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RFC 9464
Internet Key Exchange Protocol Version 2 (IKEv2) Configuration for Encrypted DNS

Abstract

This document specifies new Internet Key Exchange Protocol Version 2 (IKEv2) Configuration Payload Attribute Types to assign DNS resolvers that support encrypted DNS protocols, such as DNS over HTTPS (DoH), DNS over TLS (DoT), and DNS over QUIC (DoQ).

Status of This Memo

This is an Internet Standards Track document.

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1. Introduction

This document specifies a mechanism for assigning encrypted DNS configurations to an Internet Key Exchange Protocol Version 2 (IKEv2) initiator [RFC7296]. Specifically, it assigns one or more Authentication Domain Names (ADNs) of DNS resolvers that support encrypted DNS protocols. The specific protocols supported are described using the Service Parameters format defined in [RFC9460]; supported protocols include DNS over HTTPS (DoH) [RFC8484], DNS over TLS (DoT) [RFC7858], and DNS over QUIC (DoQ) [RFC9250].

This document introduces three new IKEv2 Configuration Payload Attribute Types (Section 3) to add support for encrypted DNS resolvers. The ENCDNS_IP4 and ENCDNS_IP6 attribute types (Section 3.1) are used to provision ADNs, a list of IP addresses, and a set of service parameters. The ENCDNS_DIGEST_INFO attribute (Section 3.2) additionally allows a specific resolver certificate to be indicated by the IKEv2 responder.

The encrypted DNS resolver hosted by a Virtual Private Network (VPN) provider can get a domain-validated certificate from a public Certificate Authority (CA). The VPN client does not need to be provisioned with the root certificate of a private CA to authenticate the certificate of the encrypted DNS resolvers. The encrypted DNS resolver can run on private IP addresses, and its access can be restricted to clients connected to the VPN.

For many years, typical designs have often assumed that the DNS resolver was usually located inside the protected domain, but they don't consider implementations where the DNS resolver could be located outside of it. With encrypted DNS, implementing the latter scenario becomes plausible. Note that existing VPN client implementations might not expect the discovered DNS resolver IP addresses to be outside of the covered IP address ranges of the VPN tunnel.

2. Terminology

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

This document uses the terms defined in [RFC8499].

Also, this document uses the terms defined in [RFC7296]. In particular, readers should be familiar with the terms "initiator" and "responder" as used in that document.

This document makes use of the following terms:

Do53: Refers to unencrypted DNS.

Encrypted DNS: Refers to a scheme where DNS messages are sent over an encrypted channel. Examples of encrypted DNS are DoT, DoH, and DoQ.

ENCDNS_IP*: Refers to any of the IKEv2 Configuration Payload Attribute Types defined in Section 3.1.

3. IKEv2 Configuration Payload Attribute Types for Encrypted DNS

3.1. ENCDNS_IP* Configuration Payload Attributes

The ENCDNS_IP* IKEv2 Configuration Payload Attribute Types, ENCDNS_IP4 and ENCDNS_IP6, are used to configure an initiator with encrypted DNS resolvers. Both attribute types share the format shown in Figure 1. The information included in these attributes adheres to the recommendation in Section 3.1.9 of [RFC9463].

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-----------------------------+-------------------------------+
|R|         Attribute Type      |            Length             |
+-+-----------------------------+---------------+---------------+
|       Service Priority        | Num Addresses |  ADN Length   |
+-------------------------------+---------------+---------------+
~                         IP Address(es)                        ~
+---------------------------------------------------------------+
~                   Authentication Domain Name                  ~
+---------------------------------------------------------------+
~                  Service Parameters (SvcParams)               ~
+---------------------------------------------------------------+
```

Figure 1: Format of ENCDNS_IP4 and ENCDNS_IP6 Configuration Attributes

The description of the fields shown in Figure 1 is as follows:

R (Reserved, 1 bit): This bit **MUST** be set to zero and **MUST** be ignored on receipt (see Section 3.15.1 of [RFC7296] for details).

Attribute Type (15 bits): Identifier for the Configuration Attribute Type. This is set to 27 for ENCDNS_IP4 or 28 for ENCDNS_IP6, as registered in Section 8.

Length (2 octets, unsigned integer): Length of the enclosed data in octets. In particular, this field is set to:

- 0, if the Configuration payload has type (1) CFG_REQUEST and no specific DNS resolver is requested or (2) CFG_ACK. If the "Length" field is set to 0, then the subsequent fields shown in Figure 1 are not present.
- (4 + 'Length of the ADN' + N * 4 + 'Length of SvcParams') for ENCDNS_IP4 attributes if the Configuration payload has type CFG_REQUEST, CFG_REPLY, or CFG_SET, with N being the number of included IPv4 addresses ("Num Addresses").

- (4 + 'Length of the ADN' + N * 16 + 'Length of SvcParams') for ENCDNS_IP6 attributes if the Configuration payload has type CFG_REQUEST, CFG_REPLY, or CFG_SET, with N being the number of included IPv6 addresses ("Num Addresses").

Service Priority (2 octets): The priority of this attribute compared to other ENCDNS_IP* instances. This 16-bit unsigned integer is interpreted following the rules specified in Section 2.4.1 of [RFC9460]. As AliasMode (Section 2.4.2 of [RFC9460]) is not supported, this field **MUST NOT** be set to 0. Note that AliasMode is not supported because such a mode will trigger additional Do53 queries while the data can be supplied directly in the IKE response.

Num Addresses (1 octet): Indicates the number of enclosed IPv4 (for ENCDNS_IP4) or IPv6 (for ENCDNS_IP6) addresses. This value **MUST NOT** be set to 0 if the Configuration payload has type CFG_REPLY or CFG_SET. This may be set to 0 in CFG_REQUEST to indicate that no IP address is encoded in the attribute.

ADN Length (1 octet): Indicates the length of the "Authentication Domain Name" field in octets. When set to 0, this means that no ADN is enclosed in the attribute.

IP Address(es) (variable): Includes one or more IP addresses that can be used to reach the encrypted DNS resolver identified by the ADN. For ENCDNS_IP4, this field contains one or more 4-octet IPv4 addresses, and for ENCDNS_IP6, this field contains one or more 16-octet IPv6 addresses.

Authentication Domain Name (variable): A fully qualified domain name of the encrypted DNS resolver, in DNS presentation format and using an Internationalized Domain Names for Applications (IDNA) A-label [RFC5890]. The name **MUST NOT** contain any terminators (e.g., NULL, CR).

An example of a valid ADN for a DoH server is "doh1.example.com".

Service Parameters (SvcParams) (variable): Specifies a set of service parameters that are encoded following the same rules for encoding SvcParams using the wire format specified in Section 2.2 of [RFC9460]. Section 3.1.5 of [RFC9463] lists a set of service parameters that are recommended to be supported by implementations.

The service parameters **MUST NOT** include "ipv4hint" or "ipv6hint" SvcParams, as they are superseded by the included IP addresses.

If no "port" service parameter is included, this indicates that default port numbers should be used. As a reminder, the default port number is 853 for DoT (Section 6 of [RFC7858]), 443 for DoH (Section 8.1 of [RFC8484]), and 853 for DoQ (Section 8 of [RFC9250]).

The service parameters apply to all IP addresses in the ENCDNS_IP* Configuration Payload Attribute.

3.2. ENCDNS_DIGEST_INFO Configuration Payload Attribute

The ENCDNS_DIGEST_INFO Configuration Payload Attribute (Figure 2) allows IKEv2 responders to specify a certificate digest that initiators can use when validating TLS connections to encrypted resolvers. This attribute can also be sent by the initiator to request specific hash algorithms for such digests.

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-----------------------------+-------------------------------+
|R|         Attribute Type      |            Length             |
+-+-------------+---------------+-------------------------------+
| Num Hash Algs |   ADN Length  |                               |
+---------------+---------------+                               +
~                 Authentication Domain Name                    ~
+---------------------------------------------------------------+
~                 List of Hash Algorithm Identifiers            ~
+---------------------------------------------------------------+
~                        Certificate Digest                     ~
+---------------------------------------------------------------+
```

Figure 2: ENCDNS_DIGEST_INFO Attribute Format

Some of the fields shown in Figure 2 can be omitted, as further detailed below.

The format of the ENCDNS_DIGEST_INFO attribute if the Configuration payload has type CFG_REQUEST is shown in Figure 3.

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-----------------------------+-------------------------------+
|R|         Attribute Type      |            Length             |
+-+-------------+---------------+-------------------------------+
| Num Hash Algs |   ADN Length  |                               |
+---------------+---------------+                               +
~                 List of Hash Algorithm Identifiers            ~
+---------------------------------------------------------------+
```

Figure 3: ENCDNS_DIGEST_INFO Attribute Format in CFG_REQUEST

The description of the fields shown in Figure 3 is as follows:

R (Reserved, 1 bit): This bit **MUST** be set to zero and **MUST** be ignored on receipt (see Section 3.15.1 of [RFC7296] for details).

Attribute Type (15 bits): Identifier for the Configuration Attribute Type. This is set to 29; see Section 8.

Length (2 octets, unsigned integer): Length of the enclosed data in octets. This field **MUST** be set to "2 + (2 * 'number of included hash algorithm identifiers')".

Num Hash Algs (1 octet): Indicates the number of identifiers included in the "List of Hash Algorithm Identifiers" field. This field **MUST** be set to "(Length - 2)/2".

ADN Length (1 octet): **MUST** be set to 0.

List of Hash Algorithm Identifiers (variable): Specifies a list of 16-bit hash algorithm identifiers that are supported by the encrypted DNS client. This list may be controlled by a local policy.

The values of this field are identifiers taken from "IKEv2 Hash Algorithms" on IANA's "Internet Key Exchange Version 2 (IKEv2) Parameters" registry [IANA-IKE-HASH].

There is no padding between the hash algorithm identifiers.

Note that SHA2-256 is mandatory to implement (see Section 5).

The format of the ENCDNS_DIGEST_INFO attribute if the Configuration payload has type CFG_REPLY or CFG_SET is shown in Figure 4.

```
                     1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-----------------------------+-------------------------------+
|R|         Attribute Type      |            Length             |
+-+-------------+---------------+-------------------------------+
| Num Hash Algs |  ADN Length   |                               |
+---------------+---------------+                               +
~                   Authentication Domain Name                  ~
+-------------------------------+-------------------------------+
| Hash Algorithm Identifier     |                               ~
+-------------------------------+                               +
~                        Certificate Digest                     ~
+---------------------------------------------------------------+
```

Figure 4: ENCDNS_DIGEST_INFO Attribute Format in CFG_REPLY or CFG_SET

The description of the fields shown in Figure 4 is as follows:

R (Reserved, 1 bit): This bit **MUST** be set to zero and **MUST** be ignored on receipt (see Section 3.15.1 of [RFC7296] for details).

Attribute Type (15 bits): Identifier for the Configuration Attribute Type. This is set to 29; see Section 8.

Length (2 octets, unsigned integer): Length of the data in octets.

Num Hash Algs (1 octet): **MUST** be set to 1.

ADN Length (1 octet): Indicates the length of the "Authentication Domain Name" field in octets. When set to 0, this means that the digest applies on the ADN conveyed in the ENCDNS_IP* Configuration Payload Attribute.

Authentication Domain Name (variable): A fully qualified domain name of the encrypted DNS resolver following the syntax defined in [RFC5890]. The name **MUST NOT** contain any terminators (e.g., NULL, CR). A name is included only when multiple ADNs are included in the ENCDNS_IP* Configuration Payload Attribute.

Hash Algorithm Identifier (2 octets): Specifies the 16-bit hash algorithm identifier selected by the DNS resolver to generate the digest of its certificate.

Certificate Digest (variable): Includes the Subject Public Key Info (SPKI) hash (Section 5) of the encrypted DNS resolver certificate using the algorithm identified in the "Hash Algorithm Identifier" field. The length of this field is "Length - 4 - 'ADN Length'".

The ENCDNS_DIGEST_INFO attribute may be present in the Configuration payload of CFG_ACK. In such a case, the ENCDNS_DIGEST_INFO **MUST** be returned with zero-length data.

As discussed in Section 3.15.1 of [RFC7296], there are no defined uses for the CFG_SET/CFG_ACK exchange. The use of the ENCDNS_DIGEST_INFO attribute for these messages is provided for completeness.

4. IKEv2 Protocol Exchange

This section describes how the attributes defined in Section 3 are used to configure an IKEv2 initiator with one or more encrypted DNS resolvers. As a reminder, badly formatted attributes or unacceptable fields are handled as per Section 2.21 of [RFC7296].

Initiators first indicate support for encrypted DNS by including ENCDNS_IP* attributes in their CFG_REQUEST payloads. Responders supply encrypted DNS configuration by including ENCDNS_IP* attributes in their CFG_REPLY payloads. Concretely:

- If the initiator supports encrypted DNS, it includes either or both of the ENCDNS_IP4 and ENCDNS_IP6 attributes in its CFG_REQUEST. If the initiator does not want to request specific DNS resolvers, it sets the "Length" field to 0 for the attribute. For a given attribute type, the initiator **MAY** send either an empty attribute or a list of distinct suggested resolvers. The initiator **MAY** also include the ENCDNS_DIGEST_INFO attribute with a list of hash algorithms that are supported by the encrypted DNS client.
- If the request includes multiple bitwise identical attributes, only the first occurrence is processed, and the rest **SHOULD** be ignored by the responder. The responder **MAY** discard the full request if the count of repeated attributes exceeds an (implementation-specific) threshold.
- For each ENCDNS_IP* attribute from the CFG_REQUEST, if the responder supports the corresponding address family, and absent any policy restrictions, the responder sends back one or more ENCDNS_IP* attributes in the CFG_REPLY with an appropriate list of IP addresses, service parameters, and an ADN. The list of IP addresses **MUST** include at least one

IP address. The service parameters **SHOULD** include at least the "alpn" service parameter. The "alpn" service parameter may not be required in contexts such as a variant of DNS over the Constrained Application Protocol (CoAP) where the messages are encrypted using Object Security for Constrained RESTful Environments (OSCORE) [RFC8613].

- The responder **MAY** ignore suggested values from the initiator (if any). Multiple instances of the same ENCDNS_IP* attribute **MAY** be returned if distinct ADNs or service parameters need to be assigned to the initiator. In such instances, the different attributes can have matching or distinct IP addresses. These instances **MUST** be presented to a local DNS client following their service priority (i.e., a smaller service priority value indicates a higher preference).
- In addition, the responder **MAY** return the ENCDNS_DIGEST_INFO attribute to convey a digest of the certificate of the encrypted DNS and the identifier of the hash algorithm that is used to generate the digest.
- If the CFG_REQUEST includes an ENCDNS_IP* attribute but the CFG_REPLY does not include an ENCDNS_IP* attribute matching the requested address family, this is an indication that the requested address family is not supported by the responder or the responder is not configured to provide corresponding resolver addresses.
- If the initiator receives both ENCDNS_IP* and INTERNAL_IP6_DNS (or INTERNAL_IP4_DNS) attributes, it is **RECOMMENDED** that the initiator use the encrypted DNS resolvers.

The DNS client establishes an encrypted DNS session (e.g., DoT, DoH, or DoQ) with the address or addresses conveyed in ENCDNS_IP* and uses the mechanisms discussed in Section 8 of [RFC8310] to authenticate the DNS resolver certificate using the ADN conveyed in ENCDNS_IP*.

If the CFG_REPLY includes an ENCDNS_DIGEST_INFO attribute, the client has to create an SPKI hash (Section 5) of the DNS resolver certificate received in the TLS handshake using the negotiated hash algorithm in the ENCDNS_DIGEST_INFO attribute. If the computed digest for an ADN matches the digest sent in the ENCDNS_DIGEST_INFO attribute, the encrypted DNS resolver certificate is successfully validated. If so, the client continues with the TLS connection as normal. Otherwise, the client **MUST** treat the resolver certificate validation failure as a non-recoverable error. This approach is similar to certificate usage PKIX-EE(1) with selector SPKI(1) as defined in [RFC7671], but without PKIX validation.

If the IPsec connection is a split-tunnel configuration and the initiator negotiated INTERNAL_DNS_DOMAIN as per [RFC8598], the DNS client resolves the internal names using ENCDNS_IP* DNS resolvers.

> Note: [RFC8598] requires that the INTERNAL_IP6_DNS (or INTERNAL_IP4_DNS) attribute be present when INTERNAL_DNS_DOMAIN is included. This specification relaxes that constraint in the presence of ENCDNS_IP* attributes. That is, if ENCDNS_IP* attributes are supplied, responders are allowed to include INTERNAL_DNS_DOMAIN even in the absence of INTERNAL_IP6_DNS (or INTERNAL_IP4_DNS) attributes.

5. Subject Public Key Info (SPKI) Hash

The SPKI hash of the encrypted DNS resolver certificate is the output of a cryptographic hash algorithm whose input is the DER-encoded ASN.1 representation of the SPKI.

Implementations **MUST** support SHA2-256 [RFC6234].

6. Security Considerations

This document adheres to the security considerations defined in [RFC7296]. In particular, this document does not alter the trust that the initiator has placed on the DNS configuration provided by a responder.

Networks are susceptible to internal attacks as discussed in Section 3.2 of [INT-THREAT-MOD]. Hosting encrypted DNS resolvers even in the case of split-VPN configuration can minimize the attack vector (e.g., a compromised network device cannot monitor/modify DNS traffic). This specification describes a mechanism for restricting access to the DNS messages to only the parties that need to know.

If the IKEv2 responder has used the NULL Authentication method [RFC7619] to authenticate itself, the initiator **MUST NOT** use returned ENCDNS_IP* resolvers configuration unless the initiator is preconfigured, e.g., in the operating system or the application.

This specification does not extend the scope of accepting DNSSEC trust anchors beyond the usage guidelines defined in Section 6 of [RFC8598].

7. Privacy Considerations

As discussed in [RFC9076], the use of encrypted DNS does not reduce the data available in the DNS resolver. For example, the reader may refer to Section 8 of [RFC8484] or Section 7 of [RFC9250] for a discussion on specific privacy considerations for encrypted DNS.

8. IANA Considerations

IANA has assigned the following new IKEv2 Configuration Payload Attribute Types in the "IKEv2 Configuration Payload Attribute Types" namespace available at [IANA-IKE-CFG].

Value	Attribute Type	Multivalued	Length	Reference
27	ENCDNS_IP4	YES	0 or more	RFC 9464
28	ENCDNS_IP6	YES	0 or more	RFC 9464
29	ENCDNS_DIGEST_INFO	YES	0 or more	RFC 9464

Table 1

9. References

9.1. Normative References

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Appendix A. Configuration Payload Examples

A.1. Configuration of Encrypted IPv6 DNS Resolvers without Suggested Values

Figure 5 depicts an example of a CFG_REQUEST to request the configuration of IPv6 DNS resolvers without providing any suggested values. In this example, the initiator uses the ENCDNS_DIGEST_INFO attribute to indicate that the encrypted DNS client supports SHA2-256 (2), SHA2-384 (3), and SHA2-512 (4) hash algorithms for certificate digests. The label of these algorithms is taken from [IANA-IKE-HASH]. The use of INTERNAL_IP6_ADDRESS is explained in [RFC7296] and thus is not reiterated here.

```
CP(CFG_REQUEST) =
  INTERNAL_IP6_ADDRESS()
  INTERNAL_IP6_DNS()
  ENCDNS_IP6()
  ENCDNS_DIGEST_INFO(0, (SHA2-256, SHA2-384, SHA2-512))
```

Figure 5: Example of a CFG_REQUEST

Figure 6 depicts an example of a CFG_REPLY that can be sent by a responder as a response to the above CFG_REQUEST. This response indicates the following information to identify the encrypted DNS resolver:

- Its service priority, which is 1.
- Its single (1) IPv6 address (2001:db8:99:88:77:66:55:44).
- Its ADN (doh.example.com). This ADN has a length of 15.
- Its supported HTTP version (h2).
- The relative form of the URI Template (/dns-query{?dns}).
- The SPKI hash of the resolver's certificate using SHA2-256 (8b6e7a5971cc6bb0b4db5a71...).

```
CP(CFG_REPLY) =
  INTERNAL_IP6_ADDRESS(2001:db8:0:1:2:3:4:5/64)
  ENCDNS_IP6(1, 1, 15,
                (2001:db8:99:88:77:66:55:44),
                "doh.example.com",
                (alpn=h2 dohpath=/dns-query{?dns}))
  ENCDNS_DIGEST_INFO(0, SHA2-256,
                      8b6e7a5971cc6bb0b4db5a71...)
```

Figure 6: Example of a CFG_REPLY

In the example depicted in Figure 6, no ADN is included in the ENCDNS_DIGEST_INFO attribute because only one ADN is provided in the ENCDNS_IP6 attribute. Identifying the encrypted resolver associated with the supplied digest is therefore unambiguous.

A.2. Configuration of Encrypted IPv6 DNS Resolvers with Suggested Values

An initiator may provide suggested values in the CFG_REQUEST when requesting an encrypted DNS resolver. For example, the initiator may:

- Indicate a preferred resolver that is identified by an IPv6 address (see Figure 7).

```
CP(CFG_REQUEST) =
  INTERNAL_IP6_ADDRESS()
  INTERNAL_IP6_DNS()
  ENCDNS_IP6(1, 1, 0,
              (2001:db8:99:88:77:66:55:44))
```

Figure 7: Example of a CFG_REQUEST with a Preferred Resolver Identified by Its IP Address

- Indicate a preferred resolver that is identified by an ADN (see Figure 8).

```
CP(CFG_REQUEST) =
  INTERNAL_IP6_ADDRESS()
  INTERNAL_IP6_DNS()
  ENCDNS_IP6(1, 0, 15, "doh.example.com")
```

Figure 8: Example of a CFG_REQUEST with a Preferred Resolver Identified by Its ADN

- Indicate a preferred transport protocol (DoT, in the example depicted in Figure 9).

```
CP(CFG_REQUEST) =
  INTERNAL_IP6_ADDRESS()
  INTERNAL_IP6_DNS()
  ENCDNS_IP6(1, 0, 0, (alpn=dot))
```

Figure 9: Example of a CFG_REQUEST with a Preferred Transport Protocol

- or any combination thereof.

A.3. Split DNS

An initiator may also indicate that it supports Split DNS by including the INTERNAL_DNS_DOMAIN attribute in a CFG_REQUEST as shown in Figure 10. In this example, the initiator does not indicate any preference for the requested encrypted DNS server, nor does it indicate which DNS queries will be forwarded through the IPsec tunnel.

```
CP(CFG_REQUEST) =
  INTERNAL_IP6_ADDRESS()
  INTERNAL_IP6_DNS()
  ENCDNS_IP6()
  INTERNAL_DNS_DOMAIN()
```

Figure 10: Example of a CFG_REQUEST with Support for Split DNS

Figure 11 shows an example of the responder's reply. Absent any prohibited local policy, the initiator uses the encrypted DNS server (doh.example.com) for any subsequent DNS queries for "example.com" and its subdomains.

```
CP(CFG_REPLY) =
  INTERNAL_IP6_ADDRESS(2001:db8:0:1:2:3:4:5/64)
  ENCDNS_IP6(1, 1, 15,
                (2001:db8:99:88:77:66:55:44),
                "doh.example.com",
                (alpn=h2 dohpath=/dns-query{?dns}))
  INTERNAL_DNS_DOMAIN(example.com)
```

Figure 11: Example of a CFG_REPLY with INTERNAL_DNS_DOMAIN

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