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DNS over DTLS (DNSoD)
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Abstract

DNS queries and responses are visible to network elements on the path between the DNS client and its server. These queries and responses can contain privacy-sensitive information which is valuable to protect. An active attacker can send bogus responses causing misdirection of the subsequent connection.

To counter passive listening and active attacks, this document proposes the use of Datagram Transport Layer Security (DTLS) for DNS, to protect against passive listeners and certain active attacks. As DNS needs to remain fast, this proposal also discusses mechanisms to reduce DTLS round trips and reduce DTLS handshake size. The proposed mechanism runs over port 853.

Status of This Memo

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

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This Internet-Draft will expire on April 20, 2016.

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1. Introduction

The Domain Name System is specified in [RFC1034] and [RFC1035]. DNS queries and responses are normally exchanged unencrypted and are thus vulnerable to eavesdropping. Such eavesdropping can result in an undesired entity learning domains that a host wishes to access, thus resulting in privacy leakage. DNS privacy problem is further discussed in [I-D.bortzmeyer-dnsop-dns-privacy].

Active attackers have long been successful at injecting bogus responses, causing cache poisoning and causing misdirection of the subsequent connection (if attacking A or AAAA records). A popular

mitigation against that attack is to use ephemeral and random source ports for DNS queries [RFC5452].

This document defines DNS over DTLS (DNSoD, pronounced "dee-enn-sod") which provides confidential DNS communication for stub resolvers, recursive resolvers, iterative resolvers and authoritative servers.

The motivations for proposing DNSoD are that

- TCP suffers from network head-of-line blocking, where the loss of a packet causes all other TCP segments to not be delivered to the application until the lost packet is re-transmitted. DNSoD, because it uses UDP, does not suffer from network head-of-line blocking.

- DTLS session resumption consumes 1 round trip whereas TLS session resumption can start only after TCP handshake is complete. Although TCP Fast Open [RFC7413] can reduce that handshake, TCP Fast Open is not yet available in commercially-popular operating systems.

2. Relationship to TCP Queries and to DNSSEC

DNS queries can be sent over UDP or TCP. The scope of this document, however, is only UDP. DNS over TCP could be protected with TLS, as described in [I-D.ietf-dprive-dns-over-tls]. Alternatively, a shim protocol could be defined between DTLS and DNS, allowing large responses to be sent over DTLS itself, see Section 7.

DNS Security Extensions (DNSSEC [RFC4033]) provides object integrity of DNS resource records, allowing end-users (or their resolver) to verify legitimacy of responses. However, DNSSEC does not protect privacy of DNS requests or responses. DNSoD works in conjunction with DNSSEC, but DNSoD does not replace the need or value of DNSSEC.

3. Common problems with DNS Privacy

This section describes problems common to any DNS privacy solution. To achieve DNS privacy an encrypted and integrity-protected channel is needed between the client and server. This channel can be blocked, and the client needs to react to such blockages.

3.1. Firewall Blocking Ports or DNS Privacy Protocol

When sending DNS over an encrypted channel, there are two choices: send the encrypted traffic over the DNS ports (UDP 53, TCP 53) or send the encrypted traffic over a different port. The encrypted traffic is not normal DNS traffic, but rather is a cryptographic

handshake followed by encrypted payloads. There can be firewalls, other security devices, or intercepting DNS proxies which block the non-DNS traffic or otherwise react negatively (e.g., quarantining the host for suspicious behavior). Alternatively, if a different port is used for the encrypted traffic, a firewall or other security device might block that port or otherwise react negatively.

There is no panacea, and only experiments on the Internet will uncover which technique or combination of techniques will work best. This document describes using DNSoD on a well-known port.

3.2. Authenticating the DNS Privacy Server

DNS privacy requires encrypting the query (and response) from passive attacks. Such encryption typically provides integrity protection as a side-effect, which means on-path attackers cannot simply inject bogus DNS responses. However, to provide stronger protection from active attackers pretending to be the server, the server itself needs to be authenticated.

To authenticate the server providing DNS privacy, the DNS client needs to be configured with the names or IP addresses of those DNS privacy servers. The server certificate MUST contain DNS-ID (subjectAltName) as described in Section 4.1 of [RFC6125]. DNS names and IP addresses can be contained in the subjectAltName entries. The client MUST use the rules and guidelines given in section 6 of [RFC6125] to validate the DNS server identity.

We imagine this could be implemented by adding the certificate name to the /etc/resolv.conf file, such as below:

```
nameserver 8.8.8.8
certificate google-public-dns.google.com
nameserver 208.67.220.220
certificate resolver.opendns.com
```

For DNS privacy servers that don't have a certificate trust chain (e.g., because they are on a home network or a corporate network), the configured list of DNS privacy servers can contain the Subject Public Key Info (SPKI) fingerprint of the DNS privacy server (i.e., a simple whitelist of name and SPKI fingerprint). The public key is used for the same reasons HTTP pinning [RFC7469] uses the public key. Raw public key-based authentication mechanism defined in [RFC7250] can be also used to authenticate the DNS server.

We imagine this could be implemented by adding the SPKI fingerprint to the /etc/resolv.conf file, such as below (line split for Internet Draft formatting):

```
nameserver 192.168.1.1
sha256 : "d6qzRu9zOECb90Uez27xWltNsj0e1Md7GkYYkVoZWmM="
```

The only algorithm considered at this time is "sha256", i.e., the hash algorithm SHA256 [RFC6234]; additional algorithms may be allowed for use in this context in the future. The quoted-string is a sequence of base 64 digits: the base64-encoded SPKI Fingerprint [RFC4648].

3.3. Downgrade attacks

Using DNS privacy with an authenticated server is most preferred, DNS privacy with an unauthenticated server is next preferred, and plain DNS is least preferred. This section gives a non-normative discussion on common behaviors and choices.

An implementation MAY attempt to obtain DNS privacy by contacting DNS servers on the local network (provided by DHCP) and on the Internet, and make those attempts in parallel to reduce user impact. If DNS privacy cannot be successfully negotiated for whatever reason, the client can do three things:

1. refuse to send DNS queries on this network, which means the client cannot make effective use of this network, as modern networks require DNS; or,

2. use opportunistic security, as described in [RFC7435]. or,

3. send plain DNS queries on this network, which means no DNS privacy is provided.

Heuristics can improve this situation, but only to a degree (e.g., previous success of DNS privacy on this network may be reason to alert the user about failure to establish DNS privacy on this network now). Still, the client (in cooperation with the end user) has to decide to use the network without the protection of DNS privacy.

4. 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 [RFC2119].

5. Incremental Deployment

DNSoD can be deployed incrementally by the Internet Service Provider or as an Internet service.

If the ISP's DNS resolver supports DNSoD, then DNS queries are protected from passive listening and from many active attacks along that path.

DNSoD can be offered as an Internet service, and a stub resolver or DNS resolver can be configured to point to that DNSoD server (rather than to the ISP-provided DNS server).

6. DTLS session initiation, Polling and Discovery

Many modern operating systems already detect if a web proxy is interfering with Internet communications, using proprietary mechanisms that are out of scope of this document. After that mechanism has run (and detected Internet connectivity is working), the DNSoD procedure described in this document should commence. This timing avoids delays in joining the network (and displaying an icon indicating successful Internet connection), at the risk that those initial DNS queries will be sent without protection afforded by DNSoD.

DNSoD MUST run over standard UDP port 853 as defined in Section 11. A DNS server that supports DNSoD MUST listen for and accept DTLS packets on a designated port 853.

The host should determine if the DNS server supports DNSoD by sending a DTLS ClientHello message. A DNS server that does not support DNSoD will not respond to ClientHello messages sent by the client. The client MUST use timer values defined in Section 4.2.4.1 of [RFC6347] for retransmission of ClientHello message and if no response is received from the DNS server. After 15 seconds, it MUST cease attempts to re-transmit its ClientHello. If the DNS client receives a hard ICMP error [RFC1122], it MUST immediately cease attempts to re-transmit its ClientHello. Thereafter, the client MAY repeat that procedure in the event the DNS server has been upgraded to support DNSoD, but such probing SHOULD NOT be done more frequently than every 24 hours and MUST NOT be done more frequently than every 15 minutes. This mechanism requires no additional signaling between the client and server.

7. Performance Considerations

To reduce number of octets of the DTLS handshake, especially the size of the certificate in the ServerHello (which can be several kilobytes), DNS client and server can use raw public keys [RFC7250] or Cached Information Extension [I-D.ietf-tls-cached-info]. Cached Information Extension avoids transmitting the server's certificate and certificate chain if the client has cached that information from a previous TLS handshake.

Multiple DNS queries can be sent over a single DTLS session and the DNSoD client need not wait for an outstanding reply before sending the next query. The existing Query ID allows multiple requests and responses to be interleaved in whatever order they can be fulfilled by the DNS server. This means DNSoD reduces the consumption of UDP port numbers, and because DTLS protects the communication between the DNS client and its server, the resolver SHOULD NOT use random ephemeral source ports (Section 9.2 of [RFC5452]) because such source port use would incur additional, unnecessary DTLS load on the DNSoD server. When sending multiple queries over a single DTLS session, clients MUST take care to avoid Message ID collisions. In other words, they MUST not re-use the DNS Message ID of an in-flight query.

It is highly advantageous to avoid server-side DTLS state and reduce the number of new DTLS sessions on the server which can be done with [RFC5077]. This also eliminates a round-trip for subsequent DNSoD queries, because with [RFC5077] the DTLS session does not need to be re-established.

Compared to normal DNS, DTLS adds at least 13 octets of header, plus cipher and authentication overhead to every query and every response. This reduces the size of the DNS payload that can be carried. Certain DNS responses are large (e.g., many AAAA records, TXT, SRV) and don't fit into a single UDP packet, causing a partial response with the truncation (TC) bit set. The client is then expected to repeat the query over TCP, which causes additional name resolution delay. We have considered two ideas, one that reduces the need to switch to TCP and another that eliminates the need to switch to TCP:

- To avoid IP fragmentation, DTLS handshake messages incorporate their own fragment offset and fragment length, but this is only for the handshake. Payloads that cause the DTLS packet to exceed the path maximum MTU need their own fragmentation support Section 9.

- DNS client and server MUST support the EDNS0 option defined in [RFC6891] so that the DNS client can indicate to the DNS server

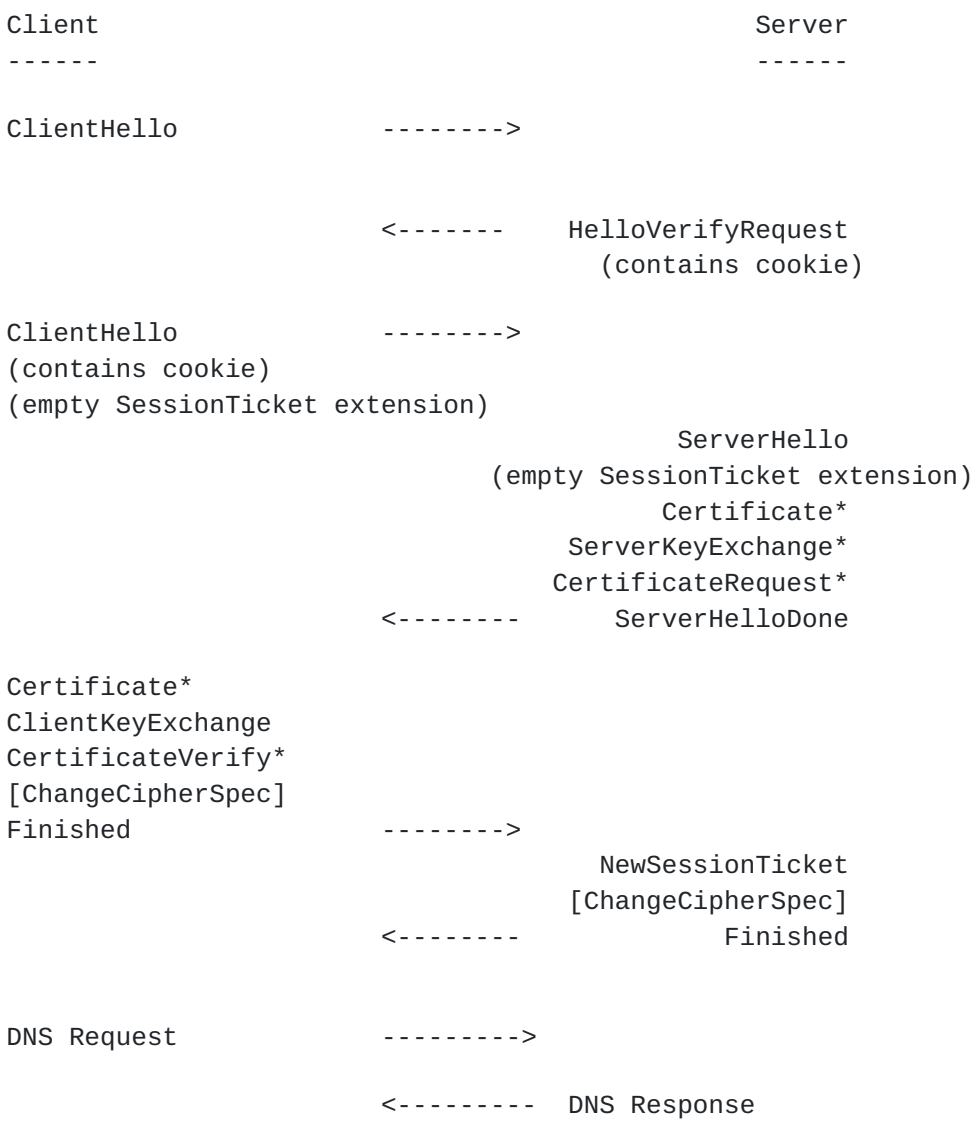
the maximum DNS response size it can handle without IP fragmentation.

DNSoD puts an additional computational load on servers. The largest gain for privacy is to protect the communication between the DNS client (the end user's machine) and its caching resolver. Implementing DNSoD on root servers is outside the scope of this document.

8. Established sessions

In DTLS, all data is protected using the same record encoding and mechanisms. When the mechanism described in this document is in effect, DNS messages are encrypted using the standard DTLS record encoding. When a user of DTLS wishes to send an DNS message, it delivers it to the DTLS implementation as an ordinary application data write (e.g., SSL_write()). A single DTLS session can be used to receive multiple DNS requests and generate DNS multiple responses.

DNSoD client and server can use DTLS heartbeat [RFC6520] to verify that the peer still has DTLS state. DTLS session is terminated by the receipt of an authenticated message that closes the connection (e.g., a DTLS fatal alert).



Message Flow for Full Handshake Issuing New Session Ticket

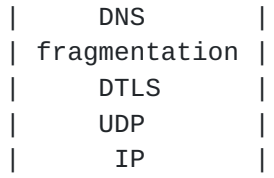
9. Fragmentation and Reassembly

This section describes an optional procedure the client and server can negotiate to send large DNS responses without IP fragmentation or reassembly.

Large DNS responses cannot exceed the DNS maximum payload size (512) unless a larger size is negotiated with EDNS0. Even using EDNS0, requesting responses larger the path MTU causes IP fragmentation. If the response exceeds that size it is truncated and the TC bit set, forcing a DNS client that wants the entire response to establish a TCP connection and send the query again over TCP. This slows down

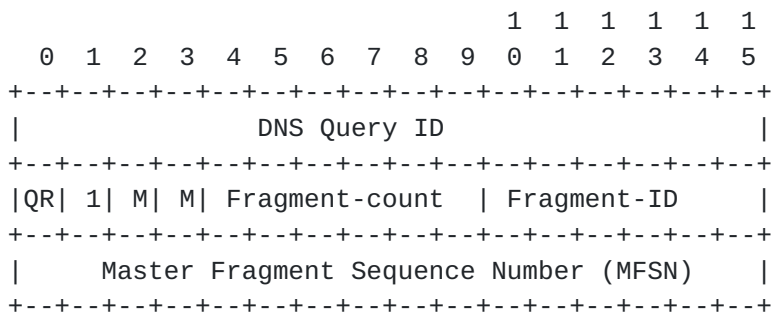
DNS lookups, and is even more troublesome if a TLS session also needs to be established.

To avoid these problems with DNS over DTLS, the DNS client and the DNS server can indicate support for a new application-layer fragmentation and reassembly mechanism, by using the new DTLS extension "DNS-fragment" in the DTLS ClientHello, and indicate how many fragments the client is willing to receive. If the server supports this extension, it includes "DNS-fragment" in its DTLS ServerHello and indicates how many fragments it is willing to send in a response. The EDNS0 value controls the size of the responses, including the size of fragmented responses. If both the DTLS client and DTLS server indicate support DNS-fragment, and the DNS server's response exceeds the EDNS0-indicated size, the DNS server fragments the response into packets that are no larger than the EDNS0-indicated size, and sends them all to the DNS client. Logically, the layering of the fragmentation is like this,



9.1. Generating fragmented packets

The response is formed, and separate packets are sent with their own fragmentation header, as follows:



The above fragment header appears at the beginning of all fragments. The fields are defined as follows:

DNS Query ID: Is the same as the ID value of the DNS response; this means the first fragment has the DNS Query ID value appear twice in the packet, and means subsequent fragments will contain their associated DNS Query ID in the fragmentation header.

QR: This is the QR field in a normal DNS packet, and is always set, because fragmentation/reassembly is only defined in this document for responses.

OP: This bit is always set. This bit corresponds to first bit of the Opcode field of a normal DNS packet; that Opcode field for a normal DNS packet must be all 0. By setting this bit to 1, this fragmentation header is distinguished from a normal DNS packet.

M: The next two "M" bits must be 0, for future use.

Fragment-count: For each query ID that generates a fragmented response, this field is set to the number of fragments that will be sent (that is, the highest Fragment-ID minus 1).

Fragment-ID: Starts at 0 for the first fragmented segment and is incremented for each fragment.

Master Fragment Sequence Number: starts at 0 and is incremented for the first packet of each fragmented response.

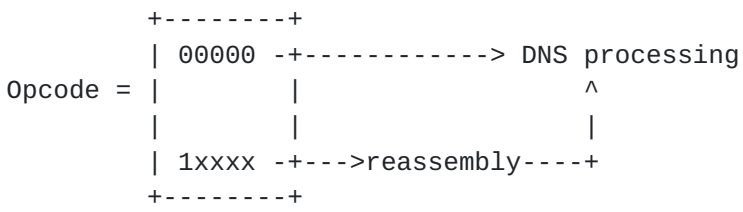
The length of each fragment is calculated from the UDP packet size minus the DTLS overhead.

It is RECOMMENDED that a value not exceeding 10 is used by the DNS client and DNS server during their DNS-fragment negotiation [RFC6928]. If the server needs to generate more fragments than were negotiated, MUST set the TC bit and SHOULD send the number of fragments negotiated.

The fragments MUST be at least 64 bytes (minimum Ethernet MTU) minus DTLS, UDP, and IP overhead. The fragments need not all be the same size. The DNS client indicates the maximum DNS size using EDNS0, which constrains the size of the response packet on the wire. When generating fragmented packets, the DNS server MUST NOT generate fragments that exceed the maximum DNS size.

9.2. Receiving fragmented packets

Upon receipt of a DTLS packet, DTLS processing is performed and the Opcode field is examined to determine if reassembly is required before processing as a DNS packet, as depicted below:



If reassembly needs to be performed, the packets are matched according to their DNS query ID value (at the top of the fragment header), their Master Fragment Sequence Number, and ordered by their Fragment-ID. Once all the fragments have been received (that is, all fragments from 0 through the Fragment-ID matching the frag-count minus 1), the fragment headers are removed and the DNS payload is handed to the DNS layer. Due to network loss or packet corruption, some fragments might not be received, which will cause the DNS layer to perform a normal re-transmission of the DNS query, with the same query ID. The re-transmitted answer, which will be fragmented identically to the original answer (assuming that resource record did not change between the two answers), will have a different Master Fragment Sequence Number.

> Design Note: Tha MFSN protects against corruption caused by DNS resource record changing between the initial query and its re-transmitted query.

After a time out, incomplete fragments are discarded by the receiver.

If the Fragment-ID is 0 and the DNS Query ID value in the fragment header does not match the ID value in the DNS header, a DTLS Alert is generated and an error is logged.

9.3. The DNS-fragment Extension

A new extension type ("DNS_fragment(TBA)") is defined and MUST be included by the client in its "ClientHello" message if it wants to use fragmentation, and MUST be included in the ServerHello if the server agrees to use fragmentation.

```
enum { DNS-fragment(TBA), (65535) } ExtensionType;
```

The "extension_data" field of the "DNS-fragment" extension MUST contain a "MaxNumOfFragments" value, which is the maximum number of fragments the client wants to receive (indicated in the ClientHello), and the maximum number of fragments the server will send (indicated in the ServerHello).

```
uint8 MaxNoOfFragments;
```

The value indicated in the ServerHello MUST be less than or equal to the value indicated in the ClientHello, and if not the client MUST terminate the DTLS association with an Alert, and MAY establish a new DTLS association without the dns_fragment extension.

10. Anycast

DNS servers are often configured with anycast addresses. While the network is stable, packets transmitted from a particular source to an anycast address will reach the same server that has the cryptographic context from the DNS over DTLS handshake. But when the network configuration changes,a DNS over DTLS packet can be received by a server that does not have the necessary cryptographic context. To encourage the client to initiate a new DTLS handshake, DNS servers SHOULD generate a DTLS Alert message in response to receiving a DTLS packet for which the server does not have any cryptographic context.

11. IANA Considerations

This document adds a new extension for DTLS, in accordance with [RFC5246]:

```
enum { DNS-Fragment(TBA), (65535) } ExtensionType;
```

[[NOTE: This value needs to be assigned by IANA]]

This extension MUST only be used with DTLS.

IANA is requested to add the following value to the "Service Name and Transport Protocol Port Number Registry" registry in the System Range. The registry for that range requires IETF Review or IESG Approval [RFC6335] and such a review has been requested using the Early Allocation process [RFC7120] for the well-known UDP port in this document.

Service Name	domain-s
Transport Protocol(s)	UDP/TCP
Port	853
Assignee	IESG
Contact	dwing@cisco.com
Description	DNS query-response protocol runs over DTLS and TLS
Reference	This document

12. Security Considerations

The interaction between a DNS client and DNS server requires Datagram Transport Layer Security (DTLS) with a ciphersuite offering confidentiality protection and guidance given in [RFC7525] must be followed to avoid attacks on DTLS. Once a DNSoD client has established a security association with a particular DNS server, and outstanding normal DNS queries with that server (if any) have been received, the DNSoD client MUST ignore any subsequent normal DNS responses from that server, as all subsequent responses should be encrypted. This behavior mitigates all possible attacks described in Measures for Making DNS More Resilient against Forged Answers [RFC5452].

The DNS Fragment extension does not impact security of DTLS session establishment or application data exchange. DNS Fragment provides fragmentation and reassembly of the encrypted DNS payload.

13. Acknowledgements

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