

tls  
Internet-Draft  
Intended status: Standards Track  
Expires: 19 April 2021

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16 October 2020

TLS Encrypted Client Hello  
draft-ietf-tls-esni-08

Abstract

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

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Internet-Draft

TLS Encrypted Client Hello

October 2020

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## [1.](#) Introduction

DISCLAIMER: This is very early a work-in-progress design and has not yet seen significant (or really any) security analysis. It should not be used as a basis for building production systems.

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 information unencrypted in TLS 1.3.

The target domain may also be visible through other channels, such as plaintext client DNS queries, visible server IP addresses (assuming the server does not use domain-based virtual hosting), or other indirect mechanisms such as traffic analysis. 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. In such environments, the SNI remains the primary explicit signal used to determine the server's identity.

The TLS Working Group has studied the problem of protecting the SNI, but has been unable to develop a completely generic solution. [RFC8744] provides a description of the problem space and some of the proposed techniques. One of the more difficult problems is "Do not stick out" ([RFC8744], Section 3.4): if only sensitive or private services use SNI encryption, then SNI encryption is a signal that a client is going to such a service. For this reason, much recent work

has focused on concealing the fact that the SNI is being protected. Unfortunately, the result often has undesirable performance consequences, incomplete coverage, or both.

The protocol specified by this document takes a different approach. It assumes that private origins will co-locate with or hide behind a provider (reverse proxy, application server, etc.) that protects sensitive ClientHello parameters, including the SNI, for all of the domains it hosts. These co-located servers form an anonymity set wherein all elements have a consistent configuration, e.g., the set of supported application protocols, ciphersuites, TLS versions, and so on. 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. Thus, it leaks no more than what is already visible from the server IP address.

This document specifies a new TLS extension, called Encrypted Client Hello (ECH), that allows clients to encrypt their ClientHello to a supporting server. This protects the SNI and other potentially sensitive fields, such as the ALPN list [RFC7301]. This extension is only supported with (D)TLS 1.3 [RFC8446] and newer versions of the protocol.

## 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".

#### 3.1. Topologies

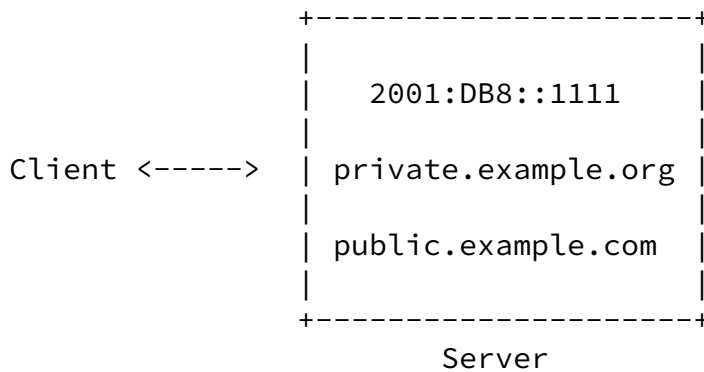
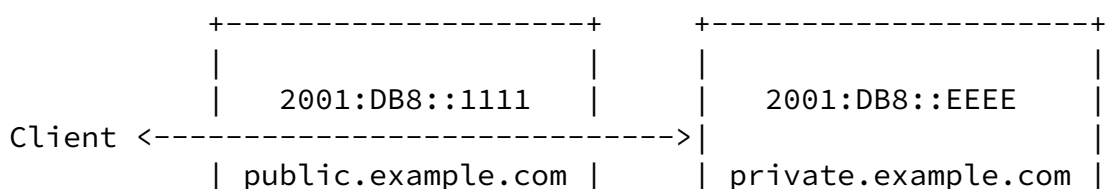


Figure 1: Shared Mode Topology

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.



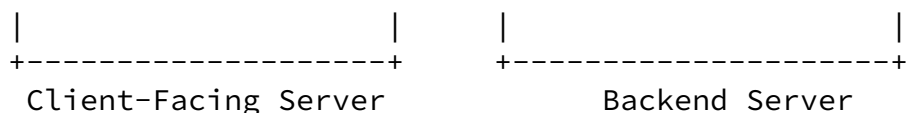


Figure 2: Split Mode Topology

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, service provider does not have access to the plaintext of the connection.

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.

### [3.2.](#) Encrypted ClientHello (ECH)

ECH allows the client to encrypt sensitive ClientHello extensions, e.g., SNI, ALPN, etc., under the public key of the client-facing server. This requires the client-facing server to publish the public key and metadata it uses for ECH for all the domains for which it serves directly or indirectly (via Split Mode). This document defines the format of the ECH encryption public key and metadata, referred to as an ECH configuration, and delegates DNS publication details to [\[HTTPS-RR\]](#), though other delivery mechanisms are possible. In particular, if some of the clients of a private server are applications rather than Web browsers, those applications might have the public key and metadata preconfigured.

When a client wants to establish a TLS session with the backend

server, it constructs its ClientHello as usual (we will refer to this as the ClientHelloInner message) and then encrypts this message using the public key of the ECH configuration. It then constructs a new ClientHello (ClientHelloOuter) with innocuous values for sensitive extensions, e.g., SNI, ALPN, etc., and with an "encrypted\_client\_hello" extension, which this document defines ([Section 5](#)). The extension's payload carries the encrypted ClientHelloInner and specifies the ECH configuration used for encryption. Finally, it sends ClientHelloOuter to the server.

Upon receiving the ClientHelloOuter, the client-facing server takes one of the following actions:

1. If it does not support ECH, it ignores the "encrypted\_client\_hello" extension and proceeds with the handshake as usual, per [\[RFC8446\]](#), [Section 4.1.2](#).
2. If it supports ECH but cannot decrypt the extension, then it terminates the handshake using the ClientHelloOuter. This is referred to as "ECH rejection". When ECH is rejected, the server sends an acceptable ECH configuration in its EncryptedExtensions message.
3. If it supports ECH and decrypts the extension, it forwards the ClientHelloInner to the backend, who terminates the connection. This is referred to as "ECH acceptance".

Upon receiving the server's response, the client determines whether or not ECH was accepted and proceeds with the handshake accordingly. (See [Section 6](#) for details.)

Informally, a primary goal of ECH is ensuring that connections to servers in the same anonymity set are indistinguishable from one another 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 [draft-05](#) of HPKE for public key encryption [[I-D.irtf-cfrg-hpke](#)]. The ECH configuration is defined by the following "ECHConfigs" structure.

```
opaque HpkePublicKey<1..2^16-1>;
uint16 HpkeKemId; // Defined in I-D.irtf-cfrg-hpke
uint16 HpkeKdfId; // Defined in I-D.irtf-cfrg-hpke
uint16 HpkeAeadId; // Defined in I-D.irtf-cfrg-hpke

struct {
    HpkeKdfId kdf_id;
    HpkeAeadId aead_id;
} ECHCipherSuite;

struct {
    opaque public_name<1..2^16-1>;

    HpkePublicKey public_key;
    HpkeKemId kem_id;
    ECHCipherSuite cipher_suites<4..2^16-4>;

    uint16 maximum_name_length;
    Extension extensions<0..2^16-1>;
} ECHConfigContents;

struct {
    uint16 version;
    uint16 length;
    select (ECHConfig.version) {
        case 0xfe08: ECHConfigContents contents;
    }
} ECHConfig;

ECHConfig ECHConfigs<1..2^16-1>;
```

The "ECHConfigs" 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.

The "ECHConfig" 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.

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:

public\_name The non-empty name of client-facing server, i.e., the entity trusted to update these encryption keys. This is used to repair misconfigurations, as described in [Section 6.3](#).

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

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.

cipher\_suites The list of HPKE AEAD and KDF identifier pairs clients can use for encrypting ClientHelloInner.

maximum\_name\_length The largest name the server expects to support, if known. If this value is not known it can be set to zero, in which case clients SHOULD use the inner ClientHello padding scheme described below. That could happen if wildcard names are in use, or if names can be added or removed from the anonymity set during the lifetime of a particular resource record value.

extensions A list of extensions that the client must take into consideration when generating a ClientHello message. These are described below ([Section 4.1](#)).

#### [4.1](#). Configuration Extensions

ECH configuration extensions are used to provide room for additional functionality as needed. See [Section 12](#) for guidance on which types of extensions are appropriate for this structure.

The format is as defined in [\[RFC8446\], Section 4.2](#). The same interpretation rules apply: extensions MAY appear in any order, but there MUST NOT be more than one extension of the same type in the extensions block. An extension can be tagged as mandatory by using an extension type codepoint with the high order bit set to 1. A client that receives a mandatory extension they do not understand MUST reject the "ECHConfig" content.

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

The encrypted ClientHelloInner is carried in an "encrypted\_client\_hello" extension, defined as follows:

```
enum {
    encrypted_client_hello(0xfe08), (65535)
} ExtensionType;
```

The extension request is carried by the ClientHelloOuter, i.e., the ClientHello transmitted to the client-facing server. The payload contains the following "ClientECH" structure:

```
struct {
    ECHCipherSuite cipher_suite;
    opaque config_id<0..255>;
    opaque enc<1..2^16-1>;
    opaque payload<1..2^16-1>;
} ClientECH;
```

**cipher\_suite** The cipher suite used to encrypt ClientHelloInner. This MUST match a value provided in the corresponding "ECHConfig.cipher\_suites" list.

**config\_id** The configuration identifier, equal to "Expand(Extract("", config), "tls ech config id", Nh)", where "config" is the "ECHConfig" structure and "Extract", "Expand", and "Nh" are as specified by the cipher suite KDF. (Passing the literal "" as the salt is interpreted by "Extract" as no salt being provided.) The length of this value SHOULD NOT be less than 16 bytes unless it is optional for an application; see [Section 10.4](#).

**enc** The HPKE encapsulated key, used by servers to decrypt the corresponding "payload" field.

payload The serialized and encrypted ClientHelloInner structure,

encrypted using HPKE as described in [Section 6.1](#).

When offering the "encrypted\_client\_hello" extension in its ClientHelloOuter, the client MUST also offer an empty "encrypted\_client\_hello" extension in its ClientHelloInner, wherever applicable. (This requirement is not applicable when the extension is generated as described in [Section 6.4](#).)

When the client offers the "encrypted\_client\_hello" extension, the server MAY include an "encrypted\_client\_hello" extension in its EncryptedExtensions message with the following payload:

```
struct {
    ECHConfigs retry_configs;
} ServerECH;
```

retry\_configs An ECHConfigs structure containing one or more ECHConfig structures, in decreasing order of preference, to be used by the client in subsequent connection attempts.

This document also defines the "ech\_required" alert, which clients 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

Some TLS 1.3 extensions can be quite large and having them both in ClientHelloInner and ClientHelloOuter will lead to a very large overall size. One particularly pathological example is "key\_share" with post-quantum algorithms. In order to reduce the impact of duplicated extensions, the client may use the "outer\_extensions" extension.

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

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

OuterExtensions consists of one or more ExtensionType values, each of which reference an extension in ClientHelloOuter.

When sending ClientHello, the client first computes ClientHelloInner, including any PSK binders. It then computes a new value, the EncodedClientHelloInner, by first making a copy of ClientHelloInner. It then replaces the legacy\_session\_id field with an empty string.

The client then MAY substitute extensions which it knows will be duplicated in ClientHelloOuter. To do so, the client removes and replaces extensions from EncodedClientHelloInner with a single "outer\_extensions" extension. Removed extensions MUST be ordered consecutively in ClientHelloInner. The list of outer extensions, OuterExtensions, includes those which were removed from EncodedClientHelloInner, in the order in which they were removed.

Finally, EncodedClientHelloInner is serialized as a ClientHello structure, defined in [Section 4.1.2 of \[RFC8446\]](#). Note this does not include the four-byte header included in the Handshake structure.

The client-facing server computes ClientHelloInner by reversing this process. First it makes a copy of EncodedClientHelloInner and copies the legacy\_session\_id field from ClientHelloOuter. It then looks for an "outer\_extensions" extension. If found, it replaces the extension with the corresponding sequence of extensions in the ClientHelloOuter. If any referenced extensions are missing or if "encrypted\_client\_hello" appears in the list, the server MUST abort the connection with an "illegal\_parameter" alert.

The "outer\_extensions" extension is only used for compressing the ClientHelloInner. It MUST NOT be sent in either ClientHelloOuter or ClientHelloInner.

## [5.2.](#) Authenticating the ClientHelloOuter

To prevent a network attacker from modifying the reconstructed ClientHelloInner (see [Section 10.10.3](#)), ECH authenticates ClientHelloOuter by deriving a ClientHelloOuterAAD value. This is computed by serializing ClientHelloOuter with the "encrypted\_client\_hello" extension removed. ClientHelloOuterAAD is

then passed as the associated data parameter to the HPKE encryption.

Note 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.

## 6. Client Behavior

### 6.1. Sending an Encrypted ClientHello

To offer ECH, the client first chooses a suitable ECH configuration. To determine if a given "ECHConfig" is suitable, it checks that it supports the KEM algorithm identified by "ECHConfig.kem\_id" and at least one KDF/AEAD algorithm identified by "ECHConfig.cipher\_suites". Once a suitable configuration is found, the client selects the cipher suite it will use for encryption. It MUST NOT choose a cipher suite not advertised by the configuration.

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. Note 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. It SHOULD contain TLS padding [[RFC7685](#)] as described in [Section 6.2](#).
4. If it intends to compress any extensions (see [Section 5.1](#)), it MUST order those extensions consecutively.

The client then constructs EncodedClientHelloInner as described in [Section 5.1](#). Finally, it constructs the ClientHelloOuter message just 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.
3. 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 10.10.1](#).)
4. 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.
5. It MUST include an "encrypted\_client\_hello" extension with a payload constructed as described below.

6. The value of "ECHConfig.public\_name" MUST be placed in the "server\_name" extension.
7. It MUST NOT include the "pre\_shared\_key" extension. (See [Section 10.10.3](#).)

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.

To encrypt EncodedClientHelloInner, the client first computes ClientHelloOuterAAD as described in [Section 5.2](#). Note this requires the "encrypted\_client\_hello" be computed after all other extensions. In particular, this is possible because the "pre\_shared\_key" extension is forbidden in ClientHelloOuter.

The client then generates the HPKE encryption context. Finally, it

computes the encapsulated key, context, HRR key (see [Section 6.3.3](#)), and payload as:

```
pkR = Deserialize(ECHConfig.public_key)
enc, context = SetupBaseS(pkR,
                          "tls ech" || 0x00 || ECHConfig)
ech_hrr_key = context.Export("tls ech hrr key", 32)
payload = context.Seal(ClientHelloOuterAAD,
                      EncodedClientHelloInner)
```

Note that the HPKE functions `Deserialize` and `SetupBaseS` are those which match `"ECHConfig.kem_id"` and the AEAD/KDF used with `"context"` are those which match the client's chosen preference from `"ECHConfig.cipher_suites"`. The `"info"` parameter to `SetupBaseS` is the concatenation of `"tls ech"`, a zero byte, and the serialized `ECHConfig`.

The value of the `"encrypted_client_hello"` extension in the `ClientHelloOuter` is a `"ClientECH"` with the following values:

- \* `"cipher_suite"`, the client's chosen cipher suite;
- \* `"config_id"`, the identifier of the chosen `ECHConfig` structure;
- \* `"enc"`, as computed above; and
- \* `"payload"`, as computed above.

If optional configuration identifiers (see [Section 10.4](#)) are used, the `"config_id"` field MAY be empty or randomly generated. Unless specified by the application using (D)TLS or externally configured on both sides, implementations MUST compute the field as specified in [Section 5](#).

## [6.2](#). Recommended Padding Scheme

This section describes a deterministic padding mechanism 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. For the "server\_name" extension with length  $D$ , clients SHOULD use the server's length hint  $L$  (ECHConfig.maximum\_name\_length) when computing the padding as follows:

1. If  $L \geq D$ , add  $L - D$  bytes of padding. This rounds to the server's advertised hint, i.e., ECHConfig.maximum\_name\_length.
2. Otherwise, let  $P = 31 - ((D - 1) \% 32)$ , and add  $P$  bytes of padding, plus an additional 32 bytes if  $D + P < L + 32$ . This rounds  $D$  up to the nearest multiple of 32 bytes that permits at least 32 bytes of length ambiguity.

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.

### [6.3.](#) Handling the Server Response

As described in [Section 7](#), the server MAY either accept ECH and use ClientHelloInner or reject it and use ClientHelloOuter. In handling



the server's response, the client's first step is to determine which value was used. The client presumes acceptance if the last 8 bytes of `ServerHello.random` are equal to "accept\_confirmation" as defined in [Section 7.2](#). Otherwise, it presumes rejection.

#### [6.3.1](#). Accepted ECH

If the server used `ClientHelloInner`, the client proceeds with the connection as usual, authenticating the connection for the origin server.

#### [6.3.2](#). Rejected ECH

If the server used `ClientHelloOuter`, the client proceeds with the handshake, authenticating for `ECHConfig.public_name` as described in [Section 6.3.2.1](#). If authentication or the handshake fails, the client **MUST** return a failure to the calling application. It **MUST NOT** use the retry keys.

Otherwise, when the handshake completes successfully with the public name authenticated, the client **MUST** abort the connection with an "ech\_required" alert. It then processes the "retry\_configs" field from the server's "encrypted\_client\_hello" extension.

If one of the values contains a version supported by the client, it can regard the ECH keys as securely replaced by the server. It **SHOULD** retry the handshake with a new transport connection, using that value to encrypt the `ClientHello`. The value may only be applied to the retry connection. The client **MUST** continue to use the previously-advertised keys for subsequent connections. This avoids introducing pinning concerns or a tracking vector, should a malicious server present client-specific retry keys to identify clients.

If none of the values provided in "retry\_configs" contains a supported version, the client can regard ECH as securely disabled by the server. As below, it **SHOULD** then retry the handshake with a new transport connection and ECH disabled.

If the field contains any other value, the client **MUST** abort the connection with an "illegal\_parameter" alert.

If the server negotiates an earlier version of TLS, or if it does not provide an "encrypted\_client\_hello" extension in `EncryptedExtensions`, the client proceeds with the handshake, authenticating for

ECHConfigContents.public\_name as described in [Section 6.3.2.1](#). If an earlier version was negotiated, the client MUST NOT enable the False Start optimization [[RFC7918](#)] for this handshake. If authentication or the handshake fails, the client MUST return a failure to the calling application. It MUST NOT treat this as a secure signal to disable ECH.

Otherwise, when the handshake completes successfully with the public name authenticated, the client MUST abort the connection with an "ech\_required" alert. The client can then regard ECH as securely disabled by the server. It SHOULD retry the handshake with a new transport connection and ECH disabled.

Clients SHOULD implement a limit on retries caused by "ech\_retry\_request" 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.

#### [6.3.2.1](#). Authenticating for the Public Name

When the server rejects ECH or otherwise ignores "encrypted\_client\_hello" extension, 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 ECHConfigContents.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.

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 6.3](#). This may be implemented, for instance, by reporting a failed connection with a dedicated error code.

### [6.3.3.](#) HelloRetryRequest

If the server sends a HelloRetryRequest in response to the ClientHello, the client sends a second updated ClientHello per the rules in [\[RFC8446\]](#). However, at this point, the client does not know whether the server processed ClientHelloOuter or ClientHelloInner, and MUST regenerate both values to be acceptable. Note: if ClientHelloOuter and ClientHelloInner use different groups for their key shares or differ in some other way, then the HelloRetryRequest may actually be invalid for one or the other ClientHello, in which case a fresh ClientHello MUST be generated, ignoring the instructions in HelloRetryRequest. Otherwise, the usual rules for HelloRetryRequest processing apply.

Clients bind encryption of the second ClientHelloInner to encryption of the first ClientHelloInner via the derived ech\_hrr\_key by modifying HPKE setup as follows:

```
pkR = Deserialize(ECHConfig.public_key)
enc, context = SetupPSKS(pkR, "tls ech" || 0x00 || ECHConfig,
                        ech_hrr_key, "hrr key")
```

The "info" parameter to SetupPSKS is the concatenation of "tls ech", a zero byte, and the serialized ECHConfig. Clients then encrypt the second ClientHelloInner using this new HPKE context. In doing so, the encrypted value is also authenticated by ech\_hrr\_key. The rationale for this is described in [Section 10.10.2](#).

Client-facing servers perform the corresponding process when decrypting second ClientHelloInner messages. In particular, upon receipt of a second ClientHello message with a ClientECH value, servers set up their HPKE context and decrypt ClientECH as follows:

```
context = SetupPSKR(ClientECH.enc, skR,
                    "tls ech" || 0x00 || ECHConfig, ech_hrr_key, "hrr key")
EncodedClientHelloInner = context.Open(ClientHelloOuterAAD,
                                       ClientECH.payload)
```

ClientHelloOuterAAD is computed from the second ClientHelloOuter as described in [Section 5.2](#). The "info" parameter to SetupPSKR is

computed as above.

If the client offered ECH in the first ClientHello, then it MUST offer ECH in the second. Likewise, if the client did not offer ECH in the first ClientHello, then it MUST NOT not offer ECH in the second.

[[OPEN ISSUE: Should we be using the PSK input or the info input? On the one hand, the requirements on info seem weaker, but maybe actually this needs to be secret? Analysis needed.]]

#### [6.4.](#) GREASE Extensions

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 as follows:

- \* Set the "suite" field to a supported ECHCipherSuite. 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 "config\_id" field to a randomly-generated string of "Nh" bytes, where "Nh" is the output length of the "Extract" function of the KDF associated with the chosen cipher suite. (The KDF API is specified in [[I-D.irtf-cfrg-hpke](#)].)
- \* 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 selected AEAD scheme and L is the size of the ClientHelloInner message the client would use given an ECHConfig structure, padded according to [Section 6.2](#).

If the server sends an "encrypted\_client\_hello" extension, 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 and MUST NOT use the retry keys.

[[OPEN ISSUE: if the client sends a GREASE "encrypted\_client\_hello" extension, should it also send a GREASE "pre\_shared\_key" extension? If not, GREASE+ticket is a trivial distinguisher.]]

Offering a GREASE extension is not considered offering an encrypted ClientHello for purposes of requirements in [Section 6](#). In particular, the client MAY offer to resume sessions established without ECH.

## [7](#). Server Behavior

### [7.1](#). Client-Facing Server

Upon receiving an "encrypted\_client\_hello" extension, 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 ECHConfigs. This set is determined by one of the two following methods:

1. Compare ClientECH.config\_id against identifiers of known ECHConfigs and select the one that matches, if any, as a candidate.
2. Collect all known ECHConfigs as candidates, with trial decryption below determining the final selection.

Some uses of ECH, such as local discovery mode, may omit the ClientECH.config\_id since it can be used as a tracking vector. In such cases, the second method should be used for matching ClientECH to known ECHConfig. See [Section 10.4](#). Unless specified by the application using (D)TLS or externally configured on both sides, implementations MUST use the first method.

The server then iterates over all candidate ECHConfigs, attempting to

decrypt the "encrypted\_client\_hello" extension:

The server verifies that the ECHConfig supports the cipher suite indicated by the ClientECH.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 ClientECH.payload, using the private key skR corresponding to ECHConfig, as follows:

```
context = SetupBaseR(ClientECH.enc, skR,  
                    "tls ech" || 0x00 || ECHConfig)  
EncodedClientHelloInner = context.Open(ClientHelloOuterAAD,  
                                       ClientECH.payload)  
ech_hrr_key = context.Export("tls ech hrr key", 32)
```

ClientHelloOuterAAD is computed from ClientHelloOuter as described in [Section 5.2](#). The "info" parameter to SetupBaseS 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 consider candidate ECHConfigs.

Upon determining the ClientHelloInner, 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 modified 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 ECHConfigs fail to decrypt the extension, the client-facing server MUST ignore the extension and proceed with

the connection using ClientHelloOuter. This connection proceeds as usual, except the server 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 6.4](#)), 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](#)). Instead, servers can measure occurrences of the "ech\_required" alert to detect this case.

#### [7.1.1.1](#). HelloRetryRequest

In case a HelloRetryRequest (HRR) is sent, the client-facing server MUST consistently accept or decline ECH between the two ClientHellos, using the same ECHConfig, and abort the handshake if this is not possible. This is achieved as follows. Let CH1 and CH2 denote, respectively, the first and second ClientHello transmitted on the wire by the client:

1. If CH1 contains the "encrypted\_client\_hello" extension but CH2 does not, or if CH2 contains the "encrypted\_client\_hello" extension but CH1 does not, then the server MUST abort the handshake with an "illegal\_parameter" alert.

2. If the "encrypted\_client\_hello" extension is sent in CH2, the server follows the procedure in [Section 7.1](#) to decrypt the extension, but it uses the previously-selected ECHConfig as the set of candidate ECHConfigs. If decryption fails, the server aborts the connection with a "decrypt\_error" alert rather than continuing the handshake with the second ClientHelloOuter.

[[OPEN ISSUE: If the client-facing server implements stateless HRR, it has no way to send a cookie, short of as-yet-unspecified integration with the backend server. Stateful HRR on the client-facing server works fine, however. See issue #333.]]

## [7.2.](#) Backend Server Behavior

When the client-facing server accepts ECH, it forwards the ClientHelloInner to the backend server, who terminates the connection. If the ClientHelloInner contains an empty "encrypted\_client\_hello" extension, then the backend server MUST confirm ECH acceptance by setting ServerHello.random[24:32] to

```
accept_confirmation = HKDF-Expand-Label(  
    HKDF-Extract(0, ClientHelloInner.random),  
    "ech accept confirmation",  
    ServerHello.random[0:24], 8)
```

where HKDF-Expand-Label and HKDF-Extract are as defined in [\[RFC8446\]](#). The value of ServerHello.random[0:24] is generated as usual by invoking a secure random number generator (see [\[RFC8446\]](#), [Section 4.1.2](#)).

## [8.](#) 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.](#) 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 respond with `ech_retry_requested`. If the server does not understand the "encrypted\_client\_hello" extension at all, it will ignore it as required by [RFC8446]; [Section 4.1.2](#). Provided the server can present a certificate valid for the public name, the client can safely retry with updated settings, as described in [Section 6.3](#).

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.

## [8.2](#). Middleboxes

A more serious problem is MITM proxies which do not support this extension. [\[RFC8446\], Section 9.3](#) requires that such proxies remove any extensions they do not understand. The handshake will then present a certificate based on the public name, without echoing the "encrypted\_client\_hello" extension to the client.

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 6.3](#) or result in a connection failure. A proxy which is not authoritative for the public name cannot forge a signal to disable ECH.

A non-conformant MITM proxy which instead forwards the ECH extension, substituting its own KeyShare value, will result in the client-facing server recognizing the key, but failing to decrypt the SNI. This causes a hard failure. Clients SHOULD NOT attempt to repair the connection in this case.

## 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 [[I-D.irtf-cfrg-hpke](#)], Section 7.1)
- \* KDF: HKDF-SHA256 (see [[I-D.irtf-cfrg-hpke](#)], Section 7.2)
- \* AEAD: AES-128-GCM (see [[I-D.irtf-cfrg-hpke](#)], Section 7.3)

## 10. Security Considerations

### 10.1. Security and Privacy Goals

ECH considers two types of attackers: passive and active. Passive attackers can read packets from the network. 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 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](#)].

Given these types of attackers, the primary goals of ECH are as follows.

1. Use of ECH does not weaken the security properties of TLS without ECH.
2. TLS connection establishment to a host with a specific ECHConfig and TLS configuration is indistinguishable from a connection to any other host with the same ECHConfig and TLS configuration. (The set of hosts which share the same ECHConfig and TLS configuration is referred to as the anonymity set.)

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 ClientECH.config\_id value. This also means public information in a TLS handshake is also

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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, (a) whether or not a specific server supports ECH and (b) whether or not ECH was accepted for a particular connection. ECH aims to achieve both properties, assuming the attacker is passive and does not know the set of ECH configurations offered by the client-facing server. It does not achieve these properties for active attackers. More specifically:

- \* Passive attackers with a known ECH configuration can distinguish between a connection that negotiates ECH with that configuration and one which does not, because the latter used a GREASE "encrypted\_client\_hello" extension (as specified in [Section 6.4](#)) or a different ECH configuration.
- \* Passive attackers without the ECH configuration cannot distinguish between a connection that negotiates ECH and one which uses a GREASE "encrypted\_client\_hello" extension.
- \* Active attackers can distinguish between a connection that negotiates ECH and one which uses a GREASE "encrypted\_client\_hello" extension.

See [Section 10.8.4](#) for more discussion about the "do not stick out" criteria from [\[RFC8744\]](#).

## [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 substituting 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.

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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.](#) Optional Configuration Identifiers and Trial Decryption

Optional 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 either an empty config\_id or a randomly generated config\_id in the ClientECH. (The precise implementation choice for this mechanism is out of scope for this document.) 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, support for optional 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 damage caused by such attacks.

### [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 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 10.8.4](#).

### [10.6.](#) 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.

### [10.7.](#) 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](#)). The backend server's signal of acceptance does not interfere with this mechanism because ECH is only supported in TLS 1.3 or higher.

## [10.8.](#) 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.

### [10.8.1.](#) 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`.

### [10.8.2.](#) 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.

### [10.8.3.](#) Prevent SNI-Based Denial-of-Service Attacks

This design requires servers to decrypt `ClientHello` messages with

ClientECH 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 TCP connections an attacker can open.

#### [10.8.4.](#) Do Not Stick Out

The only explicit signal indicating possible use of ECH is the ClientHello "encrypted\_client\_hello" extension. Server handshake messages do not contain any signal indicating use or negotiation of ECH. Clients MAY GREASE the "encrypted\_client\_hello" extension, as described in [Section 6.4](#), which helps ensure the ecosystem handles ECH correctly. Moreover, as more clients enable ECH support, e.g., as normal part of Web browser functionality, with keys supplied by shared hosting providers, the presence of ECH extensions becomes less unusual and part of typical client behavior. In other words, if all Web browsers start using ECH, the presence of this value will not signal unusual behavior to passive eavesdroppers.

#### [10.8.5.](#) 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.

#### [10.8.6.](#) 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 ECHConfigs 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.

#### [10.8.7.](#) 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.

#### [10.9.](#) Padding Policy

Variations in the length of the ClientHelloInner ciphertext could leak information about the corresponding plaintext. [Section 6.2](#) describes a RECOMMENDED padding mechanism for clients aimed at reducing potential information leakage.

#### [10.10.](#) 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.

##### [10.10.1.](#) 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.

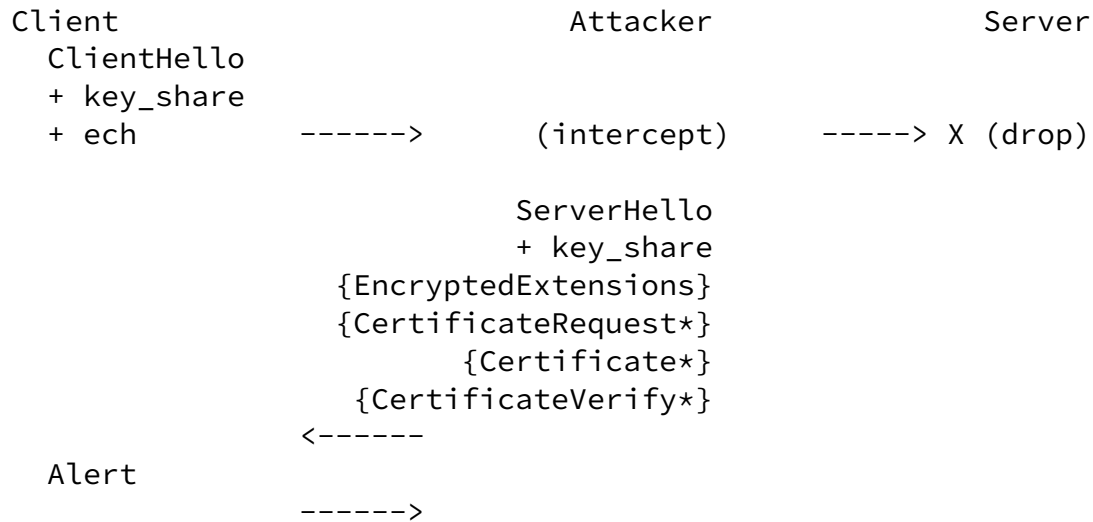


Figure 3: Client reaction attack

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.

### [10.10.2](#). 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.

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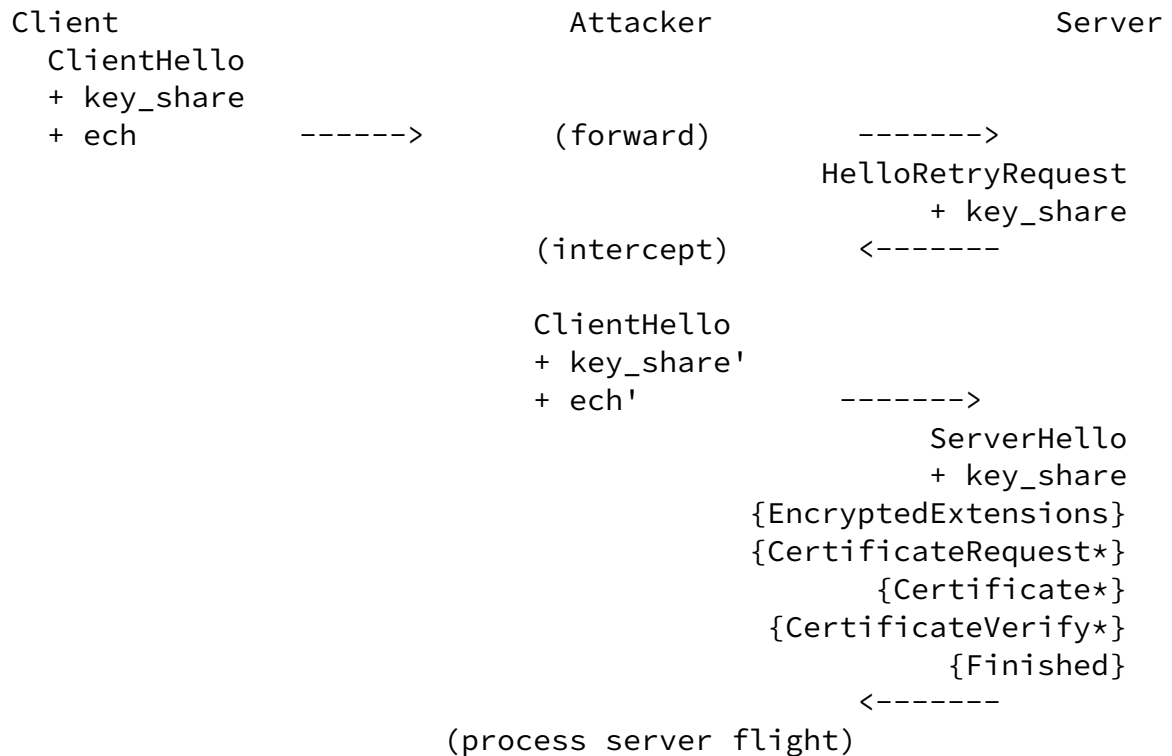


Figure 4: HelloRetryRequest hijack attack

This attack is mitigated by binding the first and second ClientHello messages together. In particular, since the attacker does not possess the ech\_hrr\_key, it cannot generate a valid encryption of the second inner ClientHello. The server will attempt decryption using ech\_hrr\_key, detect failure, and fail the connection.

If the second ClientHello were not bound to the first, 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.

### [10.10.3](#). 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.

Client	Attacker	Server
	handshake and ticket for "example.com"	
	<----->	
ClientHello		
+ key_share		
+ ech		
+ outer_extensions(pre_shared_key)		
+ pre_shared_key		
	----->	
	(intercept)	
	ClientHello	
	+ key_share	
	+ ech	
	+ outer_extensions(pre_shared_key)	
	+ pre_shared_key'	
	----->	
		Alert
		-or-
		ServerHello
		...
		Finished
		<----->

## 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](#). 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.

### [11.](#) IANA Considerations

#### [11.1.](#) Update of the TLS ExtensionType Registry

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

1. encrypted\_client\_hello(0xfe08), with "TLS 1.3" column values being set to "CH, EE", and "Recommended" column being set to "Yes".
2. outer\_extensions(0xfd00), with the "TLS 1.3" column values being set to "", and "Recommended" column being set to "Yes".

#### [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 being set to "Y".

### [12.](#) 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.

## 13. References

### 13.1. Normative References

[HTTPS-RR] Schwartz, B., Bishop, M., and E. Nygren, "Service binding and parameter specification via the DNS (DNS SVCB and HTTPS RRs)", Work in Progress, Internet-Draft, [draft-ietf-dnsop-svcb-https-01](http://www.ietf.org/internet-drafts/draft-ietf-dnsop-svcb-https-01), 13 July 2020, <<http://www.ietf.org/internet-drafts/draft-ietf-dnsop-svcb-https-01.txt>>.

[I-D.ietf-tls-exported-authenticator] Sullivan, N., "Exported Authenticators in TLS", Work in Progress, Internet-Draft, [draft-ietf-tls-exported-authenticator-13](http://www.ietf.org/internet-drafts/draft-ietf-tls-exported-authenticator-13), 26 June 2020, <<http://www.ietf.org/internet-drafts/draft-ietf-tls-exported-authenticator-13.txt>>.

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[I-D.irtf-cfrg-hpke]

Barnes, R., Bhargavan, K., Lipp, B., and C. Wood, "Hybrid Public Key Encryption", Work in Progress, Internet-Draft, [draft-irtf-cfrg-hpke-05](http://www.ietf.org/internet-drafts/draft-irtf-cfrg-hpke-05), 30 July 2020, <<http://www.ietf.org/internet-drafts/draft-irtf-cfrg-hpke-05.txt>>.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](https://www.rfc-editor.org/info/rfc2119), [RFC 2119](https://www.rfc-editor.org/info/rfc2119), DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.

[RFC7685] Langley, A., "A Transport Layer Security (TLS) ClientHello Padding Extension", [RFC 7685](https://www.rfc-editor.org/info/rfc7685), DOI 10.17487/RFC7685, October 2015, <<https://www.rfc-editor.org/info/rfc7685>>.

[RFC7918] Langley, A., Modadugu, N., and B. Moeller, "Transport Layer Security (TLS) False Start", [RFC 7918](https://www.rfc-editor.org/info/rfc7918), DOI 10.17487/RFC7918, August 2016, <<https://www.rfc-editor.org/info/rfc7918>>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in [RFC](https://www.rfc-editor.org/info/rfc8174)

[2119](#) Key Words", [BCP 14](#), [RFC 8174](#), DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.

[RFC8446] Rescorla, E., "The Transport Layer Security (TLS) Protocol Version 1.3", [RFC 8446](#), DOI 10.17487/RFC8446, August 2018, <<https://www.rfc-editor.org/info/rfc8446>>.

### 13.2. Informative References

[I-D.kazuho-protected-sni]

Oku, K., "TLS Extensions for Protecting SNI", Work in Progress, Internet-Draft, [draft-kazuho-protected-sni-00](#), 18 July 2017, <<http://www.ietf.org/internet-drafts/draft-kazuho-protected-sni-00.txt>>.

[RFC7301] Friedl, S., Popov, A., Langley, A., and E. Stephan, "Transport Layer Security (TLS) Application-Layer Protocol Negotiation Extension", [RFC 7301](#), DOI 10.17487/RFC7301, July 2014, <<https://www.rfc-editor.org/info/rfc7301>>.

[RFC7858] Hu, Z., Zhu, L., Heidemann, J., Mankin, A., Wessels, D., and P. Hoffman, "Specification for DNS over Transport Layer Security (TLS)", [RFC 7858](#), DOI 10.17487/RFC7858, May 2016, <<https://www.rfc-editor.org/info/rfc7858>>.

Rescorla, et al.

Expires 19 April 2021

[Page 34]

---

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October 2020

[RFC7924] Santesson, S. and H. Tschofenig, "Transport Layer Security (TLS) Cached Information Extension", [RFC 7924](#), DOI 10.17487/RFC7924, July 2016, <<https://www.rfc-editor.org/info/rfc7924>>.

[RFC8094] Reddy, T., Wing, D., and P. Patil, "DNS over Datagram Transport Layer Security (DTLS)", [RFC 8094](#), DOI 10.17487/RFC8094, February 2017, <<https://www.rfc-editor.org/info/rfc8094>>.

[RFC8484] Hoffman, P. and P. McManus, "DNS Queries over HTTPS (DoH)", [RFC 8484](#), DOI 10.17487/RFC8484, October 2018, <<https://www.rfc-editor.org/info/rfc8484>>.

[RFC8701] Benjamin, D., "Applying Generate Random Extensions And

Sustain Extensibility (GREASE) to TLS Extensibility", [RFC 8701](#), DOI 10.17487/RFC8701, January 2020, <<https://www.rfc-editor.org/info/rfc8701>>.

[RFC8744] Huitema, C., "Issues and Requirements for Server Name Identification (SNI) Encryption in TLS", [RFC 8744](#), DOI 10.17487/RFC8744, July 2020, <<https://www.rfc-editor.org/info/rfc8744>>.

## [Appendix A](#). Alternative SNI Protection Designs

Alternative approaches to encrypted SNI may be implemented at the TLS or application layer. In this section we describe several alternatives and discuss drawbacks in comparison to the design in this document.

### [A.1](#). TLS-layer

#### [A.1.1](#). TLS in Early Data

In this variant, TLS Client Hellos are tunneled within early data payloads belonging to outer TLS connections established with the client-facing server. This requires clients to have established a previous session --- and obtained PSKs --- with the server. The client-facing server decrypts early data payloads to uncover Client Hellos destined for the backend server, and forwards them onwards as necessary. Afterwards, all records to and from backend servers are forwarded by the client-facing server - unmodified. This avoids double encryption of TLS records.

Problems with this approach are: (1) servers may not always be able to distinguish inner Client Hellos from legitimate application data, (2) nested 0-RTT data may not function correctly, (3) 0-RTT data may

not be supported - especially under DoS - leading to availability concerns, and (4) clients must bootstrap tunnels (sessions), costing an additional round trip and potentially revealing the SNI during the initial connection. In contrast, encrypted SNI protects the SNI in a distinct Client Hello extension and neither abuses early data nor requires a bootstrapping connection.

#### [A.1.2](#). Combined Tickets



In this variant, client-facing and backend servers coordinate to produce "combined tickets" that are consumable by both. Clients offer combined tickets to client-facing servers. The latter parse them to determine the correct backend server to which the Client Hello should be forwarded. This approach is problematic due to non-trivial coordination between client-facing and backend servers for ticket construction and consumption. Moreover, it requires a bootstrapping step similar to that of the previous variant. In contrast, encrypted SNI requires no such coordination.

## [A.2.](#) Application-layer

### [A.2.1.](#) HTTP/2 CERTIFICATE Frames

In this variant, clients request secondary certificates with CERTIFICATE\_REQUEST HTTP/2 frames after TLS connection completion. In response, servers supply certificates via TLS exported authenticators [[I-D.ietf-tls-exported-authenticator](#)] in CERTIFICATE frames. Clients use a generic SNI for the underlying client-facing server TLS connection. Problems with this approach include: (1) one additional round trip before peer authentication, (2) non-trivial application-layer dependencies and interaction, and (3) obtaining the generic SNI to bootstrap the connection. In contrast, encrypted SNI induces no additional round trip and operates below the application layer.

## [Appendix B.](#) 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.

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