completes the ClientHelloOuterAAD with an "encrypted_client_hello" extension. This extension value contains the outer variant of ECHClientHello with the following fields:

- * config_id, the identifier corresponding to the chosen ECHConfig structure;
- * cipher_suite, the client's chosen cipher suite;
- * enc, as given above; and
- * payload, a placeholder byte string containing L zeros.

If configuration identifiers (see Section 10.4) are to be ignored, `config_id` SHOULD be set to a randomly generated byte in the first `ClientHelloOuter` and, in the event of HRR, MUST be left unchanged for the second `ClientHelloOuter`.

The client serializes this structure to construct the `ClientHelloOuterAAD`. It then computes the final payload as:

```
final_payload = context.Seal(ClientHelloOuterAAD,  
                             EncodedClientHelloInner)
```

Including `ClientHelloOuterAAD` as the HPKE AAD binds the `ClientHelloOuter` to the `ClientHelloInner`, this preventing attackers from modifying `ClientHelloOuter` while keeping the same `ClientHelloInner`, as described in {#flow-clienthello-malleability}.

Finally, the client replaces payload with `final_payload` to obtain `ClientHelloOuter`. The two values have the same length, so it is not necessary to recompute length prefixes in the serialized structure.

Note this construction requires the `"encrypted_client_hello"` be computed after all other extensions. This is possible because the `ClientHelloOuter`'s `"pre_shared_key"` extension is either omitted, or uses a random binder (Section 6.1.2).

6.1.2. GREASE PSK

When offering ECH, the client is not permitted to advertise PSK identities in the `ClientHelloOuter`. However, the client can send a `"pre_shared_key"` extension in the `ClientHelloInner`. In this case, when resuming a session with the client, the backend server sends a `"pre_shared_key"` extension in its `ServerHello`. This would appear to a network observer as if the server were sending this extension without solicitation, which would violate the extension rules described in [RFC8446]. When offering a PSK in `ClientHelloInner`, Clients SHOULD sending a GREASE `"pre_shared_key"` extension in the `ClientHelloOuter` to make it appear to the network as if the extension were negotiated properly.

The client generates the extension payload by constructing an `OfferedPsk` structure (see [RFC8446], Section 4.2.11) as follows. For each PSK identity advertised in the `ClientHelloInner`, the client generates a random PSK identity with the same length. It also generates a random, 32-bit, unsigned integer to use as the `obfuscated_ticket_age`. Likewise, for each inner PSK binder, the client generates a random string of the same length.

Per the rules of Section 6.1, the server is not permitted to resume a connection in the outer handshake. If ECH is rejected and the client-facing server replies with a "pre_shared_key" extension in its ServerHello, then the client MUST abort the handshake with an "illegal_parameter" alert.

6.1.3. Recommended Padding Scheme

If the ClientHelloInner is encrypted without padding, then the length of the ClientHelloOuter.payload can leak information about ClientHelloInner. In order to prevent this the EncodedClientHelloInner structure has a padding field. This section describes a deterministic mechanism for computing the required amount of padding based on the following observation: individual extensions can reveal sensitive information through their length. Thus, each extension in the inner ClientHello may require different amounts of padding. This padding may be fully determined by the client's configuration or may require server input.

By way of example, clients typically support a small number of application profiles. For instance, a browser might support HTTP with ALPN values ["http/1.1", "h2"] and WebRTC media with ALPNs ["webrtc", "c-webrtc"]. Clients SHOULD pad this extension by rounding up to the total size of the longest ALPN extension across all application profiles. The target padding length of most ClientHello extensions can be computed in this way.

In contrast, clients do not know the longest SNI value in the client-facing server's anonymity set without server input. Clients SHOULD use the ECHConfig's maximum_name_length field as follows, where L is the maximum_name_length value.

1. If the ClientHelloInner contained a "server_name" extension with a name of length D, add $\max(0, L - D)$ bytes of padding.
2. If the ClientHelloInner did not contain a "server_name" extension (e.g., if the client is connecting to an IP address), add $L + 9$ bytes of padding. This is the length of a "server_name" extension with an L-byte name.

Finally, the client SHOULD pad the entire message as follows:

1. Let L be the length of the EncodedClientHelloInner with all the padding computed so far.
2. Let $N = 31 - ((L - 1) \% 32)$ and add N bytes of padding.

This rounds the length of EncodedClientHelloInner up to a multiple of 32 bytes, reducing the set of possible lengths across all clients.

In addition to padding ClientHelloInner, clients and servers will also need to pad all other handshake messages that have sensitive-length fields. For example, if a client proposes ALPN values in ClientHelloInner, the server-selected value will be returned in an EncryptedExtension, so that handshake message also needs to be padded using TLS record layer padding.

6.1.4. Determining ECH Acceptance

As described in Section 7, the server may either accept ECH and use ClientHelloInner or reject it and use ClientHelloOuter. This is determined by the server's initial message.

If the message does not negotiate TLS 1.3 or higher, the server has rejected ECH. Otherwise, it is either a ServerHello or HelloRetryRequest.

If the message is a ServerHello, the client computes `accept_confirmation` as described in Section 7.2. If this value matches the last 8 bytes of `ServerHello.random`, the server has accepted ECH. Otherwise, it has rejected ECH.

If the message is a HelloRetryRequest, the client checks for the "encrypted_client_hello" extension. If none is found, the server has rejected ECH. Otherwise, if it has a length other than 8, the client aborts the handshake with a "decode_error" alert. Otherwise, the client computes `hrr_accept_confirmation` as described in Section 7.2.1. If this value matches the extension payload, the server has accepted ECH. Otherwise, it has rejected ECH.

[[OPEN ISSUE: Depending on what we do for issue#450, it may be appropriate to change the client behavior if the HRR extension is present but with the wrong value.]]

If the server accepts ECH, the client handshakes with ClientHelloInner as described in Section 6.1.5. Otherwise, the client handshakes with ClientHelloOuter as described in Section 6.1.6.

6.1.5. Handshaking with ClientHelloInner

If the server accepts ECH, the client proceeds with the connection as in [RFC8446], with the following modifications:

The client behaves as if it had sent ClientHelloInner as the ClientHello. That is, it evaluates the handshake using the ClientHelloInner's preferences, and, when computing the transcript hash (Section 4.4.1 of [RFC8446]), it uses ClientHelloInner as the first ClientHello.

If the server responds with a HelloRetryRequest, the client computes the updated ClientHello message as follows:

1. It computes a second ClientHelloInner based on the first ClientHelloInner, as in Section 4.1.4 of [RFC8446]. The ClientHelloInner's "encrypted_client_hello" extension is left unmodified.
2. It constructs EncodedClientHelloInner as described in Section 5.1.
3. It constructs a second partial ClientHelloOuterAAD message. This message MUST be syntactically valid. The extensions MAY be copied from the original ClientHelloOuter unmodified, or omitted. If not sensitive, the client MAY copy updated extensions from the second ClientHelloInner for compression.
4. It encrypts EncodedClientHelloInner as described in Section 6.1.1, using the second partial ClientHelloOuterAAD, to obtain a second ClientHelloOuter. It reuses the original HPKE encryption context computed in Section 6.1 and uses the empty string for enc.

The HPKE context maintains a sequence number, so this operation internally uses a fresh nonce for each AEAD operation. Reusing the HPKE context avoids an attack described in Section 10.12.2.

The client then sends the second ClientHelloOuter to the server. However, as above, it uses the second ClientHelloInner for preferences, and both the ClientHelloInner messages for the transcript hash. Additionally, it checks the resulting ServerHello for ECH acceptance as in Section 6.1.4. If the ServerHello does not also indicate ECH acceptance, the client MUST terminate the connection with an "illegal_parameter" alert.

6.1.6. Handshaking with ClientHelloOuter

If the server rejects ECH, the client proceeds with the handshake, authenticating for `ECHConfig.contents.public_name` as described in Section 6.1.7. If authentication or the handshake fails, the client MUST return a failure to the calling application. It MUST NOT use the retry configurations. It MUST NOT treat this as a secure signal to disable ECH.

If the server supplied an "encrypted_client_hello" extension in its EncryptedExtensions message, the client MUST check that it is syntactically valid and the client MUST abort the connection with a "decode_error" alert otherwise. If an earlier TLS version was negotiated, the client MUST NOT enable the False Start optimization [RFC7918] for this handshake. If both authentication and the handshake complete successfully, the client MUST perform the processing described below then abort the connection with an "ech_required" alert before sending any application data to the server.

If the server provided "retry_configs" and if at least one of the values contains a version supported by the client, the client can regard the ECH keys as securely replaced by the server. It SHOULD retry the handshake with a new transport connection, using the retry configurations supplied by the server.

Clients can implement a new transport connection in a way that best suits their deployment. For example, clients can reuse the same IP address when establishing the new transport connection or they can choose to use a different IP address if provided with options from DNS. ECH does not mandate any specific implementation choices when establishing this new connection.

The retry configurations are meant to be used for retried connections. Further use of retry configurations could yield a tracking vector. In settings where the client will otherwise already let the server track the client, e.g., because the client will send cookies to the server in parallel connections, using the retry configurations for these parallel connections does not introduce a new tracking vector.

If none of the values provided in "retry_configs" contains a supported version, the server did not supply an "encrypted_client_hello" extension in its EncryptedExtensions message, or an earlier TLS version was negotiated, the client can regard ECH as securely disabled by the server, and it SHOULD retry the handshake with a new transport connection and ECH disabled.

Clients SHOULD implement a limit on retries caused by receipt of "retry_configs" or servers which do not acknowledge the "encrypted_client_hello" extension. If the client does not retry in either scenario, it MUST report an error to the calling application.

6.1.7. Authenticating for the Public Name

When the server rejects ECH, it continues with the handshake using the plaintext "server_name" extension instead (see Section 7). Clients that offer ECH then authenticate the connection with the public name, as follows:

- * The client MUST verify that the certificate is valid for ECHConfig.contents.public_name. If invalid, it MUST abort the connection with the appropriate alert.
- * If the server requests a client certificate, the client MUST respond with an empty Certificate message, denoting no client certificate.

In verifying the client-facing server certificate, the client MUST interpret the public name as a DNS-based reference identity. Clients that incorporate DNS names and IP addresses into the same syntax (e.g. [RFC3986], Section 7.4 and [WHATWG-IPV4]) MUST reject names that would be interpreted as IPv4 addresses. Clients that enforce this by checking ECHConfig.contents.public_name do not need to repeat the check at this layer.

Note that authenticating a connection for the public name does not authenticate it for the origin. The TLS implementation MUST NOT report such connections as successful to the application. It additionally MUST ignore all session tickets and session IDs presented by the server. These connections are only used to trigger retries, as described in Section 6.1.6. This may be implemented, for instance, by reporting a failed connection with a dedicated error code.

6.2. GREASE ECH

If the client attempts to connect to a server and does not have an ECHConfig structure available for the server, it SHOULD send a GREASE [RFC8701] "encrypted_client_hello" extension in the first ClientHello as follows:

- * Set the config_id field to a random byte.

- * Set the `cipher_suite` field to a supported `HpkeSymmetricCipherSuite`. The selection SHOULD vary to exercise all supported configurations, but MAY be held constant for successive connections to the same server in the same session.
- * Set the `enc` field to a randomly-generated valid encapsulated public key output by the HPKE KEM.
- * Set the `payload` field to a randomly-generated string of `L+C` bytes, where `C` is the ciphertext expansion of the selected AEAD scheme and `L` is the size of the `EncodedClientHelloInner` the client would compute when offering ECH, padded according to Section 6.1.3.

If sending a second `ClientHello` in response to a `HelloRetryRequest`, the client copies the entire `"encrypted_client_hello"` extension from the first `ClientHello`. The identical value will reveal to an observer that the value of `"encrypted_client_hello"` was fake, but this only occurs if there is a `HelloRetryRequest`.

If the server sends an `"encrypted_client_hello"` extension in either `HelloRetryRequest` or `EncryptedExtensions`, the client MUST check the extension syntactically and abort the connection with a `"decode_error"` alert if it is invalid. It otherwise ignores the extension. It MUST NOT save the `"retry_configs"` value in `EncryptedExtensions`.

Offering a GREASE extension is not considered offering an encrypted `ClientHello` for purposes of requirements in Section 6.1. In particular, the client MAY offer to resume sessions established without ECH.

7. Server Behavior

As described in `{#topologies}`, servers can play two roles, either as the client-facing server or as the back-end server. Depending on the server role, the `ECHClientHello` will be different:

- * A client-facing server expects a `ECHClientHello.type` of `outer`, and proceeds as described in Section 7.1 to extract a `ClientHelloInner`, if available.
- * A backend server expects a `ECHClientHello.type` of `inner`, and proceeds as described in Section 7.2.

In split mode, a client-facing server which receives a ClientHello with ECHClientHello.type of inner MUST abort with an "illegal_parameter" alert. Similarly, in split mode, a backend server which receives a ClientHello with ECHClientHello.type of outer MUST abort with an "illegal_parameter" alert.

In shared mode, a server plays both roles, first decrypting the ClientHelloOuter and then using the contents of the ClientHelloInner. A shared mode server which receives a ClientHello with ECHClientHello.type of outer MUST abort with an "illegal_parameter" alert, because such a ClientHello should never be received directly from the network.

If ECHClientHello.type is not a valid ECHClientHelloType, then the server MUST abort with an "illegal_parameter" alert.

If the "encrypted_client_hello" is not present, then the server completes the handshake normally, as described in [RFC8446].

7.1. Client-Facing Server

Upon receiving an "encrypted_client_hello" extension in an initial ClientHello, the client-facing server determines if it will accept ECH, prior to negotiating any other TLS parameters. Note that successfully decrypting the extension will result in a new ClientHello to process, so even the client's TLS version preferences may have changed.

First, the server collects a set of candidate ECHConfig values. This list is determined by one of the two following methods:

1. Compare ECHClientHello.config_id against identifiers of each known ECHConfig and select the ones that match, if any, as candidates.
2. Collect all known ECHConfig values as candidates, with trial decryption below determining the final selection.

Some uses of ECH, such as local discovery mode, may randomize the ECHClientHello.config_id since it can be used as a tracking vector. In such cases, the second method SHOULD be used for matching the ECHClientHello to a known ECHConfig. See Section 10.4. Unless specified by the application profile or otherwise externally configured, implementations MUST use the first method.

The server then iterates over the candidate ECHConfig values, attempting to decrypt the "encrypted_client_hello" extension as follows.

The server verifies that the ECHConfig supports the cipher suite indicated by the ECHClientHello.cipher_suite and that the version of ECH indicated by the client matches the ECHConfig.version. If not, the server continues to the next candidate ECHConfig.

Next, the server decrypts ECHClientHello.payload, using the private key skR corresponding to ECHConfig, as follows:

```
context = SetupBaseR(ECHClientHello.enc, skR,  
                    "tls ech" || 0x00 || ECHConfig)  
EncodedClientHelloInner = context.Open(ClientHelloOuterAAD,  
                                       ECHClientHello.payload)
```

ClientHelloOuterAAD is computed from ClientHelloOuter as described in Section 5.2. The info parameter to SetupBaseR is the concatenation "tls ech", a zero byte, and the serialized ECHConfig. If decryption fails, the server continues to the next candidate ECHConfig. Otherwise, the server reconstructs ClientHelloInner from EncodedClientHelloInner, as described in Section 5.1. It then stops iterating over the candidate ECHConfig values.

Once the server has chosen the correct ECHConfig, it MAY verify that the value in the ClientHelloOuter "server_name" extension matches the value of ECHConfig.contents.public_name, and abort with an "illegal_parameter" alert if these do not match. This optional check allows the server to limit ECH connections to only use the public SNI values advertised in its ECHConfigs. The server MUST be careful not to unnecessarily reject connections if the same ECHConfig id or keypair is used in multiple ECHConfigs with distinct public names.

Upon determining the ClientHelloInner, the client-facing server checks that the message includes a well-formed "encrypted_client_hello" extension of type inner and that it does not offer TLS 1.2 or below. If either of these checks fails, the client-facing server MUST abort with an "illegal_parameter" alert.

If these checks succeed, the client-facing server then forwards the ClientHelloInner to the appropriate backend server, which proceeds as in Section 7.2. If the backend server responds with a HelloRetryRequest, the client-facing server forwards it, decrypts the client's second ClientHelloOuter using the procedure in Section 7.1.1, and forwards the resulting second ClientHelloInner. The client-facing server forwards all other TLS messages between the client and backend server unmodified.

Otherwise, if all candidate ECHConfig values fail to decrypt the extension, the client-facing server MUST ignore the extension and proceed with the connection using ClientHelloOuter, with the following modifications:

- * If sending a HelloRetryRequest, the server MAY include an "encrypted_client_hello" extension with a payload of 8 random bytes; see Section 10.10.4 for details.
- * If the server is configured with any ECHConfigs, it MUST include the "encrypted_client_hello" extension in its EncryptedExtensions with the "retry_configs" field set to one or more ECHConfig structures with up-to-date keys. Servers MAY supply multiple ECHConfig values of different versions. This allows a server to support multiple versions at once.

Note that decryption failure could indicate a GREASE ECH extension (see Section 6.2), so it is necessary for servers to proceed with the connection and rely on the client to abort if ECH was required. In particular, the unrecognized value alone does not indicate a misconfigured ECH advertisement (Section 8.1.1). Instead, servers can measure occurrences of the "ech_required" alert to detect this case.

7.1.1. Sending HelloRetryRequest

After sending or forwarding a HelloRetryRequest, the client-facing server does not repeat the steps in Section 7.1 with the second ClientHelloOuter. Instead, it continues with the ECHConfig selection from the first ClientHelloOuter as follows:

If the client-facing server accepted ECH, it checks the second ClientHelloOuter also contains the "encrypted_client_hello" extension. If not, it MUST abort the handshake with a "missing_extension" alert. Otherwise, it checks that ECHClientHello.cipher_suite and ECHClientHello.config_id are unchanged, and that ECHClientHello.enc is empty. If not, it MUST abort the handshake with an "illegal_parameter" alert.

Finally, it decrypts the new ECHClientHello.payload as a second message with the previous HPKE context:

```
EncodedClientHelloInner = context.Open(ClientHelloOuterAAD,  
                                       ECHClientHello.payload)
```

ClientHelloOuterAAD is computed as described in Section 5.2, but using the second ClientHelloOuter. If decryption fails, the client-facing server MUST abort the handshake with a "decrypt_error" alert.

Otherwise, it reconstructs the second ClientHelloInner from the new EncodedClientHelloInner as described in Section 5.1, using the second ClientHelloOuter for any referenced extensions.

The client-facing server then forwards the resulting ClientHelloInner to the backend server. It forwards all subsequent TLS messages between the client and backend server unmodified.

If the client-facing server rejected ECH, or if the first ClientHello did not include an "encrypted_client_hello" extension, the client-facing server proceeds with the connection as usual. The server does not decrypt the second ClientHello's ECHClientHello.payload value, if there is one. Moreover, if the server is configured with any ECHConfigs, it MUST include the "encrypted_client_hello" extension in its EncryptedExtensions with the "retry_configs" field set to one or more ECHConfig structures with up-to-date keys, as described in Section 7.1.

Note that a client-facing server that forwards the first ClientHello cannot include its own "cookie" extension if the backend server sends a HelloRetryRequest. This means that the client-facing server either needs to maintain state for such a connection or it needs to coordinate with the backend server to include any information it requires to process the second ClientHello.

7.2. Backend Server

Upon receipt of an "encrypted_client_hello" extension of type inner in a ClientHello, if the backend server negotiates TLS 1.3 or higher, then it MUST confirm ECH acceptance to the client by computing its ServerHello as described here.

The backend server embeds in ServerHello.random a string derived from the inner handshake. It begins by computing its ServerHello as usual, except the last 8 bytes of ServerHello.random are set to zero. It then computes the transcript hash for ClientHelloInner up to and including the modified ServerHello, as described in [RFC8446], Section 4.4.1. Let transcript_ech_conf denote the output. Finally, the backend server overwrites the last 8 bytes of the ServerHello.random with the following string:

```
accept_confirmation = HKDF-Expand-Label(  
    HKDF-Extract(0, ClientHelloInner.random),  
    "ech accept confirmation",  
    transcript_ech_conf,  
    8)
```

where HKDF-Expand-Label is defined in [RFC8446], Section 7.1, "0" indicates a string of Hash.length bytes set to zero, and Hash is the hash function used to compute the transcript hash.

The backend server MUST NOT perform this operation if it negotiated TLS 1.2 or below. Note that doing so would overwrite the downgrade signal for TLS 1.3 (see [RFC8446], Section 4.1.3).

7.2.1. Sending HelloRetryRequest

When the backend server sends HelloRetryRequest in response to the ClientHello, it similarly confirms ECH acceptance by adding a confirmation signal to its HelloRetryRequest. But instead of embedding the signal in the HelloRetryRequest.random (the value of which is specified by [RFC8446]), it sends the signal in an extension.

The backend server begins by computing HelloRetryRequest as usual, except that it also contains an "encrypted_client_hello" extension with a payload of 8 zero bytes. It then computes the transcript hash for the first ClientHelloInner, denoted ClientHelloInner1, up to and including the modified HelloRetryRequest. Let transcript_hrr_ech_conf denote the output. Finally, the backend server overwrites the payload of the "encrypted_client_hello" extension with the following string:

```
hrr_accept_confirmation = HKDF-Expand-Label(  
    HKDF-Extract(0, ClientHelloInner1.random),  
    "hrr ech accept confirmation",  
    transcript_hrr_ech_conf,  
    8)
```

In the subsequent ServerHello message, the backend server sends the accept_confirmation value as described in Section 7.2.

8. Deployment Considerations

The design of ECH as specified in this document necessarily requires changes to client, client-facing server, and backend server. Coordination between client-facing and backend server requires care, as deployment mistakes can lead to compatibility issues. These are discussed in Section 8.1.

Beyond coordination difficulties, ECH deployments may also induce challenges for use cases of information that ECH protects. In particular, use cases which depend on this unencrypted information may no longer work as desired. This is elaborated upon in Section 8.2.

8.1. Compatibility Issues

Unlike most TLS extensions, placing the SNI value in an ECH extension is not interoperable with existing servers, which expect the value in the existing plaintext extension. Thus server operators SHOULD ensure servers understand a given set of ECH keys before advertising them. Additionally, servers SHOULD retain support for any previously-advertised keys for the duration of their validity.

However, in more complex deployment scenarios, this may be difficult to fully guarantee. Thus this protocol was designed to be robust in case of inconsistencies between systems that advertise ECH keys and servers, at the cost of extra round-trips due to a retry. Two specific scenarios are detailed below.

8.1.1. Misconfiguration and Deployment Concerns

It is possible for ECH advertisements and servers to become inconsistent. This may occur, for instance, from DNS misconfiguration, caching issues, or an incomplete rollout in a multi-server deployment. This may also occur if a server loses its ECH keys, or if a deployment of ECH must be rolled back on the server.

The retry mechanism repairs inconsistencies, provided the server is authoritative for the public name. If server and advertised keys mismatch, the server will reject ECH and respond with "retry_configs". If the server does not understand the "encrypted_client_hello" extension at all, it will ignore it as required by Section 4.1.2 of [RFC8446]. Provided the server can present a certificate valid for the public name, the client can safely retry with updated settings, as described in Section 6.1.6.

Unless ECH is disabled as a result of successfully establishing a connection to the public name, the client MUST NOT fall back to using unencrypted ClientHellos, as this allows a network attacker to disclose the contents of this ClientHello, including the SNI. It MAY attempt to use another server from the DNS results, if one is provided.

In order to ensure that the retry mechanism works successfully servers SHOULD ensure that every endpoint which might receive a TLS connection is provisioned with an appropriate certificate for the public name. This is especially important during periods of server reconfiguration when different endpoints might have different configurations.

8.1.2. Middleboxes

The requirements in [RFC8446], Section 9.3 which require proxies to act as conforming TLS client and server provide interoperability with TLS-terminating proxies even in cases where the server supports ECH but the proxy does not, as detailed below.

The proxy must ignore unknown parameters, and generate its own ClientHello containing only parameters it understands. Thus, when presenting a certificate to the client or sending a ClientHello to the server, the proxy will act as if connecting to the ClientHelloOuter server_name, which SHOULD match the public name (see Section 6.1), without echoing the "encrypted_client_hello" extension.

Depending on whether the client is configured to accept the proxy's certificate as authoritative for the public name, this may trigger the retry logic described in Section 6.1.6 or result in a connection failure. A proxy which is not authoritative for the public name cannot forge a signal to disable ECH.

8.2. Deployment Impact

Some use cases which depend on information ECH encrypts may break with the deployment of ECH. The extent of breakage depends on a number of external factors, including, for example, whether ECH can be disabled, whether or not the party disabling ECH is trusted to do so, and whether or not client implementations will fall back to TLS without ECH in the event of disablement.

Depending on implementation details and deployment settings, use cases which depend on plaintext TLS information may require fundamentally different approaches to continue working. For example, in managed enterprise settings, one approach may be to disable ECH entirely via group policy and for client implementations to honor this action.

In the context of Section 6.1.6, another approach may be to intercept and decrypt client TLS connections. The feasibility of alternative solutions is specific to individual deployments.

9. Compliance Requirements

In the absence of an application profile standard specifying otherwise, a compliant ECH application MUST implement the following HPKE cipher suite:

* KEM: DHKEM(X25519, HKDF-SHA256) (see Section 7.1 of [HPKE])

- * KDF: HKDF-SHA256 (see Section 7.2 of [HPKE])
- * AEAD: AES-128-GCM (see Section 7.3 of [HPKE])

10. Security Considerations

This section contains security considerations for ECH.

10.1. Security and Privacy Goals

ECH considers two types of attackers: passive and active. Passive attackers can read packets from the network, but they cannot perform any sort of active behavior such as probing servers or querying DNS. A middlebox that filters based on plaintext packet contents is one example of a passive attacker. In contrast, active attackers can also write packets into the network for malicious purposes, such as interfering with existing connections, probing servers, and querying DNS. In short, an active attacker corresponds to the conventional threat model for TLS 1.3 [RFC8446].

Passive and active attackers can exist anywhere in the network, including between the client and client-facing server, as well as between the client-facing and backend servers when running ECH in Split Mode. However, for Split Mode in particular, ECH makes two additional assumptions:

1. The channel between each client-facing and each backend server is authenticated such that the backend server only accepts messages from trusted client-facing servers. The exact mechanism for establishing this authenticated channel is out of scope for this document.
2. The attacker cannot correlate messages between client and client-facing server with messages between client-facing and backend server. Such correlation could allow an attacker to link information unique to a backend server, such as their server name or IP address, with a client's encrypted ClientHelloInner. Correlation could occur through timing analysis of messages across the client-facing server, or via examining the contents of messages sent between client-facing and backend servers. The exact mechanism for preventing this sort of correlation is out of scope for this document.

Given this threat model, the primary goals of ECH are as follows.

1. Security preservation. Use of ECH does not weaken the security properties of TLS without ECH.

2. Handshake privacy. TLS connection establishment to a host within an anonymity set is indistinguishable from a connection to any other host within the anonymity set. (The anonymity set is defined in Section 1.)
3. Downgrade resistance. An attacker cannot downgrade a connection that attempts to use ECH to one that does not use ECH.

These properties were formally proven in [ECH-Analysis].

With regards to handshake privacy, client-facing server configuration determines the size of the anonymity set. For example, if a client-facing server uses distinct ECHConfig values for each host, then each anonymity set has size $k = 1$. Client-facing servers SHOULD deploy ECH in such a way so as to maximize the size of the anonymity set where possible. This means client-facing servers should use the same ECHConfig for as many hosts as possible. An attacker can distinguish two hosts that have different ECHConfig values based on the ECHClientHello.config_id value. This also means public information in a TLS handshake should be consistent across hosts. For example, if a client-facing server services many backend origin hosts, only one of which supports some cipher suite, it may be possible to identify that host based on the contents of unencrypted handshake messages.

Beyond these primary security and privacy goals, ECH also aims to hide, to some extent, the fact that it is being used at all. Specifically, the GREASE ECH extension described in Section 6.2 does not change the security properties of the TLS handshake at all. Its goal is to provide "cover" for the real ECH protocol (Section 6.1), as a means of addressing the "do not stick out" requirements of [RFC8744]. See Section 10.10.4 for details.

10.2. Unauthenticated and Plaintext DNS

In comparison to [I-D.kazuho-protected-sni], wherein DNS Resource Records are signed via a server private key, ECH records have no authenticity or provenance information. This means that any attacker which can inject DNS responses or poison DNS caches, which is a common scenario in client access networks, can supply clients with fake ECH records (so that the client encrypts data to them) or strip the ECH record from the response. However, in the face of an attacker that controls DNS, no encryption scheme can work because the attacker can replace the IP address, thus blocking client connections, or substitute a unique IP address which is 1:1 with the DNS name that was looked up (modulo DNS wildcards). Thus, allowing the ECH records in the clear does not make the situation significantly worse.

Clearly, DNSSEC (if the client validates and hard fails) is a defense against this form of attack, but DoH/DPRIVE are also defenses against DNS attacks by attackers on the local network, which is a common case where ClientHello and SNI encryption are desired. Moreover, as noted in the introduction, SNI encryption is less useful without encryption of DNS queries in transit via DoH or DPRIVE mechanisms.

10.3. Client Tracking

A malicious client-facing server could distribute unique, per-client ECHConfig structures as a way of tracking clients across subsequent connections. On-path adversaries which know about these unique keys could also track clients in this way by observing TLS connection attempts.

The cost of this type of attack scales linearly with the desired number of target clients. Moreover, DNS caching behavior makes targeting individual users for extended periods of time, e.g., using per-client ECHConfig structures delivered via HTTPS RRs with high TTLs, challenging. Clients can help mitigate this problem by flushing any DNS or ECHConfig state upon changing networks.

10.4. Ignored Configuration Identifiers and Trial Decryption

Ignoring configuration identifiers may be useful in scenarios where clients and client-facing servers do not want to reveal information about the client-facing server in the "encrypted_client_hello" extension. In such settings, clients send a randomly generated config_id in the ECHClientHello. Servers in these settings must perform trial decryption since they cannot identify the client's chosen ECH key using the config_id value. As a result, ignoring configuration identifiers may exacerbate DoS attacks. Specifically, an adversary may send malicious ClientHello messages, i.e., those which will not decrypt with any known ECH key, in order to force wasteful decryption. Servers that support this feature should, for example, implement some form of rate limiting mechanism to limit the potential damage caused by such attacks.

Unless specified by the application using (D)TLS or externally configured, implementations MUST NOT use this mode.

10.5. Outer ClientHello

Any information that the client includes in the ClientHelloOuter is visible to passive observers. The client SHOULD NOT send values in the ClientHelloOuter which would reveal a sensitive ClientHelloInner property, such as the true server name. It MAY send values associated with the public name in the ClientHelloOuter.

In particular, some extensions require the client send a server-name-specific value in the ClientHello. These values may reveal information about the true server name. For example, the "cached_info" ClientHello extension [RFC7924] can contain the hash of a previously observed server certificate. The client SHOULD NOT send values associated with the true server name in the ClientHelloOuter. It MAY send such values in the ClientHelloInner.

A client may also use different preferences in different contexts. For example, it may send a different ALPN lists to different servers or in different application contexts. A client that treats this context as sensitive SHOULD NOT send context-specific values in ClientHelloOuter.

Values which are independent of the true server name, or other information the client wishes to protect, MAY be included in ClientHelloOuter. If they match the corresponding ClientHelloInner, they MAY be compressed as described in Section 5.1. However, note that the payload length reveals information about which extensions are compressed, so inner extensions which only sometimes match the corresponding outer extension SHOULD NOT be compressed.

Clients MAY include additional extensions in ClientHelloOuter to avoid signaling unusual behavior to passive observers, provided the choice of value and value itself are not sensitive. See Section 10.10.4.

10.6. Inner ClientHello

Values which depend on the contents of ClientHelloInner, such as the true server name, can influence how client-facing servers process this message. In particular, timing side channels can reveal information about the contents of ClientHelloInner. Implementations should take such side channels into consideration when reasoning about the privacy properties that ECH provides.

10.7. Related Privacy Leaks

ECH requires encrypted DNS to be an effective privacy protection mechanism. However, verifying the server's identity from the Certificate message, particularly when using the X509 CertificateType, may result in additional network traffic that may reveal the server identity. Examples of this traffic may include requests for revocation information, such as OCSP or CRL traffic, or requests for repository information, such as authorityInformationAccess. It may also include implementation-specific traffic for additional information sources as part of verification.

Implementations SHOULD avoid leaking information that may identify the server. Even when sent over an encrypted transport, such requests may result in indirect exposure of the server's identity, such as indicating a specific CA or service being used. To mitigate this risk, servers SHOULD deliver such information in-band when possible, such as through the use of OCSP stapling, and clients SHOULD take steps to minimize or protect such requests during certificate validation.

Attacks that rely on non-ECH traffic to infer server identity in an ECH connection are out of scope for this document. For example, a client that connects to a particular host prior to ECH deployment may later resume a connection to that same host after ECH deployment. An adversary that observes this can deduce that the ECH-enabled connection was made to a host that the client previously connected to and which is within the same anonymity set.

10.8. Cookies

Section 4.2.2 of [RFC8446] defines a cookie value that servers may send in HelloRetryRequest for clients to echo in the second ClientHello. While ECH encrypts the cookie in the second ClientHelloInner, the backend server's HelloRetryRequest is unencrypted. This means differences in cookies between backend servers, such as lengths or cleartext components, may leak information about the server identity.

Backend servers in an anonymity set SHOULD NOT reveal information in the cookie which identifies the server. This may be done by handling HelloRetryRequest statefully, thus not sending cookies, or by using the same cookie construction for all backend servers.

Note that, if the cookie includes a key name, analogous to Section 4 of [RFC5077], this may leak information if different backend servers issue cookies with different key names at the time of the connection. In particular, if the deployment operates in Split Mode, the backend servers may not share cookie encryption keys. Backend servers may mitigate this by either handling key rotation with trial decryption, or coordinating to match key names.

10.9. Attacks Exploiting Acceptance Confirmation

To signal acceptance, the backend server overwrites 8 bytes of its ServerHello.random with a value derived from the ClientHelloInner.random. (See Section 7.2 for details.) This behavior increases the likelihood of the ServerHello.random colliding with the ServerHello.random of a previous session, potentially reducing the overall security of the protocol. However, the

remaining 24 bytes provide enough entropy to ensure this is not a practical avenue of attack.

On the other hand, the probability that two 8-byte strings are the same is non-negligible. This poses a modest operational risk. Suppose the client-facing server terminates the connection (i.e., ECH is rejected or bypassed): if the last 8 bytes of its `ServerHello.random` coincide with the confirmation signal, then the client will incorrectly presume acceptance and proceed as if the backend server terminated the connection. However, the probability of a false positive occurring for a given connection is only 1 in 2^{64} . This value is smaller than the probability of network connection failures in practice.

Note that the same bytes of the `ServerHello.random` are used to implement downgrade protection for TLS 1.3 (see [RFC8446], Section 4.1.3). These mechanisms do not interfere because the backend server only signals ECH acceptance in TLS 1.3 or higher.

10.10. Comparison Against Criteria

[RFC8744] lists several requirements for SNI encryption. In this section, we re-iterate these requirements and assess the ECH design against them.

10.10.1. Mitigate Cut-and-Paste Attacks

Since servers process either `ClientHelloInner` or `ClientHelloOuter`, and because `ClientHelloInner.random` is encrypted, it is not possible for an attacker to "cut and paste" the ECH value in a different Client Hello and learn information from `ClientHelloInner`.

10.10.2. Avoid Widely Shared Secrets

This design depends upon DNS as a vehicle for semi-static public key distribution. Server operators may partition their private keys however they see fit provided each server behind an IP address has the corresponding private key to decrypt a key. Thus, when one ECH key is provided, sharing is optimally bound by the number of hosts that share an IP address. Server operators may further limit sharing by publishing different DNS records containing `ECHConfig` values with different keys using a short TTL.

10.10.3. Prevent SNI-Based Denial-of-Service Attacks

This design requires servers to decrypt ClientHello messages with ECHClientHello extensions carrying valid digests. Thus, it is possible for an attacker to force decryption operations on the server. This attack is bound by the number of valid transport connections an attacker can open.

10.10.4. Do Not Stick Out

As a means of reducing the impact of network ossification, [RFC8744] recommends SNI-protection mechanisms be designed in such a way that network operators do not differentiate connections using the mechanism from connections not using the mechanism. To that end, ECH is designed to resemble a standard TLS handshake as much as possible. The most obvious difference is the extension itself: as long as middleboxes ignore it, as required by [RFC8446], the rest of the handshake is designed to look very much as usual.

The GREASE ECH protocol described in Section 6.2 provides a low-risk way to evaluate the deployability of ECH. It is designed to mimic the real ECH protocol (Section 6.1) without changing the security properties of the handshake. The underlying theory is that if GREASE ECH is deployable without triggering middlebox misbehavior, and real ECH looks enough like GREASE ECH, then ECH should be deployable as well. Thus, our strategy for mitigating network ossification is to deploy GREASE ECH widely enough to disincentivize differential treatment of the real ECH protocol by the network.

Ensuring that networks do not differentiate between real ECH and GREASE ECH may not be feasible for all implementations. While most middleboxes will not treat them differently, some operators may wish to block real ECH usage but allow GREASE ECH. This specification aims to provide a baseline security level that most deployments can achieve easily, while providing implementations enough flexibility to achieve stronger security where possible. Minimally, real ECH is designed to be indistinguishable from GREASE ECH for passive adversaries with following capabilities:

1. The attacker does not know the ECHConfigList used by the server.
2. The attacker keeps per-connection state only. In particular, it does not track endpoints across connections.

Moreover, real ECH and GREASE ECH are designed so that the following features do not noticeably vary to the attacker, i.e., they are not distinguishers:

1. the code points of extensions negotiated in the clear, and their order;
2. the length of messages; and
3. the values of plaintext alert messages.

This leaves a variety of practical differentiators out-of-scope. including, though not limited to, the following:

1. the value of the configuration identifier;
2. the value of the outer SNI;
3. the TLS version negotiated, which may depend on ECH acceptance;
4. client authentication, which may depend on ECH acceptance; and
5. HRR issuance, which may depend on ECH acceptance.

These can be addressed with more sophisticated implementations, but some mitigations require coordination between the client and server, and even across different client and server implementations. These mitigations are out-of-scope for this specification.

10.10.5. Maintain Forward Secrecy

This design is not forward secret because the server's ECH key is static. However, the window of exposure is bound by the key lifetime. It is RECOMMENDED that servers rotate keys frequently.

10.10.6. Enable Multi-party Security Contexts

This design permits servers operating in Split Mode to forward connections directly to backend origin servers. The client authenticates the identity of the backend origin server, thereby avoiding unnecessary MiTM attacks.

Conversely, assuming ECH records retrieved from DNS are authenticated, e.g., via DNSSEC or fetched from a trusted Recursive Resolver, spoofing a client-facing server operating in Split Mode is not possible. See Section 10.2 for more details regarding plaintext DNS.

Authenticating the ECHConfig structure naturally authenticates the included public name. This also authenticates any retry signals from the client-facing server because the client validates the server certificate against the public name before retrying.

10.10.7. Support Multiple Protocols

This design has no impact on application layer protocol negotiation. It may affect connection routing, server certificate selection, and client certificate verification. Thus, it is compatible with multiple application and transport protocols. By encrypting the entire ClientHello, this design additionally supports encrypting the ALPN extension.

10.11. Padding Policy

Variations in the length of the ClientHelloInner ciphertext could leak information about the corresponding plaintext. Section 6.1.3 describes a RECOMMENDED padding mechanism for clients aimed at reducing potential information leakage.

10.12. Active Attack Mitigations

This section describes the rationale for ECH properties and mechanics as defenses against active attacks. In all the attacks below, the attacker is on-path between the target client and server. The goal of the attacker is to learn private information about the inner ClientHello, such as the true SNI value.

10.12.1. Client Reaction Attack Mitigation

This attack uses the client's reaction to an incorrect certificate as an oracle. The attacker intercepts a legitimate ClientHello and replies with a ServerHello, Certificate, CertificateVerify, and Finished messages, wherein the Certificate message contains a "test" certificate for the domain name it wishes to query. If the client decrypted the Certificate and failed verification (or leaked information about its verification process by a timing side channel), the attacker learns that its test certificate name was incorrect. As an example, suppose the client's SNI value in its inner ClientHello is "example.com," and the attacker replied with a Certificate for "test.com". If the client produces a verification failure alert because of the mismatch faster than it would due to the Certificate signature validation, information about the name leaks. Note that the attacker can also withhold the CertificateVerify message. In that scenario, a client which first verifies the Certificate would then respond similarly and leak the same information.

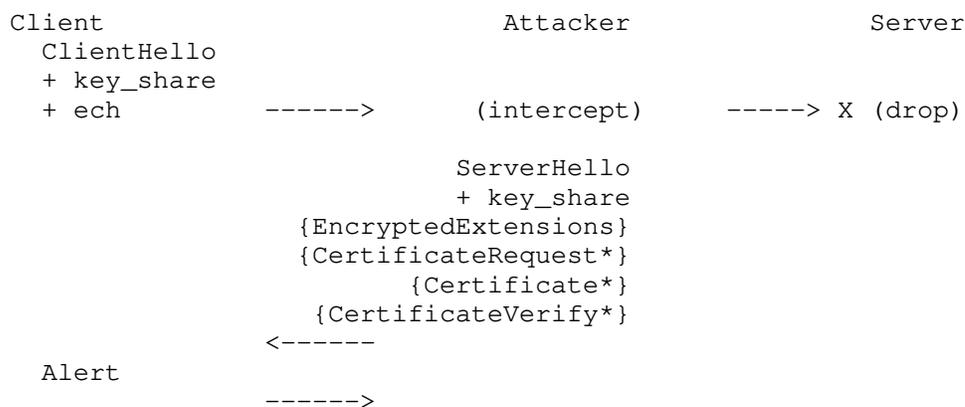


Figure 3: Client reaction attack

ClientHelloInner.random prevents this attack. In particular, since the attacker does not have access to this value, it cannot produce the right transcript and handshake keys needed for encrypting the Certificate message. Thus, the client will fail to decrypt the Certificate and abort the connection.

10.12.2. HelloRetryRequest Hijack Mitigation

This attack aims to exploit server HRR state management to recover information about a legitimate ClientHello using its own attacker-controlled ClientHello. To begin, the attacker intercepts and forwards a legitimate ClientHello with an "encrypted_client_hello" (ech) extension to the server, which triggers a legitimate HelloRetryRequest in return. Rather than forward the retry to the client, the attacker attempts to generate its own ClientHello in response based on the contents of the first ClientHello and HelloRetryRequest exchange with the result that the server encrypts the Certificate to the attacker. If the server used the SNI from the first ClientHello and the key share from the second (attacker-controlled) ClientHello, the Certificate produced would leak the client's chosen SNI to the attacker.

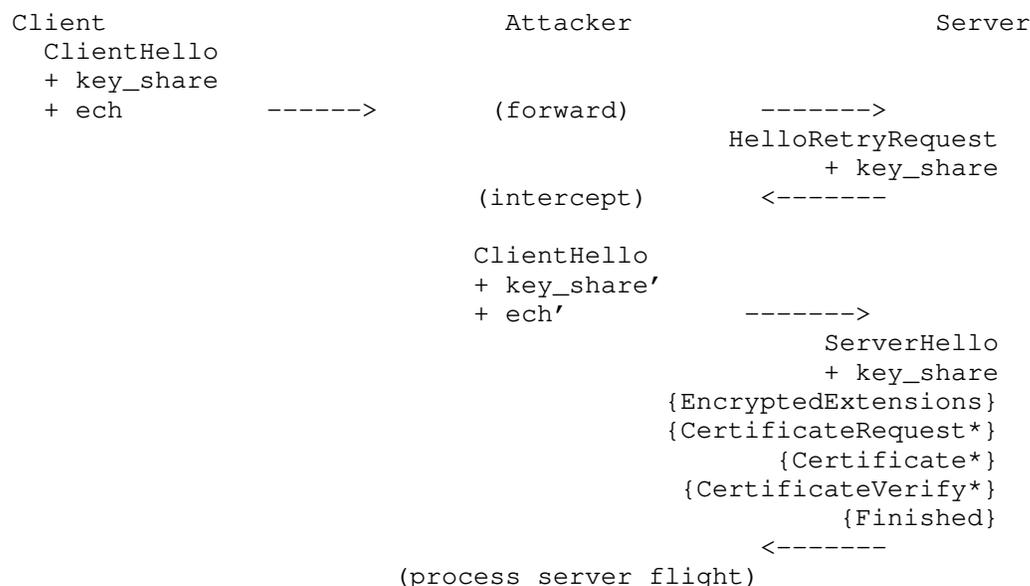


Figure 4: HelloRetryRequest hijack attack

This attack is mitigated by using the same HPKE context for both ClientHello messages. The attacker does not possess the context's keys, so it cannot generate a valid encryption of the second inner ClientHello.

If the attacker could manipulate the second ClientHello, it might be possible for the server to act as an oracle if it required parameters from the first ClientHello to match that of the second ClientHello. For example, imagine the client's original SNI value in the inner ClientHello is "example.com", and the attacker's hijacked SNI value in its inner ClientHello is "test.com". A server which checks these for equality and changes behavior based on the result can be used as an oracle to learn the client's SNI.

10.12.3. ClientHello Malleability Mitigation

This attack aims to leak information about secret parts of the encrypted ClientHello by adding attacker-controlled parameters and observing the server's response. In particular, the compression mechanism described in Section 5.1 references parts of a potentially attacker-controlled ClientHelloOuter to construct ClientHelloInner, or a buggy server may incorrectly apply parameters from ClientHelloOuter to the handshake.

To begin, the attacker first interacts with a server to obtain a resumption ticket for a given test domain, such as "example.com". Later, upon receipt of a ClientHelloOuter, it modifies it such that the server will process the resumption ticket with ClientHelloInner. If the server only accepts resumption PSKs that match the server name, it will fail the PSK binder check with an alert when ClientHelloInner is for "example.com" but silently ignore the PSK and continue when ClientHelloInner is for any other name. This introduces an oracle for testing encrypted SNI values.

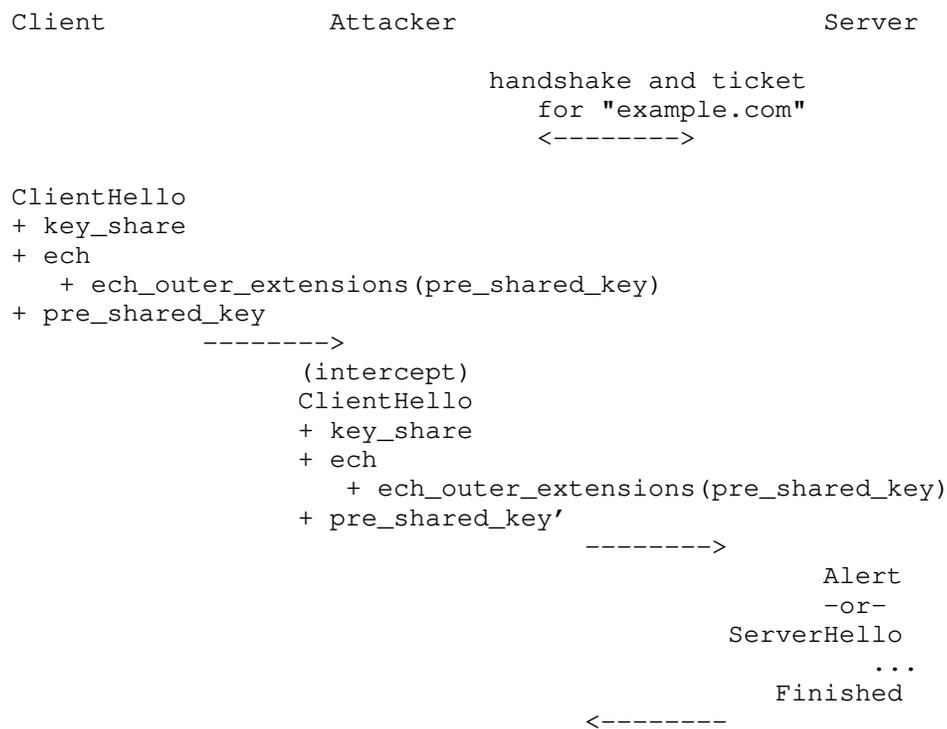


Figure 5: Message flow for malleable ClientHello

This attack may be generalized to any parameter which the server varies by server name, such as ALPN preferences.

ECH mitigates this attack by only negotiating TLS parameters from ClientHelloInner and authenticating all inputs to the ClientHelloInner (EncodedClientHelloInner and ClientHelloOuter) with the HPKE AEAD. See Section 5.2. The decompression process in Section 5.1 forbids "encrypted_client_hello" in OuterExtensions. This ensures the unauthenticated portion of ClientHelloOuter is not incorporated into ClientHelloInner. An earlier iteration of this

specification only encrypted and authenticated the "server_name" extension, which left the overall ClientHello vulnerable to an analogue of this attack.

10.12.4. ClientHelloInner Packet Amplification Mitigation

Client-facing servers must decompress EncodedClientHelloInners. A malicious attacker may craft a packet which takes excessive resources to decompress or may be much larger than the incoming packet:

- * If looking up a ClientHelloOuter extension takes time linear in the number of extensions, the overall decoding process would take $O(M*N)$ time, where M is the number of extensions in ClientHelloOuter and N is the size of OuterExtensions.
- * If the same ClientHelloOuter extension can be copied multiple times, an attacker could cause the client-facing server to construct a large ClientHelloInner by including a large extension in ClientHelloOuter, of length L , and an OuterExtensions list referencing N copies of that extension. The client-facing server would then use $O(N*L)$ memory in response to $O(N+L)$ bandwidth from the client. In split-mode, an $O(N*L)$ sized packet would then be transmitted to the backend server.

ECH mitigates this attack by requiring that OuterExtensions be referenced in order, that duplicate references be rejected, and by recommending that client-facing servers use a linear scan to perform decompression. These requirements are detailed in Section 5.1.

11. IANA Considerations

11.1. Update of the TLS ExtensionType Registry

IANA is requested to create the following entries in the existing registry for ExtensionType (defined in [RFC8446]):

1. encrypted_client_hello(0xfe0d), with "TLS 1.3" column values set to "CH, HRR, EE", "DTLS-Only" column set to "N", and "Recommended" column set to "Yes".
2. ech_outer_extensions(0xfd00), with the "TLS 1.3" column values set to "CH", "DTLS-Only" column set to "N", "Recommended" column set to "Yes", and the "Comment" column set to "Only appears in inner CH."

11.2. Update of the TLS Alert Registry

IANA is requested to create an entry, `ech_required(121)` in the existing registry for Alerts (defined in [RFC8446]), with the "DTLS-OK" column set to "Y".

11.3. ECH Configuration Extension Registry

IANA is requested to create a new "ECHConfig Extension" registry in a new "TLS Encrypted Client Hello (ECH) Configuration Extensions" page. New registrations need to list the following attributes:

Value: The two-byte identifier for the ECHConfigExtension, i.e., the ECHConfigExtensionType
Extension Name: Name of the ECHConfigExtension
Recommended: A "Y" or "N" value indicating if the extension is TLS WG recommends that the extension be supported. This column is assigned a value of "N" unless explicitly requested. Adding a value with a value of "Y" requires Standards Action [RFC8126].
Reference: The specification where the ECHConfigExtension is defined
Notes: Any notes associated with the entry

New entries in this registry are subject to the Specification Required registration policy ([RFC8126], Section 4.6).

The registration policy for for the "ECHConfig Extension Type" registry is Specification Required [RFC8126].

This document defines several Reserved values for ECH configuration extensions. These can be used by servers to "grease" the contents of the ECH configuration, as inspired by [RFC8701]. This helps ensure clients process ECH extensions correctly. When constructing ECH configurations, servers SHOULD randomly select from reserved values with the high-order bit clear. Correctly-implemented client will ignore those extensions.

The reserved values with the high-order bit set are mandatory, as defined in Section 4.2. Servers SHOULD randomly select from these values and include them in extraneous ECH configurations. These extraneous ECH configurations SHOULD have invalid keys, and public names which the server does not respond to. Correctly-implemented clients will ignore these configurations.

The initial contents for this registry consists of multiple reserved values, with the following attributes, which are repeated for each registration:

Value: 0x0000, 0x1A1A, 0x2A2A, 0x3A3A, 0x4A4A, 0x5A5A, 0x6A6A,

0x7A7A, 0x8A8A, 0x9A9A, 0xAAAA, 0xBABA, 0xCACA, 0xDADA, 0xEAEA,
0xFAFA

Extension Name: RESERVED

Recommended: Y

Reference: This document

Notes: None

12. References

12.1. Normative References

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Appendix A. ECHConfig Extension Guidance

Any future information or hints that influence ClientHelloOuter SHOULD be specified as ECHConfig extensions. This is primarily because the outer ClientHello exists only in support of ECH. Namely, it is both an envelope for the encrypted inner ClientHello and enabler for authenticated key mismatch signals (see Section 7). In contrast, the inner ClientHello is the true ClientHello used upon ECH negotiation.

Appendix B. Linear-time Outer Extension Processing

The following procedure processes the "ech_outer_extensions" extension (see Section 5.1) in linear time, ensuring that each referenced extension in the ClientHelloOuter is included at most once:

1. Let I be initialized to zero and N be set to the number of extensions in ClientHelloOuter.

2. For each extension type, E, in OuterExtensions:

- * If E is "encrypted_client_hello", abort the connection with an "illegal_parameter" alert and terminate this procedure.
- * While I is less than N and the I-th extension of ClientHelloOuter does not have type E, increment I.
- * If I is equal to N, abort the connection with an "illegal_parameter" alert and terminate this procedure.
- * Otherwise, the I-th extension of ClientHelloOuter has type E. Copy it to the EncodedClientHelloInner and increment I.

Appendix C. Acknowledgements

This document draws extensively from ideas in [I-D.kazuho-protected-sni], but is a much more limited mechanism because it depends on the DNS for the protection of the ECH key. Richard Barnes, Christian Huitema, Patrick McManus, Matthew Prince, Nick Sullivan, Martin Thomson, and David Benjamin also provided important ideas and contributions.

Appendix D. Change Log

RFC Editor's Note: Please remove this section prior to publication of a final version of this document.

Issue and pull request numbers are listed with a leading octothorp.

D.1. Since draft-ietf-tls-esni-16

- * Keep-alive

D.2. Since draft-ietf-tls-esni-15

- * Add CCS2022 reference and summary (#539)

D.3. Since draft-ietf-tls-esni-14

- * Keep-alive

D.4. Since draft-ietf-tls-esni-13

- * Editorial improvements

D.5. Since draft-ietf-tls-esni-12

- * Abort on duplicate OuterExtensions (#514)
- * Improve EncodedClientHelloInner definition (#503)
- * Clarify retry configuration usage (#498)
- * Expand on config_id generation implications (#491)
- * Server-side acceptance signal extension GREASE (#481)
- * Refactor overview, client implementation, and middlebox sections (#480, #478, #475, #508)
- * Editorial improvements (#485, #488, #490, #495, #496, #499, #500, #501, #504, #505, #507, #510, #511)

D.6. Since draft-ietf-tls-esni-11

- * Move ClientHello padding to the encoding (#443)
- * Align codepoints (#464)
- * Relax OuterExtensions checks for alignment with RFC8446 (#467)
- * Clarify HRR acceptance and rejection logic (#470)
- * Editorial improvements (#468, #465, #462, #461)

D.7. Since draft-ietf-tls-esni-10

- * Make HRR confirmation and ECH acceptance explicit (#422, #423)
- * Relax computation of the acceptance signal (#420, #449)
- * Simplify ClientHelloOuterAAD generation (#438, #442)
- * Allow empty enc in ECHClientHello (#444)
- * Authenticate ECHClientHello extensions position in ClientHelloOuterAAD (#410)
- * Allow clients to send a dummy PSK and early_data in ClientHelloOuter when applicable (#414, #415)
- * Compress ECHConfigContents (#409)

- * Validate ECHConfig.contents.public_name (#413, #456)
- * Validate ClientHelloInner contents (#411)
- * Note split-mode challenges for HRR (#418)
- * Editorial improvements (#428, #432, #439, #445, #458, #455)

D.8. Since draft-ietf-tls-esni-09

- * Finalize HPKE dependency (#390)
- * Move from client-computed to server-chosen, one-byte config identifier (#376, #381)
- * Rename ECHConfigs to ECHConfigList (#391)
- * Clarify some security and privacy properties (#385, #383)

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