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CHAIN Query Requests in DNS

Abstract

This document defines an EDNS0 extension that can be used by a security-aware validating resolver configured to use a forwarding resolver to send a single query, requesting a complete validation path along with the regular query answer. The reduction in queries potentially lowers the latency and reduces the need to send multiple queries at once. This extension mandates the use of source-IP-verified transport such as TCP or UDP with EDNS-COOKIE, so it cannot be abused in amplification attacks.

Status of This Memo

This document is not an Internet Standards Track specification; it is published for examination, experimental implementation, and evaluation.

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Table of Contents

1. Introduction

Traditionally, a DNS client operates in stub mode. For each DNS question the DNS client needs to resolve, it sends a single query to an upstream recursive resolver to obtain a single DNS answer. When DNSSEC [RFC4033] is deployed on such DNS clients, validation requires that the client obtain all the intermediate information from the DNS root down to the queried-for host name, so it can perform DNSSEC validation on the complete chain of trust.

Currently, applications send out many UDP requests concurrently. This requires more resources on the DNS client with respect to state (CPU, memory, battery) and bandwidth. There is also no guarantee that the initial set of UDP questions will result in all the records required for DNSSEC validation. More round trips could be required depending on the resulting DNS answers. This especially affects high-latency links.

This document specifies an EDNS0 extension that allows a validating resolver running as a forwarding resolver to open a TCP connection to another resolver and request a DNS chain answer using one DNS query/answer pair. This reduces the number of round trips to two. If combined with long-lived TCP or [RFC7828], there is only one round trip. While the upstream resolver still needs to perform all the individual queries required for the complete answer, it usually has a much bigger cache and does not experience significant slowdown from last-mile latency.

This EDNS0 extension allows the forwarding resolver to indicate which part of the DNS hierarchy it already contains in its cache. This reduces the amount of data required to be transferred and reduces the work the upstream recursive resolver has to perform.

This EDNS0 extension is only intended to be sent by forwarding resolvers to recursive resolvers. It MUST be ignored by authoritative servers.

1.1. Requirements Notation

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

2. Terminology

The DNS terminology used in this document is that of [RFC7719]. Additionally, the following terms are used:

Forwarding Resolver: A nameserver that does not do iterative resolution itself; instead, it passes that responsibility to another recursive resolver, called a "forwarder" in [RFC2308], Section 1.

Recursive Resolver: A nameserver that is responsible for resolving domain names for clients by following the domain's delegation chain, starting at the root. Recursive resolvers frequently use caches to be able to respond to client queries quickly, as described in [RFC1035], Section 7.

Validating Resolver: A recursive nameserver that also performs DNSSEC [RFC4033] validation. Also known as "security-aware resolver".

3. Overview

When DNSSEC is deployed on a host, it can no longer delegate all DNS work to the upstream recursive resolver. Obtaining just the DNS answer itself is not enough to validate that answer using DNSSEC. For DNSSEC validation, the DNS client requires a locally running validating resolver, so it can confirm DNSSEC validation of all intermediary DNS answers. It can configure itself as a forwarding resolver if it obtains the IP addresses of one or more recursive resolvers that are available or as a stand-alone recursive resolver if no functional recursive resolvers were obtained. Generating the required queries for validation adds a significant delay in answering the DNS question of the locally running application. The application must wait while the resolver validates all intermediate answers. Each round trip adds to the total time waiting on DNS resolution with validation to complete. This makes DNSSEC resolving impractical for devices on networks with a high latency.

This document defines the CHAIN option that allows the resolver to request all intermediate DNS data it requires to resolve and validate a particular DNS answer in a single round trip. The resolver could be part of the application or a recursive resolver running on the host.

Servers answering with CHAIN data should ensure that the peer's IP address is not a spoofed source IP address. See Section 7. This prevents DNS amplification attacks.

Applications that support CHAIN internally can perform validation without requiring the host to run a recursive resolver. This is particularly useful for virtual servers in a cloud or container-based deployment where it is undesirable to run a recursive resolver per virtual machine.

The format of this option is described in Section 4.

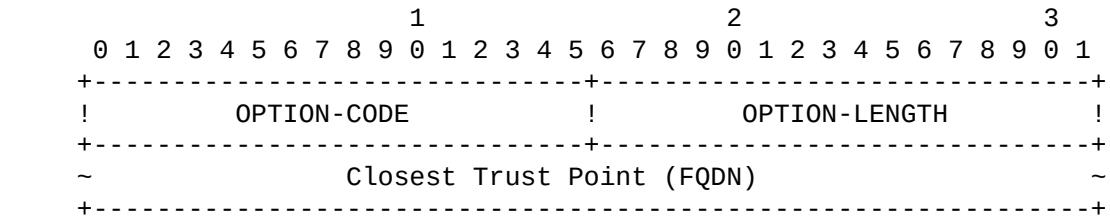
As described in Section 5.4, a recursive resolver can use this EDNS0 option to include additional data required by the resolver in the Authority Section of the DNS answer packet. The Answer Section remains unchanged from a traditional DNS answer and contains the answer and related DNSSEC entries.

An empty CHAIN EDNS0 option MAY be sent over any transport as a discovery method. A DNS server receiving such an empty CHAIN option SHOULD add an empty CHAIN option in its answer to indicate that it supports the CHAIN option.

The mechanisms provided by CHAIN raise various security concerns related to the additional work, bandwidth, amplification attacks, and privacy issues with the cache. These concerns are described in Section 7.

4. Option Format

This document uses an EDNS0 option [RFC6891] to include client IP information in DNS messages. The option is structured as follows:



- OPTION-CODE, 2 octets, for CHAIN is 13.
- OPTION-LENGTH, 2 octets, contains the length of the payload (everything after Option-length) in octets.
- Closest trust point, a variable-length Fully-Qualified Domain Name (FQDN) in DNS wire format of the requested start point of the chain. This entry is the "lowest" known entry in the DNS chain known by the recursive server seeking a CHAIN answer for which it has a validated Delegation Signer (DS) and DNSKEY record. The

endpoint of the chain is obtained from the DNS Query Section itself. No DNS name compression is allowed for this value.

5. Protocol Description

5.1. Discovery of Support

A forwarding resolver may include a zero-length CHAIN option in a regular query over any transport to discover the DNS server capability for CHAIN. Recursive resolvers that support and are willing to accept CHAIN queries over source IP verified transport respond to a zero-length CHAIN received by including a zero-length CHAIN option in the answer. If not already using a source-IP-verified transport, the forwarding resolver MAY then switch to a source-IP-verified transport and start sending queries with the CHAIN option to request a CHAIN response from the recursive resolver. Examples of source-IP-verified transports are the three-way TCP handshake and UDP with DNS cookies [RFC7873].

5.2. Generate a Query

In this option value, the forwarding resolver sets the closest trust point in the chain -- furthest from the root -- that it already has a DNSSEC-validated (secure or not) answer for in its cache. The upstream recursive resolver does not need to include any part of the chain from the root down to this option's FQDN. A complete example is described in Section 8.1.

The CHAIN option should generally be sent by system forwarding resolvers and resolvers within an application that also performs DNSSEC validation.

5.3. Send the Option

When CHAIN is available, the downstream recursive resolver can adjust its query strategy based on the desired queries and its cache contents.

A forwarding resolver can request the CHAIN option with every outgoing DNS query. However, it is RECOMMENDED that forwarding resolvers remember which upstream recursive resolvers did not return the option (and additional data) with their response. The forwarding resolver SHOULD fall back to regular DNS for subsequent queries to those recursive resolvers. It MAY switch to another recursive resolver that does support the CHAIN option or try again later to see if the server has become less loaded and is now willing to answer with CHAIN queries. A fallback strategy similar to that described in

[RFC6891], Section 6.2.2 SHOULD be employed to avoid persistent interference due to non-clean paths.

5.4. Generate a Response

When a query containing a non-zero CHAIN option is received from a forwarding resolver, the upstream recursive resolver supporting CHAIN MAY respond by confirming that it is returning a CHAIN. To do so, it MUST set the CHAIN option to the lowest trust point sent as part of the chain, with its corresponding OPTION-LENGTH. It extends the Authority Section in the DNS answer packet with the DNS RRsets required for validating the answer. The added DNS RRsets start with the first chain element below the received closest trust point up to and including the NS and DS RRsets that represent the zone cut (authoritative servers) of the QNAME. The added RRsets MAY be added in matching hierarchical order, but a DNS client MUST NOT depend on the order of the added RRsets for validation. The actual DNS answer to the question in the Query Section is placed in the DNS Answer Section identical to the traditional DNS answer. All required DNSSEC-related records must be added to their appropriate sections. This includes records required for proof of nonexistence of regular and/or wildcard records, such as NextSECure (NSEC) or NSEC3 records.

Recursive resolvers that have not implemented or enabled support for the CHAIN option, or are otherwise unwilling to perform the additional work for a CHAIN query due to workload, may safely ignore the option in the incoming queries. Such a server MUST NOT include a CHAIN option when sending DNS answer replies back, thus indicating it is not able or willing to support CHAIN queries at this time.

Requests with wrongly formatted options (i.e., bogus FQDN) MUST be rejected; a FORMERR response must be returned to the sender, as described by [RFC6891].

Requests resulting in chains that the receiving resolver is unwilling to serve can be rejected by answering the query as a regular DNS reply but with an empty CHAIN payload. Replying with an empty CHAIN can be used for chains that would be too big or for chains that would reveal too much information considered private.

At any time, a recursive resolver that has determined that it is running low on resources can refuse CHAIN queries by replying with a regular DNS reply with an empty CHAIN payload.

If a CHAIN answer would be bigger than the recursive resolver is willing to serve, it SHOULD send a partial chain starting with the data closest to the top of the chain. The client MAY resend the query with an updated closest trust point until it has received the

full chain. The CHAIN response will contain the lowest closest trust point that was included in the CHAIN answer.

If the DNS request results in a CNAME or DNAME for the Answer Section, the recursive resolver MUST return these records in the Answer Section similar to regular DNS processing. The CNAME or DNAME target MAY be placed in the Additional Section only if all supporting records for DNSSEC validation of the CNAME or DNAME target are also added to the Authority Section.

The response from a recursive resolver to a resolver MUST NOT contain the CHAIN option if none was present in the resolver's original request.

A DNS query that contains the CHAIN option MUST also have the "DNSSEC OK" (DO) bit set. If this bit is not set, or if the "Checking Disabled" (CD) bit is set, the CHAIN option received MUST be ignored.

6. Protocol Considerations

6.1. DNSSEC Considerations

The presence or absence of an OPT resource record containing a CHAIN option in a DNS query does not change the usage of those resource records and mechanisms used to provide data origin authentication and data integrity to the DNS, as described in [RFC4033], [RFC4034], and [RFC4035].

6.2. NS Record Considerations

CHAIN responses SHOULD include the authoritative NS RRset with its RRSIG records required for validation. It MUST NOT include the NS RRset from the parent zone, as this RRset is not signed. If the size of the answer is an important factor, the NS RRset MAY be omitted.

When a DNSSEC chain is supplied via CHAIN, the forwarding resolver is no longer required to use the NS RRset, as it can construct the validation path via the DNSKEY and DS RRsets without using the NS RRset. However, the forwarding resolver might be forced to switch from forwarding resolver mode to recursive resolver mode due to a network topology change. In recursive resolver mode, the NS RRsets are needed to find and query authoritative servers directly. It is RECOMMENDED that the DNS forwarding resolver populate its cache with this information to avoid requiring future queries to obtain any missing NS records. Therefore, CHAIN responses MUST include the NS RRset from the child zone, including the RRSIG records required for validation.

6.3. Session Management

The use of TCP keepalive [RFC7828] on DNS TCP sessions is RECOMMENDED; thus, TCP sessions should not immediately be closed after the DNS answer to the first query is received.

Both DNS clients and servers are subject to resource constraints that will limit the extent to which CHAIN queries can be executed. Effective limits for the number of active sessions that can be maintained on individual clients and servers should be established either as configuration options or by interrogation of process limits imposed by the operating system.

In the event that there is greater demand for CHAIN queries than can be accommodated, DNS servers may stop advertising the CHAIN option in successive DNS messages. This allows, for example, clients with other candidate servers to query to establish new sessions with different servers in expectation that those servers might still allow CHAIN queries.

6.4. Negative Trust Anchors

If a CHAIN answer would intersect with a negative trust anchor [RFC7646], a partial CHAIN up to the node above the negative trust anchor should be returned.

6.5. Anycast Considerations

Recursive resolvers of various types are commonly deployed using anycast [RFC4786].

Successive DNS transactions between a client and server using UDP transport may involve responses generated by different anycast nodes, and the use of anycast in the implementation of a DNS server is effectively undetectable by the client. The CHAIN option SHOULD NOT be included in responses using UDP transport from servers provisioned using anycast unless all anycast server nodes are capable of processing the CHAIN option.

Since DNS queries using CHAIN may result in longer TCP sessions, network topology changes may disrupt them more frequently. Anycast servers MAY make use of Multipath TCP [RFC6824] to anchor the server side of the TCP connection to an unambiguously unicast address in order to avoid disruption due to topology changes.

7. Security Considerations

7.1. Additional Work and Bandwidth

Producing CHAIN answers incurs additional load and bandwidth on the recursive resolver. At any time, a recursive resolver may decide to no longer answer with CHAIN answers and fall back to traditional DNS answers.

7.2. Amplification Attacks

CHAIN queries can potentially send very large DNS answers. Attackers could abuse this using spoofed source IP addresses to inflict large distributed denial-of-service attacks using CHAINS as an amplification vector in their attack. While TCP is not vulnerable for this type of abuse, the UDP protocol is vulnerable to this.

A recursive resolver MUST NOT return CHAIN answers to clients over UDP without source IP address verification. An example of UDP-based source IP address verification is [RFC7873]. A recursive resolver refusing a CHAIN option MUST respond with a zero-length CHAIN option to indicate support for CHAIN queries when a proper transport is used. It MUST NOT send an RCODE of REFUSED.

7.3. Privacy Considerations

A client producing CHAIN queries reveals a little more information about its cache contents than regular DNS clients. This could be used to fingerprint a client across network reconnections. If DNS privacy is a concern, a CHAIN query client MAY try to use a DNS transport that provides privacy, such as [RFC7858] or a trusted DNS server that is contacted through a VPN connection such as IPsec.

8. Examples

8.1. CHAIN Query for "www.example.com"

- A web browser on a client machine asks the forwarding resolver running on the local host to resolve the A record of "www.example.com." by sending a regular DNS UDP query on port 53 to 127.0.0.1.

- The resolver on the client machine checks its cache and notices it already has a DNSSEC-validated entry of "com." in its cache. This includes the DNSKEY RRset with its RRSIG records. In other words, according to its cache, ".com" is DNSSEC validated as "secure" and can be used to continue a DNSSEC-validated chain.

- The resolver on the client opens a TCP connection to its upstream recursive resolver on port 53. It adds the CHAIN option as follows:
  - Option-code, set to 13
  - Option-length, set to 5
  - Closest trust point set to "com." (0x03 0x63 0x6f 0x6d 0x00)
- The upstream recursive resolver receives a DNS query over TCP with the CHAIN closest trust point set to "com.". After accepting the query, it starts constructing a DNS reply packet.
- The upstream recursive resolver performs all the regular work to ensure it has all the answers to the query for the A record of "www.example.com.". It does so without using the CHAIN option -- unless it is also configured as a forwarding resolver. The answer to the original DNS question could be the actual A record, the DNSSEC proof of nonexistence, or an insecure NXDOMAIN response.
- The upstream recursive resolver adds the CHAIN option to the DNS response as follows:
  - Option-code, set to 13
  - Option-length, set to 5
  - The closest trust point is set to "com." (0x03 0x63 0x6f 0x6d 0x00)
- The upstream recursive resolver constructs the DNS Authority Section and fills it (in any order) with:
  - The DS RRset for "example.com." and its corresponding RRSIGs (made by the "com." DNSKEY(s))
  - The DNSKEY RRset for "example.com." and its corresponding RRSIGs (made by the "example.com." DNSKEY(s))
  - The authoritative NS RRset for "example.com." and its corresponding RRSIGs (from the child zone)

  If the answer does not exist, and the zone uses DNSSEC, it also adds the proof of nonexistence, such as NSEC or NSEC3 records, to the Authority Section.

- The upstream recursive resolver constructs the DNS Answer section and fills it with:

  * The A record of "www.example.com." and its corresponding RRSIGs.

  If the answer does not exist (NODATA or NXDOMAIN), the Answer Section remains empty. For the NXDOMAIN case, the RCODE of the DNS answer packet is set to NXDOMAIN. Otherwise, it remains as NOERROR.

- The upstream recursive resolver returns the DNS answer over the existing TCP connection. When all data is sent, it SHOULD keep the TCP connection open to allow for additional incoming DNS queries -- provided it has enough resources to do so.

- The resolver on the client receives the DNS answer. It processes the Authority and the Answer Sections and places the information in its local cache. It ensures that no data is accepted into the cache without having proper DNSSEC validation. It MAY do so by looping over the entries in the Authority and Answer Sections. When an entry is validated for its cache, it is removed from the processing list. If an entry cannot be validated, it is left in the process list. When the end of the list is reached, the list is processed again until either all entries are placed in the cache or the remaining items cannot be placed in the cache due to lack of validation. Those entries are then discarded.

- If the cache contains a valid answer to the application's query, this answer is returned to the application via a regular DNS answer packet. This packet MUST NOT contain a CHAIN option. If no valid answer can be returned, normal error processing is done. For example, an NXDOMAIN or an empty Answer Section could be returned depending on the error condition.

8.2. Out-of-Path Query for "example.com"

A recursive resolver receives a query for the A record for "example.com". It includes the CHAIN option with the following parameters:

- Option-code, set to 13

- Option-length, set to 14

- The closest trust point set to "unrelated.ca." (0x09 0x75 0x6e 0x72 0x65 0x6c 0x61 0x74 0x65 0x64 0x03 0x63 0x61 0x00)

As there is no chain that leads from "unrelated.ca." to "example.com.", the resolving nameserver answers with an empty CHAIN specified using:

- Option-code, set to 13
- Option-length, set to 0x00 0x00
- The closest trust point is omitted (zero length)

Note that the regular answer is still present just as it would be for a query that did not specify the CHAIN option.

8.3. Nonexistent Data

A recursive resolver receives a query for the A record for "ipv6.toronto.redhat.ca". It includes the CHAIN option with the following parameters:

- Option-code, set to 13
- Option-length, set to 0x00 0x03
- The closest trust point set to "ca."

Using regular UDP queries towards authoritative nameservers, it locates the NS RRset for "toronto.redhat.ca.". When querying for the A record, it receives a reply with RCODE "NoError" and an empty Answer Section. The Authority Section contains NSEC3 and RRSIG records proving there is no A RRTYPE for the QNAME "ipv6.toronto.redhat.ca".

The recursive resolver constructs a DNS reply with the following CHAIN option parameters:

- Option-code, set to 13
- Option-length, set to 0x00 0x00
- The closest trust point is omitted (zero length)

The RCODE is set to "NoError". The Authority Section is filled in with:

- The DS RRset for "redhat.ca." plus RRSIGs
- The DNSKEY RRset for "redhat.ca." plus RRSIGs

- The NS RRset for "redhat.ca." plus RRSIGs (e.g., ns[01].redhat.ca)
- The A RRset for "ns0.redhat.ca." and "ns1.redhat.ca." plus RRSIGs
- The DS RRset for "toronto.redhat.ca." plus RRSIGs
- The NS RRset for "toronto.redhat.ca." plus RRSIGs (e.g., ns[01].toronto.redhat.ca)
- The DNSKEY RRset for "toronto.redhat.ca." plus RRSIGs
- The A RRset and/or AAAA RRset for "ns0.toronto.redhat.ca." and "ns1.toronto.redhat.ca." plus RRSIGs
- The NSEC record for "ipv6.toronto.redhat.ca." (proves what RRTYPEs do exist; does not include A)
- The NSEC record for "toronto.redhat.ca." (proves no wildcard exists)

The Answer Section is empty. The RCODE is set to NOERROR.

9. IANA Considerations

9.1. EDNS0 Option Code for CHAIN

IANA has assigned option code 13 in the "DNS EDNS0 Option Codes (OPT)" registry to CHAIN.

10. Normative References

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