

DNSOP Working Group  
Internet-Draft  
Updates: 1035, 7766 (if approved)  
Intended status: Standards Track  
Expires: June 9, 2019

R. Bellis  
ISC  
S. Cheshire  
Apple Inc.  
J. Dickinson  
S. Dickinson  
Sinodun  
T. Lemon  
Nibbhaya Consulting  
T. Pusateri  
Unaffiliated  
December 06, 2018

DNS Stateful Operations  
draft-ietf-dnsop-session-signal-20

Abstract

This document defines a new DNS OPCODE for DNS Stateful Operations (DSO). DSO messages communicate operations within persistent stateful sessions, using type-length-value (TLV) syntax. Three TLVs are defined that manage session timeouts, termination, and encryption padding, and a framework is defined for extensions to enable new stateful operations. This document updates RFC 1035 by adding a new DNS header opcode which has different message semantics, and a new result code. This document updates RFC 7766 by redefining a session, providing new guidance on connection re-use, and providing a new mechanism for handling session idle timeouts.

Status of This Memo

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

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <https://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on June 9, 2019.

## Copyright Notice

Copyright (c) 2018 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

|   |    |
|---|----|
| 1. Introduction . . . . .                                 | 3  |
| 2. Requirements Language . . . . .                        | 5  |
| 3. Terminology . . . . .                                  | 6  |
| 4. Applicability . . . . .                                | 9  |
| 4.1. Use Cases . . . . .                                  | 9  |
| 4.1.1. Session Management . . . . .                       | 9  |
| 4.1.2. Long-lived Subscriptions . . . . .                 | 9  |
| 4.2. Applicable Transports . . . . .                      | 10 |
| 5. Protocol Details . . . . .                             | 11 |
| 5.1. DSO Session Establishment . . . . .                  | 12 |
| 5.1.1. Session Establishment Failure . . . . .            | 13 |
| 5.1.2. Session Establishment Success . . . . .            | 14 |
| 5.2. Operations After Session Establishment . . . . .     | 14 |
| 5.3. Session Termination . . . . .                        | 15 |
| 5.3.1. Handling Protocol Errors . . . . .                 | 15 |
| 5.4. Message Format . . . . .                             | 16 |
| 5.4.1. DNS Header Fields in DSO Messages . . . . .        | 17 |
| 5.4.2. DSO Data . . . . .                                 | 19 |
| 5.4.3. TLV Syntax . . . . .                               | 21 |
| 5.4.4. EDNS(0) and TSIG . . . . .                         | 24 |
| 5.5. Message Handling . . . . .                           | 25 |
| 5.5.1. Delayed Acknowledgement Management . . . . .       | 26 |
| 5.5.2. MESSAGE ID Namespaces . . . . .                    | 27 |
| 5.5.3. Error Responses . . . . .                          | 28 |
| 5.6. Responder-Initiated Operation Cancellation . . . . . | 29 |
| 6. DSO Session Lifecycle and Timers . . . . .             | 30 |
| 6.1. DSO Session Initiation . . . . .                     | 30 |
| 6.2. DSO Session Timeouts . . . . .                       | 31 |
| 6.3. Inactive DSO Sessions . . . . .                      | 32 |
| 6.4. The Inactivity Timeout . . . . .                     | 33 |
| 6.4.1. Closing Inactive DSO Sessions . . . . .            | 33 |

|        |  |    |
|--------|--|----|
| 6.4.2. | Values for the Inactivity Timeout . . . . .                  | 34 |
| 6.5.   | The Keepalive Interval . . . . .                             | 35 |
| 6.5.1. | Keepalive Interval Expiry . . . . .                          | 35 |
| 6.5.2. | Values for the Keepalive Interval . . . . .                  | 35 |
| 6.6.   | Server-Initiated Session Termination . . . . .               | 37 |
| 6.6.1. | Server-Initiated Retry Delay Message . . . . .               | 38 |
| 6.6.2. | Misbehaving Clients . . . . .                                | 39 |
| 6.6.3. | Client Reconnection . . . . .                                | 39 |
| 7.     | Base TLVs for DNS Stateful Operations . . . . .              | 41 |
| 7.1.   | Keepalive TLV . . . . .                                      | 41 |
| 7.1.1. | Client handling of received Session Timeout values . . . . . | 43 |
| 7.1.2. | Relationship to edns-tcp-keepalive EDNS0 Option . . . . .    | 44 |
| 7.2.   | Retry Delay TLV . . . . .                                    | 45 |
| 7.2.1. | Retry Delay TLV used as a Primary TLV . . . . .              | 45 |
| 7.2.2. | Retry Delay TLV used as a Response Additional TLV . . . . .  | 47 |
| 7.3.   | Encryption Padding TLV . . . . .                             | 48 |
| 8.     | Summary Highlights . . . . .                                 | 49 |
| 8.1.   | QR bit and MESSAGE ID . . . . .                              | 49 |
| 8.2.   | TLV Usage . . . . .  | 50 |
| 9.     | Additional Considerations . . . . .                          | 52 |
| 9.1.   | Service Instances . . . . .                                  | 52 |
| 9.2.   | Anycast Considerations . . . . .                             | 53 |
| 9.3.   | Connection Sharing . . . . .                                 | 54 |
| 9.4.   | Operational Considerations for Middlebox . . . . .           | 55 |
| 9.5.   | TCP Delayed Acknowledgement Considerations . . . . .         | 56 |
| 10.    | IANA Considerations . . . . .                                | 59 |
| 10.1.  | DSO OPCODE Registration . . . . .                            | 59 |
| 10.2.  | DSO RCODE Registration . . . . .                             | 59 |
| 10.3.  | DSO Type Code Registry . . . . .                             | 59 |
| 11.    | Security Considerations . . . . .                            | 60 |
| 11.1.  | TLS 0-RTT Considerations . . . . .                           | 61 |
| 12.    | Acknowledgements . . . . .                                   | 62 |
| 13.    | References . . . . .   | 62 |
| 13.1.  | Normative References . . . . .                               | 62 |
| 13.2.  | Informative References . . . . .                             | 63 |
|        | Authors' Addresses . . . . .                                 | 65 |

## 1. Introduction

This document specifies a mechanism for managing stateful DNS connections. DNS most commonly operates over a UDP transport, but can also operate over streaming transports; the original DNS RFC specifies DNS over TCP [RFC1035] and a profile for DNS over TLS [RFC7858] has been specified. These transports can offer persistent, long-lived sessions and therefore when using them for transporting DNS messages it is of benefit to have a mechanism that can establish parameters associated with those sessions, such as timeouts. In such

situations it is also advantageous to support server-initiated messages (such as DNS Push Notifications [I-D.ietf-dnssd-push]).

The existing EDNS(0) Extension Mechanism for DNS [RFC6891] is explicitly defined to only have "per-message" semantics. While EDNS(0) has been used to signal at least one session-related parameter (edns-tcp-keepalive EDNS0 Option [RFC7828]) the result is less than optimal due to the restrictions imposed by the EDNS(0) semantics and the lack of server-initiated signalling. For example, a server cannot arbitrarily instruct a client to close a connection because the server can only send EDNS(0) options in responses to queries that contained EDNS(0) options.

This document defines a new DNS OPCODE, DSO ([TBA1], tentatively 6), for DNS Stateful Operations. DSO messages are used to communicate operations within persistent stateful sessions, expressed using type-length-value (TLV) syntax. This document defines an initial set of three TLVs, used to manage session timeouts, termination, and encryption padding.

All three TLVs defined here are mandatory for all implementations of DSO. Further TLVs may be defined in additional specifications.

DSO messages may or may not be acknowledged; this is signalled by providing a non-zero message ID for messages that must be acknowledged (DSO request messages) and a zero message ID for messages that are not to be acknowledged (DSO unidirectional messages), and is also specified in the definition of a particular DSO message type. Messages are pipelined; answers may appear out of order when more than one answer is pending.

The format for DSO messages (Section 5.4) differs somewhat from the traditional DNS message format used for standard queries and responses. The standard twelve-byte header is used, but the four count fields (QDCOUNT, ANCOUNT, NSCOUNT, ARCOUNT) are set to zero and accordingly their corresponding sections are not present.

The actual data pertaining to DNS Stateful Operations (expressed in TLV syntax) is appended to the end of the DNS message header. Just as in traditional DNS over TCP [RFC1035] [RFC7766] the stream protocol carrying DSO messages (which are just another kind of DNS message) frames them by putting a 16-bit message length at the start, so the length of the DSO message is determined from that length, rather than from any of the DNS header counts.

When displayed using packet analyzer tools that have not been updated to recognize the DSO format, this will result in the DSO data being

displayed as unknown additional data after the end of the DNS message.

This new format has distinct advantages over an RR-based format because it is more explicit and more compact. Each TLV definition is specific to its use case, and as a result contains no redundant or overloaded fields. Importantly, it completely avoids conflating DNS Stateful Operations in any way with normal DNS operations or with existing EDNS(0)-based functionality. A goal of this approach is to avoid the operational issues that have befallen EDNS(0), particularly relating to middlebox behaviour (see for example [I-D.ietf-dnsop-no-response-issue] sections 3.2 and 4).

With EDNS(0), multiple options may be packed into a single OPT pseudo-RR, and there is no generalized mechanism for a client to be able to tell whether a server has processed or otherwise acted upon each individual option within the combined OPT pseudo-RR. The specifications for each individual option need to define how each different option is to be acknowledged, if necessary.

In contrast to EDNS(0), with DSO there is no compelling motivation to pack multiple operations into a single message for efficiency reasons, because DSO always operates using a connection-oriented transport protocol. Each DSO operation is communicated in its own separate DNS message, and the transport protocol can take care of packing several DNS messages into a single IP packet if appropriate. For example, TCP can pack multiple small DNS messages into a single TCP segment. This simplification allows for clearer semantics. Each DSO request message communicates just one primary operation, and the RCODE in the corresponding response message indicates the success or failure of that operation.

## 2. Requirements Language

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.

### 3. Terminology

DSO: DNS Stateful Operations.

connection: a bidirectional byte (or message) stream, where the bytes (or messages) are delivered reliably and in-order, such as provided by using DNS over TCP [RFC1035] [RFC7766] or DNS over TLS [RFC7858].

session: The unqualified term "session" in the context of this document refers to a persistent network connection between two endpoints which allows for the exchange of DNS messages over a connection where either end of the connection can send messages to the other end. (The term has no relationship to the "session layer" of the OSI "seven-layer model".)

DSO Session: a session established between two endpoints that acknowledge persistent DNS state via the exchange of DSO messages over the connection. This is distinct from a DNS-over-TCP session as described in the previous specification for DNS over TCP [RFC7766].

close gracefully: a normal session shutdown, where the client closes the TCP connection to the server using a graceful close, such that no data is lost (e.g., using TCP FIN, see Section 5.3).

forcibly abort: a session shutdown as a result of a fatal error, where the TCP connection is unilaterally aborted without regard for data loss (e.g., using TCP RST, see Section 5.3).

server: the software with a listening socket, awaiting incoming connection requests, in the usual DNS sense.

client: the software which initiates a connection to the server's listening socket, in the usual DNS sense.

initiator: the software which sends a DSO request message or a DSO unidirectional message during a DSO session. Either a client or server can be an initiator

responder: the software which receives a DSO request message or a DSO unidirectional message during a DSO

session. Either a client or server can be a responder.

sender: the software which is sending a DNS message, a DSO message, a DNS response, or a DSO response.

receiver: the software which is receiving a DNS message, a DSO message, a DNS response, or a DSO response.

service instance: a specific instance of server software running on a specific host (Section 9.1).

long-lived operation: a long-lived operation is an outstanding operation on a DSO session where either the client or server, acting as initiator, has requested that the responder send new information regarding the request, as it becomes available.

Early Data: A TLS 1.3 handshake containing early data that begins a DSO session ([RFC8446] section 2.3). TCP Fast Open is only permitted when using TLS.

DNS message: any DNS message, including DNS queries, response, updates, DSO messages, etc.

DNS request message: any DNS message where the QR bit is 0.

DNS response message: any DNS message where the QR bit is 1.

DSO message: a DSO request message, DSO unidirectional message, or a DSO response to a DSO request message. If the QR bit is 1 in a DSO message, it is a DSO response message. If the QR bit is 0 in a DSO message, it is a DSO request message or DSO unidirectional message, as determined by the specification of its primary TLV.

DSO response message: a response to a DSO request message.

DSO request message: a DSO message that requires a response.

DSO unidirectional message: a DSO message that does not require and cannot induce a response.

Primary TLV: The first TLV in a DSO message or DSO response; in the DSO message this determines the nature of the operation being performed.

Additional TLV: Any TLVs in a DSO message response that follow the primary TLV.

Response Primary TLV: The (optional) first TLV in a DSO response.

Response Additional TLV: Any TLVs in a DSO response that follow the (optional) Response Primary TLV.

**inactivity timer:** the time since the most recent non-keepalive DNS message was sent or received. (see Section 6.4)

**keepalive timer:** the time since the most recent DNS message was sent or received. (see Section 6.5)

**session timeouts:** the inactivity timer and the keepalive timer.

**inactivity timeout:** the maximum value that the inactivity timer can have before the connection is gracefully closed.

**keepalive interval:** the maximum value that the keepalive timer can have before the client is required to send a keepalive. (see Section 7.1)

**resetting a timer:** setting the timer value to zero and restarting the timer.

**clearing a timer:** setting the timer value to zero but not restarting the timer.

## 4. Applicability

DNS Stateful Operations are applicable to several known use cases and are only applicable on transports that are capable of supporting a DSO Session.

### 4.1. Use Cases

There are several use cases for DNS Stateful operations that can be described here.

#### 4.1.1. Session Management

Firstly, establishing session parameters such as server-defined timeouts is of great use in the general management of persistent connections. For example, using DSO sessions for stub-to-recursive DNS-over-TLS [RFC7858] is more flexible for both the client and the server than attempting to manage sessions using just the edns-tcp-keepalive EDNS0 Option [RFC7828]. The simple set of TLVs defined in this document is sufficient to greatly enhance connection management for this use case.

#### 4.1.2. Long-lived Subscriptions

Secondly, DNS-SD [RFC6763] has evolved into a naturally session-based mechanism where, for example, long-lived subscriptions lend themselves to 'push' mechanisms as opposed to polling. Long-lived stateful connections and server-initiated messages align with this use case [I-D.ietf-dnssd-push].

A general use case is that DNS traffic is often bursty but session establishment can be expensive. One challenge with long-lived connections is to maintain sufficient traffic to maintain NAT and firewall state. To mitigate this issue this document introduces a new concept for the DNS, that is DSO "Keepalive traffic". This traffic carries no DNS data and is not considered 'activity' in the classic DNS sense, but serves to maintain state in middleboxes, and to assure client and server that they still have connectivity to each other.

#### 4.2. Applicable Transports

DNS Stateful Operations are applicable in cases where it is useful to maintain an open session between a DNS client and server, where the transport allows such a session to be maintained, and where the transport guarantees in-order delivery of messages, on which DSO depends. Examples of transports that can support DNS Stateful Operations are DNS-over-TCP [RFC1035] [RFC7766] and DNS-over-TLS [RFC7858].

Note that in the case of DNS over TLS, there is no mechanism for upgrading from DNS-over-TCP to DNS-over-TLS mid-connection (see [RFC7858] section 7). A connection is either DNS-over-TCP from the start, or DNS-over-TLS from the start.

DNS Stateful Operations are not applicable for transports that cannot support clean session semantics, or that do not guarantee in-order delivery. While in principle such a transport could be constructed over UDP, the current DNS specification over UDP transport [RFC1035] does not provide in-order delivery or session semantics, and hence cannot be used. Similarly, DNS-over-HTTP [I-D.ietf-doh-dns-over-https] cannot be used because HTTP has its own mechanism for managing sessions, and this is incompatible with the mechanism specified here.

No other transports are currently defined for use with DNS Stateful Operations. Such transports can be added in the future, if they meet the requirements set out in the first paragraph of this section.

## 5. Protocol Details

The overall flow of DNS Stateful Operations goes through a series of phases:

**Connection Establishment:** A client establishes a connection to a server. (Section 4.2)

**Connected but sessionless:** A connection exists, but a DSO session has not been established. DNS messages can be sent from the client to server, and DNS responses can be sent from servers to clients. In this state a client that wishes to use DSO can attempt to establish a DSO session (Section 5.1). Standard DNS-over-TCP inactivity timeout handling is in effect [RFC7766] (see Section 7.1.2).

**DSO Session Establishment in Progress:** A client has sent a DSO request, but has not yet received a DSO response. In this phase, the client may send more DSO requests and more DNS requests, but **MUST NOT** send DSO unidirectional messages (Section 5.1).

**DSO Session Establishment Failed:** The attempt to establish the DSO session did not succeed. At this point, the client is permitted to continue operating without a DSO session (Connected but Sessionless) but does not send further DSO messages (Section 5.1).

**DSO Session Established:** Both client and server may send DSO messages and DNS messages; both may send replies in response to messages they receive (Section 5.2). The inactivity timer (Section 6.4) is active; the keepalive timer (Section 6.5) is active. Standard DNS-over-TCP inactivity timeout handling is no longer in effect [RFC7766] (see Section 7.1.2).

**Server Shutdown:** The server has decided to gracefully terminate the session, and has sent the client a Retry Delay message (Section 6.6.1). There may still be unprocessed messages from the client; the server will ignore these. The server will not send any further messages to the client (Section 6.6.1.1).

**Client Shutdown:** The client has decided to disconnect, either because it no longer needs service, the connection is inactive (Section 6.4.1), or because the server sent it a Retry Delay message (Section 6.6.1). The client closes the connection gracefully Section 5.3.

**Reconnect:** The client disconnected as a result of a server shutdown. The client either waits for the server-specified Retry Delay to expire (Section 6.6.3), or else contacts a different server

instance. If the client no longer needs service, it does not reconnect.

**Forcibly Abort:** The client or server detected a protocol error, and further communication would have undefined behavior. The client or server forcibly aborts the connection (Section 5.3).

**Abort Reconnect Wait:** The client has forcibly aborted the connection, but still needs service. Or, the server forcibly aborted the connection, but the client still needs service. The client either connects to a different service instance (Section 9.1) or waits to reconnect (Section 6.6.3.1).

#### 5.1. DSO Session Establishment

In order for a session to be established between a client and a server, the client must first establish a connection to the server, using an applicable transport (see Section 4).

In some environments it may be known in advance by external means that both client and server support DSO, and in these cases either client or server may initiate DSO messages at any time. In this case, the session is established as soon as the connection is established; this is referred to as implicit session establishment.

However, in the typical case a server will not know in advance whether a client supports DSO, so in general, unless it is known in advance by other means that a client does support DSO, a server **MUST NOT** initiate DSO request messages or DSO unidirectional messages until a DSO Session has been mutually established by at least one successful DSO request/response exchange initiated by the client, as described below. This is referred to as explicit session establishment.

Until a DSO session has been implicitly or explicitly established, a client **MUST NOT** initiate DSO unidirectional messages.

A DSO Session is established over a connection by the client sending a DSO request message, such as a DSO Keepalive request message (Section 7.1), and receiving a response, with matching MESSAGE ID, and RCODE set to NOERROR (0), indicating that the DSO request was successful.

Some DSO messages are permitted as early data (Section 11.1). Others are not. Unidirectional messages are never permitted as early data unless an implicit session exists.

If a server receives a DSO message in early data whose primary TLV is not permitted to appear in early data, the server MUST forcibly abort the connection. If a client receives a DSO message in early data, and there is no implicit DSO session, the client MUST forcibly abort the connection. This can only be enforced on TLS connections; therefore, servers MUST NOT enable TFO when listening for a connection that does not require TLS.

#### 5.1.1.1. Session Establishment Failure

If the response RCODE is set to NOTIMP (4), or in practise any value other than NOERROR (0) or DSOTYPENI (defined below), then the client MUST assume that the server does not implement DSO at all. In this case the client is permitted to continue sending DNS messages on that connection, but the client MUST NOT issue further DSO messages on that connection.

If the RCODE in the response is set to DSOTYPENI ("DSO-TYPE Not Implemented", [TBA2] tentatively RCODE 11) this indicates that the server does support DSO, but does not implement the DSO-TYPE of the primary TLV in this DSO request message. A server implementing DSO MUST NOT return DSOTYPENI for a DSO Keepalive request message, because the Keepalive TLV is mandatory to implement. But in the future, if a client attempts to establish a DSO Session using a response-requiring DSO request message using some newly-defined DSO-TYPE that the server does not understand, that would result in a DSOTYPENI response. If the server returns DSOTYPENI then a DSO Session is not considered established, but the client is permitted to continue sending DNS messages on the connection, including other DSO messages such as the DSO Keepalive, which may result in a successful NOERROR response, yielding the establishment of a DSO Session.

Two other possibilities exist: the server might drop the connection, or the server might send no response to the DSO message.

In the first case, the client SHOULD mark that service instance as not supporting DSO, and not attempt a DSO connection for some period of time (at least an hour) after the failed attempt. The client MAY reconnect but not use DSO, if appropriate (Section 6.6.3.2).

In the second case, the client SHOULD wait 30 seconds, after which time the server will be assumed not to support DSO. If the server doesn't respond within 30 seconds, the client MUST forcibly abort the connection to the server, since the server's behavior is out of spec, and hence its state is undefined. The client MAY reconnect, but not use DSO, if appropriate (Section 6.6.3.1).

### 5.1.2. Session Establishment Success

When the server receives a DSO request message from a client, and transmits a successful NOERROR response to that request, the server considers the DSO Session established.

When the client receives the server's NOERROR response to its DSO request message, the client considers the DSO Session established.

Once a DSO Session has been established, either end may unilaterally send appropriate DSO messages at any time, and therefore either client or server may be the initiator of a message.

### 5.2. Operations After Session Establishment

Once a DSO Session has been established, clients and servers should behave as described in this specification with regard to inactivity timeouts and session termination, not as previously prescribed in the earlier specification for DNS over TCP [RFC7766].

Because a server that supports DNS Stateful Operations MUST return an RCODE of NOERROR when it receives a Keepalive TLV DSO request message, the Keepalive TLV is an ideal candidate for use in establishing a DSO session. Any other option that can only succeed when sent to a server of the desired kind is also a good candidate for use in establishing a DSO session. For clients that implement only the DSO-TYPES defined in this base specification, sending a Keepalive TLV is the only DSO request message they have available to initiate a DSO Session. Even for clients that do implement other future DSO-TYPES, for simplicity they MAY elect to always send an initial DSO Keepalive request message as their way of initiating a DSO Session. A future definition of a new response-requiring DSO-TYPE gives implementers the option of using that new DSO-TYPE if they wish, but does not change the fact that sending a Keepalive TLV remains a valid way of initiating a DSO Session.

### 5.3. Session Termination

A "DSO Session" is terminated when the underlying connection is closed. Sessions are "closed gracefully" as a result of the server closing a session because it is overloaded, the client closing the session because it is done, or the client closing the session because it is inactive. Sessions are "forcibly aborted" when either the client or server closes the connection because of a protocol error.

- o Where this specification says, "close gracefully," that means sending a TLS close\_notify (if TLS is in use) followed by a TCP FIN, or the equivalents for other protocols. Where this specification requires a connection to be closed gracefully, the requirement to initiate that graceful close is placed on the client, to place the burden of TCP's TIME-WAIT state on the client rather than the server.
- o Where this specification says, "forcibly abort," that means sending a TCP RST, or the equivalent for other protocols. In the BSD Sockets API this is achieved by setting the SO\_LINGER option to zero before closing the socket.

#### 5.3.1. Handling Protocol Errors

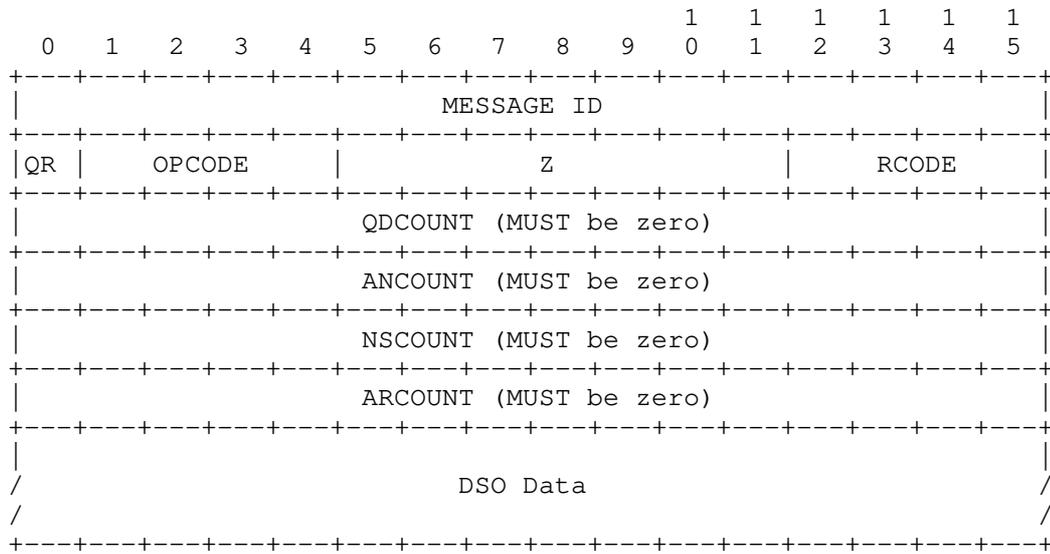
In protocol implementation there are generally two kinds of errors that software writers have to deal with. The first is situations that arise due to factors in the environment, such as temporary loss of connectivity. While undesirable, these situations do not indicate a flaw in the software, and they are situations that software should generally be able to recover from.

The second is situations that should never happen when communicating with a compliant DSO implementation. If they do happen, they indicate a serious flaw in the protocol implementation, beyond what it is reasonable to expect software to recover from. This document describes this latter form of error condition as a "fatal error" and specifies that an implementation encountering a fatal error condition "MUST forcibly abort the connection immediately".

5.4. Message Format

A DSO message begins with the standard twelve-byte DNS message header [RFC1035] with the OPCODE field set to the DSO OPCODE. However, unlike standard DNS messages, the question section, answer section, authority records section and additional records sections are not present. The corresponding count fields (QDCOUNT, ANCOUNT, NSCOUNT, ARCOUNT) MUST be set to zero on transmission.

If a DSO message is received where any of the count fields are not zero, then a FORMERR MUST be returned.



#### 5.4.1.1. DNS Header Fields in DSO Messages

In a DSO unidirectional message the MESSAGE ID field MUST be set to zero. In a DSO request message the MESSAGE ID field MUST be set to a unique nonzero value, that the initiator is not currently using for any other active operation on this connection. For the purposes here, a MESSAGE ID is in use in this DSO Session if the initiator has used it in a DSO request message for which it is still awaiting a response, or if the client has used it to set up a long-lived operation that has not yet been cancelled. For example, a long-lived operation could be a Push Notification subscription [I-D.ietf-dnssd-push] or a Discovery Relay interface subscription [I-D.ietf-dnssd-mdns-relay].

Whether a message is a DSO request message or a DSO unidirectional message is determined only by the specification for the Primary TLV. An acknowledgment cannot be requested by including a nonzero message ID in a message that is required according to its primary TLV to be unidirectional. Nor can an acknowledgment be prevented by sending a message ID of zero in a message that is required to be a DSO request message according to its primary TLV. A responder that receives either such malformed message MUST treat it as a fatal error and forcibly abort the connection immediately.

In a DSO request message or DSO unidirectional message the DNS Header QR bit MUST be zero (QR=0). If the QR bit is not zero the message is not a DSO request or DSO unidirectional message.

In a DSO response message the DNS Header QR bit MUST be one (QR=1). If the QR bit is not one, the message is not a response message.

In a DSO response message (QR=1) the MESSAGE ID field MUST contain a copy of the value of the MESSAGE ID field in the DSO request message being responded to. In a DSO response message (QR=1) the MESSAGE ID field MUST NOT be zero. If a DSO response message (QR=1) is received where the MESSAGE ID is zero this is a fatal error and the recipient MUST forcibly abort the connection immediately.

The DNS Header OPCODE field holds the DSO OPCODE value.

The Z bits are currently unused in DSO messages, and in both DSO request messages and DSO responses the Z bits MUST be set to zero (0) on transmission and MUST be ignored on reception.

In a DSO request message (QR=0) the RCODE is set according to the definition of the request. For example, in a Retry Delay message (Section 6.6.1) the RCODE indicates the reason for termination. However, in most cases, except where clearly specified otherwise, in

a DSO request message (QR=0) the RCODE is set to zero on transmission, and silently ignored on reception.

The RCODE value in a response message (QR=1) may be one of the following values:

| Code         | Mnemonic  | Description   |
|--------------|-----------|---|
| 0            | NOERROR   | Operation processed successfully  |
| 1            | FORMERR   | Format error  |
| 2            | SERVFAIL  | Server failed to process DSO request message due to a problem with the server |
| 4            | NOTIMP    | DSO not supported   |
| 5            | REFUSED   | Operation declined for policy reasons   |
| [TBA2]<br>11 | DSOTYPENI | Primary TLV's DSO-Type is not implemented                                     |

Use of the above RCODEs is likely to be common in DSO but does not preclude the definition and use of other codes in future documents that make use of DSO.

If a document defining a new DSO-TYPE makes use of response codes not defined here, then that document MUST specify the specific interpretation of those RCODE values in the context of that new DSO TLV.

#### 5.4.2. DSO Data

The standard twelve-byte DNS message header with its zero-valued count fields is followed by the DSO Data, expressed using TLV syntax, as described below in Section 5.4.3.

A DSO request message or DSO unidirectional message MUST contain at least one TLV. The first TLV in a DSO request message or DSO unidirectional message is referred to as the "Primary TLV" and determines the nature of the operation being performed, including whether it is a DSO request or a DSO unidirectional operation. In some cases it may be appropriate to include other TLVs in a DSO request message or DSO unidirectional message, such as the Encryption Padding TLV (Section 7.3), and these extra TLVs are referred to as the "Additional TLVs" and are not limited to what is defined in this document. New "Additional TLVs" may be defined in the future and those definitions will describe when their use is appropriate.

A DSO response message may contain no TLVs, or it may be specified to contain one or more TLVs appropriate to the information being communicated. This includes "Primary TLVs" and "Additional TLVs" defined in this document as well as in future TLV definitions. It may be permissible for an additional TLV to appear in a response to a primary TLV even though the specification of that primary TLV does not specify it explicitly. See Section 8.2 for more information.

A DSO response message may contain one or more TLVs with the Primary TLV DSO-TYPE the same as the Primary TLV from the corresponding DSO request message or it may contain zero or more Additional TLVs only. The MESSAGE ID field in the DNS message header is sufficient to identify the DSO request message to which this response message relates.

A DSO response message may contain one or more TLVs with DSO-TYPES different from the Primary TLV from the corresponding DSO request message, in which case those TLV(s) are referred to as "Response Additional TLVs".

Response Primary TLV(s), if present, MUST occur first in the response message, before any Response Additional TLVs.

It is anticipated that most DSO operations will be specified to use DSO request messages, which generate corresponding DSO responses. In some specialized high-traffic use cases, it may be appropriate to specify DSO unidirectional messages. DSO unidirectional messages can be more efficient on the network, because they don't generate a stream of corresponding reply messages. Using DSO unidirectional messages can also simplify software in some cases, by removing need

for an initiator to maintain state while it waits to receive replies it doesn't care about. When the specification for a particular TLV states that, when used as a Primary TLV (i.e., first) in an outgoing DSO request message (i.e., QR=0), that message is to be unidirectional, the MESSAGE ID field MUST be set to zero and the receiver MUST NOT generate any response message corresponding to this DSO unidirectional message.

The previous point, that the receiver MUST NOT generate responses to DSO unidirectional messages, applies even in the case of errors.

When a DSO message is received where both the QR bit and the MESSAGE ID field are zero, the receiver MUST NOT generate any response. For example, if the DSO-TYPE in the Primary TLV is unrecognized, then a DSOTYPENI error MUST NOT be returned; instead the receiver MUST forcibly abort the connection immediately.

DSO unidirectional messages MUST NOT be used "speculatively" in cases where the sender doesn't know if the receiver supports the Primary TLV in the message, because there is no way to receive any response to indicate success or failure. DSO unidirectional messages are only appropriate in cases where the sender already knows that the receiver supports, and wishes to receive, these messages.

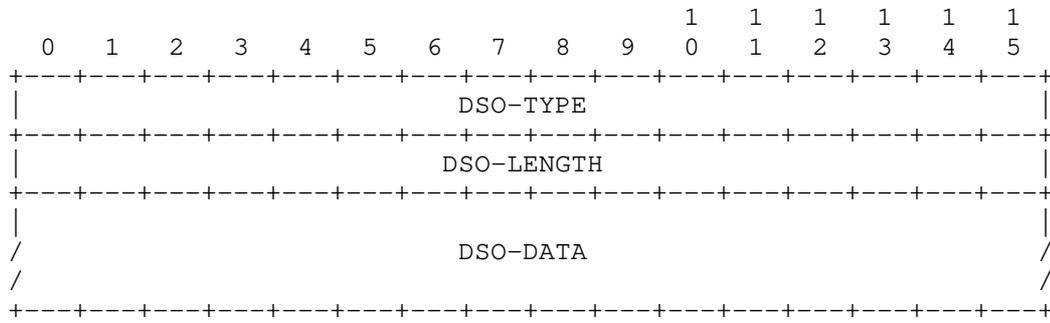
For example, after a client has subscribed for Push Notifications [I-D.ietf-dnssd-push], the subsequent event notifications are then sent as DSO unidirectional messages, and this is appropriate because the client initiated the message stream by virtue of its Push Notification subscription, thereby indicating its support of Push Notifications, and its desire to receive those notifications.

Similarly, after a Discovery Relay client has subscribed to receive inbound mDNS (multicast DNS, [RFC6762]) traffic from a Discovery Relay, the subsequent stream of received packets is then sent using DSO unidirectional messages, and this is appropriate because the client initiated the message stream by virtue of its Discovery Relay link subscription, thereby indicating its support of Discovery Relay, and its desire to receive inbound mDNS packets over that DSO session [I-D.ietf-dnssd-mdns-relay].

5.4.3. TLV Syntax

All TLVs, whether used as "Primary", "Additional", "Response Primary", or "Response Additional", use the same encoding syntax.

Specifications that define new TLVs must specify whether the DSO-TYPE can be used as the Primary TLV, used as an Additional TLV, or used in either context, both in the case of requests and of responses. The specification for a TLV must also state whether, when used as the Primary (i.e., first) TLV in a DSO message (i.e., QR=0), that DSO message is unidirectional or is a request message which requires a response. If the DSO message requires a response, the specification must also state which TLVs, if any, are to be included in the response. The Primary TLV may or may not be contained in the response, depending on what is specified for that TLV.



DSO-TYPE: A 16-bit unsigned integer, in network (big endian) byte order, giving the DSO-TYPE of the current DSO TLV per the IANA DSO Type Code Registry.

DSO-LENGTH: A 16-bit unsigned integer, in network (big endian) byte order, giving the size in bytes of the DSO-DATA.

DSO-DATA: Type-code specific format. The generic DSO machinery treats the DSO-DATA as an opaque "blob" without attempting to interpret it. Interpretation of the meaning of the DSO-DATA for a particular DSO-TYPE is the responsibility of the software that implements that DSO-TYPE.

#### 5.4.3.1. Request TLVs

The first TLV in a DSO request message or DSO unidirectional message is the "Primary TLV" and indicates the operation to be performed. A DSO request message or DSO unidirectional message MUST contain at least one TLV—the Primary TLV.

Immediately following the Primary TLV, a DSO request message or DSO unidirectional message MAY contain one or more "Additional TLVs", which specify additional parameters relating to the operation.

#### 5.4.3.2. Response TLVs

Depending on the operation, a DSO response message MAY contain no TLVs, because it is simply a response to a previous DSO request message, and the MESSAGE ID in the header is sufficient to identify the DSO request in question. Or it may contain a single response TLV, with the same DSO-TYPE as the Primary TLV in the request message. Alternatively it may contain one or more TLVs of other types, or a combination of the above, as appropriate for the information that needs to be communicated. The specification for each DSO TLV determines what TLVs are required in a response to a DSO request message using that TLV.

If a DSO response is received for an operation where the specification requires that the response carry a particular TLV or TLVs, and the required TLV(s) are not present, then this is a fatal error and the recipient of the defective response message MUST forcibly abort the connection immediately.

## 5.4.3.3. Unrecognized TLVs

If DSO request message is received containing an unrecognized Primary TLV, with a nonzero MESSAGE ID (indicating that a response is expected), then the receiver MUST send an error response with matching MESSAGE ID, and RCODE DSOTYPENI. The error response MUST NOT contain a copy of the unrecognized Primary TLV.

If DSO unidirectional message is received containing an unrecognized Primary TLV, with a zero MESSAGE ID (indicating that no response is expected), then this is a fatal error and the recipient MUST forcibly abort the connection immediately.

If a DSO request message or DSO unidirectional message is received where the Primary TLV is recognized, containing one or more unrecognized Additional TLVs, the unrecognized Additional TLVs MUST be silently ignored, and the remainder of the message is interpreted and handled as if the unrecognized parts were not present.

Similarly, if a DSO response message is received containing one or more unrecognized TLVs, the unrecognized TLVs MUST be silently ignored, and the remainder of the message is interpreted and handled as if the unrecognized parts were not present.

## 5.4.4. EDNS(0) and TSIG

Since the ARCOUNT field MUST be zero, a DSO message cannot contain a valid EDNS(0) option in the additional records section. If functionality provided by current or future EDNS(0) options is desired for DSO messages, one or more new DSO TLVs need to be defined to carry the necessary information.

For example, the EDNS(0) Padding Option [RFC7830] used for security purposes is not permitted in a DSO message, so if message padding is desired for DSO messages then the Encryption Padding TLV described in Section 7.3 MUST be used.

A DSO message can't contain a TSIG record, because a TSIG record is included in the additional section of the message, which would mean that ARCOUNT would be greater than zero. DSO messages are required to have an ARCOUNT of zero. Therefore, if use of signatures with DSO messages becomes necessary in the future, a new DSO TLV would have to be defined to perform this function.

Note however that, while DSO \*messages\* cannot include EDNS(0) or TSIG records, a DSO \*session\* is typically used to carry a whole series of DNS messages of different kinds, including DSO messages, and other DNS message types like Query [RFC1034] [RFC1035] and Update [RFC2136], and those messages can carry EDNS(0) and TSIG records.

Although messages may contain other EDNS(0) options as appropriate, this specification explicitly prohibits use of the edns-tcp-keepalive EDNS0 Option [RFC7828] in \*any\* messages sent on a DSO Session (because it is obsoleted by the functionality provided by the DSO Keepalive operation). If any message sent on a DSO Session contains an edns-tcp-keepalive EDNS0 Option this is a fatal error and the recipient of the defective message MUST forcibly abort the connection immediately.

### 5.5. Message Handling

As described above in Section 5.4.1, whether an outgoing DSO message with the QR bit in the DNS header set to zero is a DSO request or DSO unidirectional message is determined by the specification for the Primary TLV, which in turn determines whether the MESSAGE ID field in that outgoing message will be zero or nonzero.

Every DSO message with the QR bit in the DNS header set to zero and a nonzero MESSAGE ID field is a DSO request message, and MUST elicit a corresponding response, with the QR bit in the DNS header set to one and the MESSAGE ID field set to the value given in the corresponding DSO request message.

Valid DSO request messages sent by the client with a nonzero MESSAGE ID field elicit a response from the server, and valid DSO request messages sent by the server with a nonzero MESSAGE ID field elicit a response from the client.

Every DSO message with both the QR bit in the DNS header and the MESSAGE ID field set to zero is a DSO unidirectional message, and MUST NOT elicit a response.

### 5.5.1. Delayed Acknowledgement Management

Generally, most good TCP implementations employ a delayed acknowledgement timer to provide more efficient use of the network and better performance.

With a bidirectional exchange over TCP, as for example with a DSO request message, the operating system TCP implementation waits for the application-layer client software to generate the corresponding DSO response message. It can then send a single combined packet containing the TCP acknowledgement, the TCP window update, and the application-generated DSO response message. This is more efficient than sending three separate packets, as would occur if the TCP packet containing the DSO request were acknowledged immediately.

With a DSO unidirectional message or DSO response message, there is no corresponding application-generated DSO response message, and consequently, no hint to the transport protocol about when it should send its acknowledgement and window update.

Some networking APIs provide a mechanism that allows the application-layer client software to signal to the transport protocol that no response will be forthcoming (in effect it can be thought of as a zero-length "empty" write). Where available in the networking API being used, the recipient of a DSO unidirectional message or DSO response message, having parsed and interpreted the message, SHOULD then use this mechanism provided by the networking API to signal that no response for this message will be forthcoming, so that the TCP implementation can go ahead and send its acknowledgement and window update without further delay. See Section 9.5 for further discussion of why this is important.

### 5.5.2. MESSAGE ID Namespaces

The namespaces of 16-bit MESSAGE IDs are independent in each direction. This means it is *\*not\** an error for both client and server to send DSO request messages at the same time as each other, using the same MESSAGE ID, in different directions. This simplification is necessary in order for the protocol to be implementable. It would be infeasible to require the client and server to coordinate with each other regarding allocation of new unique MESSAGE IDs. It is also not necessary to require the client and server to coordinate with each other regarding allocation of new unique MESSAGE IDs. The value of the 16-bit MESSAGE ID combined with the identity of the initiator (client or server) is sufficient to unambiguously identify the operation in question. This can be thought of as a 17-bit message identifier space, using message identifiers 0x00001-0x0FFFF for client-to-server DSO request messages, and message identifiers 0x10001-0x1FFFF for server-to-client DSO request messages. The least-significant 16 bits are stored explicitly in the MESSAGE ID field of the DSO message, and the most-significant bit is implicit from the direction of the message.

As described above in Section 5.4.1, an initiator **MUST NOT** reuse a MESSAGE ID that it already has in use for an outstanding DSO request message (unless specified otherwise by the relevant specification for the DSO-TYPE in question). At the very least, this means that a MESSAGE ID can't be reused in a particular direction on a particular DSO Session while the initiator is waiting for a response to a previous DSO request message using that MESSAGE ID on that DSO Session (unless specified otherwise by the relevant specification for the DSO-TYPE in question), and for a long-lived operation the MESSAGE ID for the operation can't be reused while that operation remains active.

If a client or server receives a response (QR=1) where the MESSAGE ID is zero, or is any other value that does not match the MESSAGE ID of any of its outstanding operations, this is a fatal error and the recipient **MUST** forcibly abort the connection immediately.

If a responder receives a DSO request message (QR=0) where the MESSAGE ID is not zero, and the responder tracks request MESSAGE IDs, and the MESSAGE ID matches the MESSAGE ID of a DSO request message it received for which a response has not yet been sent, it **MUST** forcibly abort the connection immediately. This behavior is required to prevent a hypothetical attack that takes advantage of undefined behavior in this case. However, if the responder does not track MESSAGE IDs in this way, no such risk exists, so tracking MESSAGE IDs just to implement this sanity check is not required.

### 5.5.3. Error Responses

When a DSO unidirectional message type is received (MESSAGE ID field is zero), the receiver should already be expecting this DSO message type. Section 5.4.3.3 describes the handling of unknown DSO message types. Parsing errors MUST also result in the receiver forcibly aborting the connection. When a DSO unidirectional message of an unexpected type is received, the receiver SHOULD forcibly abort the connection. Whether the connection should be forcibly aborted for other internal errors processing the DSO unidirectional message is implementation dependent, according to the severity of the error.

When a DSO request message is unsuccessful for some reason, the responder returns an error code to the initiator.

In the case of a server returning an error code to a client in response to an unsuccessful DSO request message, the server MAY choose to end the DSO Session, or MAY choose to allow the DSO Session to remain open. For error conditions that only affect the single operation in question, the server SHOULD return an error response to the client and leave the DSO Session open for further operations.

For error conditions that are likely to make all operations unsuccessful in the immediate future, the server SHOULD return an error response to the client and then end the DSO Session by sending a Retry Delay message, as described in Section 6.6.1.

Upon receiving an error response from the server, a client SHOULD NOT automatically close the DSO Session. An error relating to one particular operation on a DSO Session does not necessarily imply that all other operations on that DSO Session have also failed, or that future operations will fail. The client should assume that the server will make its own decision about whether or not to end the DSO Session, based on the server's determination of whether the error condition pertains to this particular operation, or would also apply to any subsequent operations. If the server does not end the DSO Session by sending the client a Retry Delay message (Section 6.6.1) then the client SHOULD continue to use that DSO Session for subsequent operations.

## 5.6. Responder-Initiated Operation Cancellation

This document, the base specification for DNS Stateful Operations, does not itself define any long-lived operations, but it defines a framework for supporting long-lived operations, such as Push Notification subscriptions [I-D.ietf-dnssd-push] and Discovery Relay interface subscriptions [I-D.ietf-dnssd-mdns-relay].

Long-lived operations, if successful, will remain active until the initiator terminates the operation.

However, it is possible that a long-lived operation may be valid at the time it was initiated, but then a later change of circumstances may render that operation invalid. For example, a long-lived client operation may pertain to a name that the server is authoritative for, but then the server configuration is changed such that it is no longer authoritative for that name.

In such cases, instead of terminating the entire session it may be desirable for the responder to be able to cancel selectively only those operations that have become invalid.

The responder performs this selective cancellation by sending a new response message, with the MESSAGE ID field containing the MESSAGE ID of the long-lived operation that is to be terminated (that it had previously acknowledged with a NOERROR RCODE), and the RCODE field of the new response message giving the reason for cancellation.

After a response message with nonzero RCODE has been sent, that operation has been terminated from the responder's point of view, and the responder sends no more messages relating to that operation.

After a response message with nonzero RCODE has been received by the initiator, that operation has been terminated from the initiator's point of view, and the cancelled operation's MESSAGE ID is now free for reuse.

## 6. DSO Session Lifecycle and Timers

### 6.1. DSO Session Initiation

A DSO Session begins as described in Section 5.1.

The client may perform as many DNS operations as it wishes using the newly created DSO Session. When the client has multiple messages to send, it SHOULD NOT wait for each response before sending the next message.

The server MUST act on messages in the order they are received, but SHOULD NOT delay sending responses to those messages as they become available in order to return them in the order the requests were received.

Section 6.2.1.1 of the DNS-over-TCP specification [RFC7766] specifies this in more detail.

## 6.2. DSO Session Timeouts

Two timeout values are associated with a DSO Session: the inactivity timeout, and the keepalive interval. Both values are communicated in the same TLV, the Keepalive TLV (Section 7.1).

The first timeout value, the inactivity timeout, is the maximum time for which a client may speculatively keep an inactive DSO Session open in the expectation that it may have future requests to send to that server.

The second timeout value, the keepalive interval, is the maximum permitted interval between messages if the client wishes to keep the DSO Session alive.

The two timeout values are independent. The inactivity timeout may be lower, the same, or higher than the keepalive interval, though in most cases the inactivity timeout is expected to be shorter than the keepalive interval.

A shorter inactivity timeout with a longer keepalive interval signals to the client that it should not speculatively keep an inactive DSO Session open for very long without reason, but when it does have an active reason to keep a DSO Session open, it doesn't need to be sending an aggressive level of DSO keepalive traffic to maintain that session. An example of this would be a client that has subscribed to DNS Push notifications: in this case, the client is not sending any traffic to the server, but the session is not inactive, because there is a active request to the server to receive push notifications.

A longer inactivity timeout with a shorter keepalive interval signals to the client that it may speculatively keep an inactive DSO Session open for a long time, but to maintain that inactive DSO Session it should be sending a lot of DSO keepalive traffic. This configuration is expected to be less common.

In the usual case where the inactivity timeout is shorter than the keepalive interval, it is only when a client has a long-lived, low-traffic, operation that the keepalive interval comes into play, to ensure that a sufficient residual amount of traffic is generated to maintain NAT and firewall state and to assure client and server that they still have connectivity to each other.

On a new DSO Session, if no explicit DSO Keepalive message exchange has taken place, the default value for both timeouts is 15 seconds.

For both timeouts, lower values of the timeout result in higher network traffic, and higher CPU load on the server.

### 6.3. Inactive DSO Sessions

At both servers and clients, the generation or reception of any complete DNS message (including DNS requests, responses, updates, DSO messages, etc.) resets both timers for that DSO Session, with the one exception that a DSO Keepalive message resets only the keepalive timer, not the inactivity timeout timer.

In addition, for as long as the client has an outstanding operation in progress, the inactivity timer remains cleared, and an inactivity timeout cannot occur.

For short-lived DNS operations like traditional queries and updates, an operation is considered in progress for the time between request and response, typically a period of a few hundred milliseconds at most. At the client, the inactivity timer is cleared upon transmission of a request and remains cleared until reception of the corresponding response. At the server, the inactivity timer is cleared upon reception of a request and remains cleared until transmission of the corresponding response.

For long-lived DNS Stateful operations (such as a Push Notification subscription [I-D.ietf-dnssd-push] or a Discovery Relay interface subscription [I-D.ietf-dnssd-mdns-relay]), an operation is considered in progress for as long as the operation is active, i.e. until it is cancelled. This means that a DSO Session can exist, with active operations, with no messages flowing in either direction, for far longer than the inactivity timeout, and this is not an error. This is why there are two separate timers: the inactivity timeout, and the keepalive interval. Just because a DSO Session has no traffic for an extended period of time does not automatically make that DSO Session "inactive", if it has an active operation that is awaiting events.

#### 6.4. The Inactivity Timeout

The purpose of the inactivity timeout is for the server to balance the trade off between the costs of setting up new DSO Sessions and the costs of maintaining inactive DSO Sessions. A server with abundant DSO Session capacity can offer a high inactivity timeout, to permit clients to keep a speculative DSO Session open for a long time, to save the cost of establishing a new DSO Session for future communications with that server. A server with scarce memory resources can offer a low inactivity timeout, to cause clients to promptly close DSO Sessions whenever they have no outstanding operations with that server, and then create a new DSO Session later when needed.

##### 6.4.1. Closing Inactive DSO Sessions

When a connection's inactivity timeout is reached the client **MUST** begin closing the idle connection, but a client is not required to keep an idle connection open until the inactivity timeout is reached. A client **MAY** close a DSO Session at any time, at the client's discretion. If a client determines that it has no current or reasonably anticipated future need for a currently inactive DSO Session, then the client **SHOULD** gracefully close that connection.

If, at any time during the life of the DSO Session, the inactivity timeout value (i.e., 15 seconds by default) elapses without there being any operation active on the DSO Session, the client **MUST** close the connection gracefully.

If, at any time during the life of the DSO Session, twice the inactivity timeout value (i.e., 30 seconds by default), or five seconds, if twice the inactivity timeout value is less than five seconds, elapses without there being any operation active on the DSO Session, the server **MUST** consider the client delinquent, and **MUST** forcibly abort the DSO Session.

In this context, an operation being active on a DSO Session includes a query waiting for a response, an update waiting for a response, or an active long-lived operation, but not a DSO Keepalive message exchange itself. A DSO Keepalive message exchange resets only the keepalive interval timer, not the inactivity timeout timer.

If the client wishes to keep an inactive DSO Session open for longer than the default duration then it uses the DSO Keepalive message to request longer timeout values, as described in Section 7.1.

#### 6.4.2. Values for the Inactivity Timeout

For the inactivity timeout value, lower values result in more frequent DSO Session teardown and re-establishment. Higher values result in lower traffic and lower CPU load on the server, but higher memory burden to maintain state for inactive DSO Sessions.

A server may dictate any value it chooses for the inactivity timeout (either in a response to a client-initiated request, or in a server-initiated message) including values under one second, or even zero.

An inactivity timeout of zero informs the client that it should not speculatively maintain idle connections at all, and as soon as the client has completed the operation or operations relating to this server, the client should immediately begin closing this session.

A server will forcibly abort an idle client session after twice the inactivity timeout value, or five seconds, whichever is greater. In the case of a zero inactivity timeout value, this means that if a client fails to close an idle client session then the server will forcibly abort the idle session after five seconds.

An inactivity timeout of 0xFFFFFFFF represents "infinity" and informs the client that it may keep an idle connection open as long as it wishes. Note that after granting an unlimited inactivity timeout in this way, at any point the server may revise that inactivity timeout by sending a new DSO Keepalive message dictating new Session Timeout values to the client.

The largest \*finite\* inactivity timeout supported by the current Keepalive TLV is 0xFFFFFFFFE ( $2^{32}-2$  milliseconds, approximately 49.7 days).

## 6.5. The Keepalive Interval

The purpose of the keepalive interval is to manage the generation of sufficient messages to maintain state in middleboxes (such as NAT gateways or firewalls) and for the client and server to periodically verify that they still have connectivity to each other. This allows them to clean up state when connectivity is lost, and to establish a new session if appropriate.

### 6.5.1. Keepalive Interval Expiry

If, at any time during the life of the DSO Session, the keepalive interval value (i.e., 15 seconds by default) elapses without any DNS messages being sent or received on a DSO Session, the client **MUST** take action to keep the DSO Session alive, by sending a DSO Keepalive message (Section 7.1). A DSO Keepalive message exchange resets only the keepalive timer, not the inactivity timer.

If a client disconnects from the network abruptly, without cleanly closing its DSO Session, perhaps leaving a long-lived operation uncanceled, the server learns of this after failing to receive the required DSO keepalive traffic from that client. If, at any time during the life of the DSO Session, twice the keepalive interval value (i.e., 30 seconds by default) elapses without any DNS messages being sent or received on a DSO Session, the server **SHOULD** consider the client delinquent, and **SHOULD** forcibly abort the DSO Session.

### 6.5.2. Values for the Keepalive Interval

For the keepalive interval value, lower values result in a higher volume of DSO keepalive traffic. Higher values of the keepalive interval reduce traffic and CPU load, but have minimal effect on the memory burden at the server, because clients keep a DSO Session open for the same length of time (determined by the inactivity timeout) regardless of the level of DSO keepalive traffic required.

It may be appropriate for clients and servers to select different keepalive interval values depending on the nature of the network they are on.

A corporate DNS server that knows it is serving only clients on the internal network, with no intervening NAT gateways or firewalls, can impose a higher keepalive interval, because frequent DSO keepalive traffic is not required.

A public DNS server that is serving primarily residential consumer clients, where it is likely there will be a NAT gateway on the path,

may impose a lower keepalive interval, to generate more frequent DSO keepalive traffic.

A smart client may be adaptive to its environment. A client using a private IPv4 address [RFC1918] to communicate with a DNS server at an address outside that IPv4 private address block, may conclude that there is likely to be a NAT gateway on the path, and accordingly request a lower keepalive interval.

By default it is RECOMMENDED that clients request, and servers grant, a keepalive interval of 60 minutes. This keepalive interval provides for reasonably timely detection if a client abruptly disconnects without cleanly closing the session, and is sufficient to maintain state in firewalls and NAT gateways that follow the IETF recommended Best Current Practice that the "established connection idle-timeout" used by middleboxes be at least 2 hours 4 minutes [RFC5382] [RFC7857].

Note that the lower the keepalive interval value, the higher the load on client and server. Moreover for a keep-alive value that is smaller than the time needed for the transport to retransmit, a single packet loss would cause a server to overzealously abort the connect. For example, a (hypothetical and unrealistic) keepalive interval value of 100 ms would result in a continuous stream of ten messages per second or more (if allowed by the current congestion control window), in both directions, to keep the DSO Session alive. And, in this extreme example, a single retransmission over a path with, e.g., 100ms RTT would introduce a momentary pause in the stream of messages, long enough to cause the server to abort the connection.

Because of this concern, the server MUST NOT send a DSO Keepalive message (either a response to a client-initiated request, or a server-initiated message) with a keepalive interval value less than ten seconds. If a client receives a DSO Keepalive message specifying a keepalive interval value less than ten seconds this is a fatal error and the client MUST forcibly abort the connection immediately.

A keepalive interval value of 0xFFFFFFFF represents "infinity" and informs the client that it should generate no DSO keepalive traffic. Note that after signaling that the client should generate no DSO keepalive traffic in this way, at any point the server may revise that DSO keepalive traffic requirement by sending a new DSO Keepalive message dictating new Session Timeout values to the client.

The largest \*finite\* keepalive interval supported by the current Keepalive TLV is 0xFFFFFFFFE ( $2^{32}-2$  milliseconds, approximately 49.7 days).

## 6.6. Server-Initiated Session Termination

In addition to cancelling individual long-lived operations selectively (Section 5.6) there are also occasions where a server may need to terminate one or more entire sessions. An entire session may need to be terminated if the client is defective in some way, or departs from the network without closing its session. Sessions may also need to be terminated if the server becomes overloaded, or if the server is reconfigured and lacks the ability to be selective about which operations need to be cancelled.

This section discusses various reasons a session may be terminated, and the mechanisms for doing so.

In normal operation, closing a DSO Session is the client's responsibility. The client makes the determination of when to close a DSO Session based on an evaluation of both its own needs, and the inactivity timeout value dictated by the server. A server only causes a DSO Session to be ended in the exceptional circumstances outlined below. Some of the exceptional situations in which a server may terminate a DSO Session include:

- o The server application software or underlying operating system is shutting down or restarting.
- o The server application software terminates unexpectedly (perhaps due to a bug that makes it crash, causing the underlying operating system to send a TCP RST).
- o The server is undergoing a reconfiguration or maintenance procedure, that, due to the way the server software is implemented, requires clients to be disconnected. For example, some software is implemented such that it reads a configuration file at startup, and changing the server's configuration entails modifying the configuration file and then killing and restarting the server software, which generally entails a loss of network connections.
- o The client fails to meet its obligation to generate the required DSO keepalive traffic, or to close an inactive session by the prescribed time (twice the time interval dictated by the server, or five seconds, whichever is greater, as described in Section 6.2).
- o The client sends a grossly invalid or malformed request that is indicative of a seriously defective client implementation.
- o The server is over capacity and needs to shed some load.

#### 6.6.1. Server-Initiated Retry Delay Message

In the cases described above where a server elects to terminate a DSO Session, it could do so simply by forcibly aborting the connection. However, if it did this the likely behavior of the client might be simply to treat this as a network failure and reconnect immediately, putting more burden on the server.

Therefore, to avoid this reconnection implosion, a server SHOULD instead choose to shed client load by sending a Retry Delay message, with an appropriate RCODE value informing the client of the reason the DSO Session needs to be terminated. The format of the Retry Delay TLV, and the interpretations of the various RCODE values, are described in Section 7.2. After sending a Retry Delay message, the server MUST NOT send any further messages on that DSO Session.

The server MAY randomize retry delays in situations where many retry delays are sent in quick succession, so as to avoid all the clients attempting to reconnect at once. In general, implementations should avoid using the Retry Delay message in a way that would result in many clients reconnecting at the same time, if every client attempts to reconnect at the exact time specified.

Upon receipt of a Retry Delay message from the server, the client MUST make note of the reconnect delay for this server, and then immediately close the connection gracefully.

After sending a Retry Delay message the server SHOULD allow the client five seconds to close the connection, and if the client has not closed the connection after five seconds then the server SHOULD forcibly abort the connection.

A Retry Delay message MUST NOT be initiated by a client. If a server receives a Retry Delay message this is a fatal error and the server MUST forcibly abort the connection immediately.

##### 6.6.1.1. Outstanding Operations

At the instant a server chooses to initiate a Retry Delay message there may be DNS requests already in flight from client to server on this DSO Session, which will arrive at the server after its Retry Delay message has been sent. The server MUST silently ignore such incoming requests, and MUST NOT generate any response messages for them. When the Retry Delay message from the server arrives at the client, the client will determine that any DNS requests it previously sent on this DSO Session, that have not yet received a response, now will certainly not be receiving any response. Such requests should

be considered failed, and should be retried at a later time, as appropriate.

In the case where some, but not all, of the existing operations on a DSO Session have become invalid (perhaps because the server has been reconfigured and is no longer authoritative for some of the names), but the server is terminating all affected DSO Sessions en masse by sending them all a Retry Delay message, the reconnect delay MAY be zero, indicating that the clients SHOULD immediately attempt to re-establish operations.

It is likely that some of the attempts will be successful and some will not, depending on the nature of the reconfiguration.

In the case where a server is terminating a large number of DSO Sessions at once (e.g., if the system is restarting) and the server doesn't want to be inundated with a flood of simultaneous retries, it SHOULD send different reconnect delay values to each client. These adjustments MAY be selected randomly, pseudorandomly, or deterministically (e.g., incrementing the time value by one tenth of a second for each successive client, yielding a post-restart reconnection rate of ten clients per second).

#### 6.6.2. Misbehaving Clients

A server may determine that a client is not following the protocol correctly. There may be no way for the server to recover the session, in which case the server forcibly terminates the connection. Since the client doesn't know why the connection dropped, it may reconnect immediately. If the server has determined that a client is not following the protocol correctly, it may terminate the DSO session as soon as it is established, specifying a long retry-delay to prevent the client from immediately reconnecting.

#### 6.6.3. Client Reconnection

After a DSO Session is ended by the server (either by sending the client a Retry Delay message, or by forcibly aborting the underlying transport connection) the client SHOULD try to reconnect, to that service instance, or to another suitable service instance, if more than one is available. If reconnecting to the same service instance, the client MUST respect the indicated delay, if available, before attempting to reconnect. Clients should not attempt to randomize the delay; the server will randomly jitter the retry delay values it sends to each client if this behavior is desired.

If the service instance will only be out of service for a short maintenance period, it should use a value a little longer than the

expected maintenance window. It should not default to a very large delay value, or clients may not attempt to reconnect after it resumes service.

If a particular service instance does not want a client to reconnect ever (perhaps the service instance is being de-commissioned), it SHOULD set the retry delay to the maximum value 0xFFFFFFFF (2<sup>32</sup>-1 milliseconds, approximately 49.7 days). It is not possible to instruct a client to stay away for longer than 49.7 days. If, after 49.7 days, the DNS or other configuration information still indicates that this is the valid service instance for a particular service, then clients MAY attempt to reconnect. In reality, if a client is rebooted or otherwise lose state, it may well attempt to reconnect before 49.7 days elapses, for as long as the DNS or other configuration information continues to indicate that this is the service instance the client should use.

#### 6.6.3.1. Reconnecting After a Forcible Abort

If a connection was forcibly aborted by the client, the client SHOULD mark that service instance as not supporting DSO. The client MAY reconnect but not attempt to use DSO, or may connect to a different service instance, if applicable.

#### 6.6.3.2. Reconnecting After an Unexplained Connection Drop

It is also possible for a server to forcibly terminate the connection; in this case the client doesn't know whether the termination was the result of a protocol error or a network outage. When the client notices that the connection has been dropped, it can attempt to reconnect immediately. However, if the connection is dropped again without the client being able to successfully do whatever it is trying to do, it should mark the server as not supporting DSO.

#### 6.6.3.3. Probing for Working DSO Support

Once a server has been marked by the client as not supporting DSO, the client SHOULD NOT attempt DSO operations on that server until some time has elapsed. A reasonable minimum would be an hour. Since forcibly aborted connections are the result of a software failure, it's not likely that the problem will be solved in the first hour after it's first encountered. However, by restricting the retry interval to an hour, the client will be able to notice when the problem has been fixed without placing an undue burden on the server.

7. Base TLVs for DNS Stateful Operations

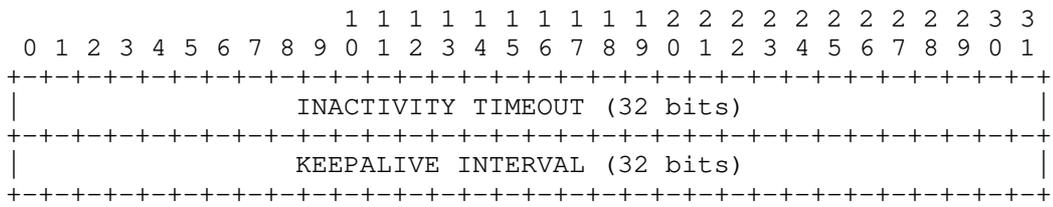
This section describes the three base TLVs for DNS Stateful Operations: Keepalive, Retry Delay, and Encryption Padding.

7.1. Keepalive TLV

The Keepalive TLV (DSO-TYPE=1) performs two functions. Primarily it establishes the values for the Session Timeouts. Incidentally, it also resets the keepalive timer for the DSO Session, meaning that it can be used as a kind of "no-op" message for the purpose of keeping a session alive. The client will request the desired session timeout values and the server will acknowledge with the response values that it requires the client to use.

DSO messages with the Keepalive TLV as the primary TLV may appear in early data.

The DSO-DATA for the Keepalive TLV is as follows:



**INACTIVITY TIMEOUT:** The inactivity timeout for the current DSO Session, specified as a 32-bit unsigned integer, in network (big endian) byte order, in units of milliseconds. This is the timeout at which the client MUST begin closing an inactive DSO Session. The inactivity timeout can be any value of the server's choosing. If the client does not gracefully close an inactive DSO Session, then after twice this interval, or five seconds, whichever is greater, the server will forcibly abort the connection.

**KEEPALIVE INTERVAL:** The keepalive interval for the current DSO Session, specified as a 32-bit unsigned integer, in network (big endian) byte order, in units of milliseconds. This is the interval at which a client MUST generate DSO keepalive traffic to maintain connection state. The keepalive interval MUST NOT be less than ten seconds. If the client does not generate the mandated DSO keepalive traffic, then after twice this interval the server will forcibly abort the connection. Since the minimum allowed keepalive interval is ten seconds, the minimum time at which a server will forcibly disconnect a client for failing to generate the mandated DSO keepalive traffic is twenty seconds.

The transmission or reception of DSO Keepalive messages (i.e., messages where the Keepalive TLV is the first TLV) reset only the keepalive timer, not the inactivity timer. The reason for this is that periodic DSO Keepalive messages are sent for the sole purpose of keeping a DSO Session alive, when that DSO Session has current or recent non-maintenance activity that warrants keeping that DSO Session alive. Sending DSO keepalive traffic itself is not considered a client activity; it is considered a maintenance activity that is performed in service of other client activities. If DSO keepalive traffic itself were to reset the inactivity timer, then that would create a circular livelock where keepalive traffic would be sent indefinitely to keep a DSO Session alive, where the only activity on that DSO Session would be the keepalive traffic keeping the DSO Session alive so that further keepalive traffic can be sent. For a DSO Session to be considered active, it must be carrying something more than just keepalive traffic. This is why merely sending or receiving a DSO Keepalive message does not reset the inactivity timer.

When sent by a client, the DSO Keepalive request message MUST be sent as an DSO request message, with a nonzero MESSAGE ID. If a server receives a DSO Keepalive message with a zero MESSAGE ID then this is a fatal error and the server MUST forcibly abort the connection immediately. The DSO Keepalive request message resets a DSO Session's keepalive timer, and at the same time communicates to the server the client's requested Session Timeout values. In a server response to a client-initiated DSO Keepalive request message, the Session Timeouts contain the server's chosen values from this point forward in the DSO Session, which the client MUST respect. This is modeled after the DHCP protocol, where the client requests a certain lease lifetime using DHCP option 51 [RFC2132], but the server is the ultimate authority for deciding what lease lifetime is actually granted.

When a client is sending its second and subsequent DSO Keepalive request messages to the server, the client SHOULD continue to request its preferred values each time. This allows flexibility, so that if conditions change during the lifetime of a DSO Session, the server can adapt its responses to better fit the client's needs.

Once a DSO Session is in progress (Section 5.1) a DSO Keepalive message MAY be initiated by a server. When sent by a server, the DSO Keepalive message MUST be sent as a DSO unidirectional message, with the MESSAGE ID set to zero. The client MUST NOT generate a response to a server-initiated DSO Keepalive message. If a client receives a DSO Keepalive request message with a nonzero MESSAGE ID then this is a fatal error and the client MUST forcibly abort the connection immediately. The DSO Keepalive unidirectional message from the

server resets a DSO Session's keepalive timer, and at the same time unilaterally informs the client of the new Session Timeout values to use from this point forward in this DSO Session. No client DSO response to this unilateral declaration is required or allowed.

In DSO Keepalive response messages, the Keepalive TLV is REQUIRED and is used only as a Response Primary TLV sent as a reply to a DSO Keepalive request message from the client. A Keepalive TLV MUST NOT be added to other responses as a Response Additional TLV. If the server wishes to update a client's Session Timeout values other than in response to a DSO Keepalive request message from the client, then it does so by sending an DSO Keepalive unidirectional message of its own, as described above.

It is not required that the Keepalive TLV be used in every DSO Session. While many DNS Stateful operations will be used in conjunction with a long-lived session state, not all DNS Stateful operations require long-lived session state, and in some cases the default 15-second value for both the inactivity timeout and keepalive interval may be perfectly appropriate. However, note that for clients that implement only the DSO-TYPEs defined in this document, a DSO Keepalive request message is the only way for a client to initiate a DSO Session.

#### 7.1.1. Client handling of received Session Timeout values

When a client receives a response to its client-initiated DSO Keepalive message, or receives a server-initiated DSO Keepalive message, the client has then received Session Timeout values dictated by the server. The two timeout values contained in the Keepalive TLV from the server may each be higher, lower, or the same as the respective Session Timeout values the client previously had for this DSO Session.

In the case of the keepalive timer, the handling of the received value is straightforward. The act of receiving the message containing the DSO Keepalive TLV itself resets the keepalive timer, and updates the keepalive interval for the DSO Session. The new keepalive interval indicates the maximum time that may elapse before another message must be sent or received on this DSO Session, if the DSO Session is to remain alive.

In the case of the inactivity timeout, the handling of the received value is a little more subtle, though the meaning of the inactivity timeout remains as specified -- it still indicates the maximum permissible time allowed without useful activity on a DSO Session. The act of receiving the message containing the Keepalive TLV does not itself reset the inactivity timer. The time elapsed since the

last useful activity on this DSO Session is unaffected by exchange of DSO Keepalive messages. The new inactivity timeout value in the Keepalive TLV in the received message does update the timeout associated with the running inactivity timer; that becomes the new maximum permissible time without activity on a DSO Session.

- o If the current inactivity timer value is less than the new inactivity timeout, then the DSO Session may remain open for now. When the inactivity timer value reaches the new inactivity timeout, the client MUST then begin closing the DSO Session, as described above.
- o If the current inactivity timer value is equal to the new inactivity timeout, then this DSO Session has been inactive for exactly as long as the server will permit, and now the client MUST immediately begin closing this DSO Session.
- o If the current inactivity timer value is already greater than the new inactivity timeout, then this DSO Session has already been inactive for longer than the server permits, and the client MUST immediately begin closing this DSO Session.
- o If the current inactivity timer value is already more than twice the new inactivity timeout, then the client is immediately considered delinquent (this DSO Session is immediately eligible to be forcibly terminated by the server) and the client MUST immediately begin closing this DSO Session. However if a server abruptly reduces the inactivity timeout in this way, then, to give the client time to close the connection gracefully before the server resorts to forcibly aborting it, the server SHOULD give the client an additional grace period of one quarter of the new inactivity timeout, or five seconds, whichever is greater.

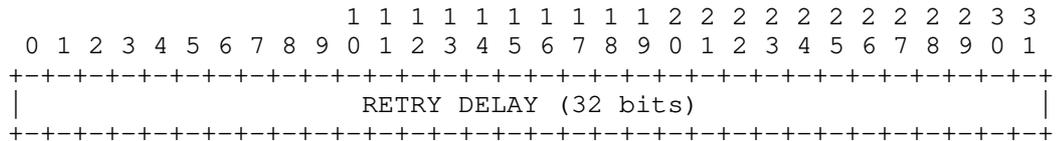
#### 7.1.2. Relationship to edns-tcp-keepalive EDNS0 Option

The inactivity timeout value in the Keepalive TLV (DSO-TYPE=1) has similar intent to the edns-tcp-keepalive EDNS0 Option [RFC7828]. A client/server pair that supports DSO MUST NOT use the edns-tcp-keepalive EDNS0 Option within any message after a DSO Session has been established. A client that has sent a DSO message to establish a session MUST NOT send an edns-tcp-keepalive EDNS0 Option from this point on. Once a DSO Session has been established, if either client or server receives a DNS message over the DSO Session that contains an edns-tcp-keepalive EDNS0 Option, this is a fatal error and the receiver of the edns-tcp-keepalive EDNS0 Option MUST forcibly abort the connection immediately.

7.2. Retry Delay TLV

The Retry Delay TLV (DSO-TYPE=2) can be used as a Primary TLV (unidirectional) in a server-to-client message, or as a Response Additional TLV in either direction. DSO messages with a Relay Delay TLV as their primary TLV are not permitted in early data.

The DSO-DATA for the Retry Delay TLV is as follows:



RETRY DELAY: A time value, specified as a 32-bit unsigned integer, in network (big endian) byte order, in units of milliseconds, within which the initiator MUST NOT retry this operation, or retry connecting to this server. Recommendations for the RETRY DELAY value are given in Section 6.6.1.

7.2.1. Retry Delay TLV used as a Primary TLV

When sent from server to client, the Retry Delay TLV is used as the Primary TLV in a DSO unidirectional message. It is used by a server to instruct a client to close the DSO Session and underlying connection, and not to reconnect for the indicated time interval.

In this case it applies to the DSO Session as a whole, and the client MUST begin closing the DSO Session, as described in Section 6.6.1. The RCODE in the message header SHOULD indicate the principal reason for the termination:

- o NOERROR indicates a routine shutdown or restart.
- o FORMERR indicates that a client request was too badly malformed for the session to continue.
- o SERVFAIL indicates that the server is overloaded due to resource exhaustion and needs to shed load.
- o REFUSED indicates that the server has been reconfigured, and at this time it is now unable to perform one or more of the long-lived client operations that were previously being performed on this DSO Session.
- o NOTAUTH indicates that the server has been reconfigured and at this time it is now unable to perform one or more of the long-

lived client operations that were previously being performed on this DSO Session because it does not have authority over the names in question (for example, a DNS Push Notification server could be reconfigured such that it is no longer accepting DNS Push Notification requests for one or more of the currently subscribed names).

This document specifies only these RCODE values for the Retry Delay message. Servers sending Retry Delay messages SHOULD use one of these values. However, future circumstances may create situations where other RCODE values are appropriate in Retry Delay messages, so clients MUST be prepared to accept Retry Delay messages with any RCODE value.

In some cases, when a server sends a Retry Delay message to a client, there may be more than one reason for the server wanting to end the session. Possibly the configuration could have been changed such that some long-lived client operations can no longer be continued due to policy (REFUSED), and other long-lived client operations can no longer be performed due to the server no longer being authoritative for those names (NOTAUTH). In such cases the server MAY use any of the applicable RCODE values, or RCODE=NOERROR (routine shutdown or restart).

Note that the selection of RCODE value in a Retry Delay message is not critical, since the RCODE value is generally used only for information purposes, such as writing to a log file for future human analysis regarding the nature of the disconnection. Generally clients do not modify their behavior depending on the RCODE value. The RETRY DELAY in the message tells the client how long it should wait before attempting a new connection to this service instance.

For clients that do in some way modify their behavior depending on the RCODE value, they should treat unknown RCODE values the same as RCODE=NOERROR (routine shutdown or restart).

A Retry Delay message from server to client is a DSO unidirectional message; the MESSAGE ID MUST be set to zero in the outgoing message and the client MUST NOT send a response.

A client MUST NOT send a Retry Delay DSO message to a server. If a server receives a DSO message where the Primary TLV is the Retry Delay TLV, this is a fatal error and the server MUST forcibly abort the connection immediately.

### 7.2.2. Retry Delay TLV used as a Response Additional TLV

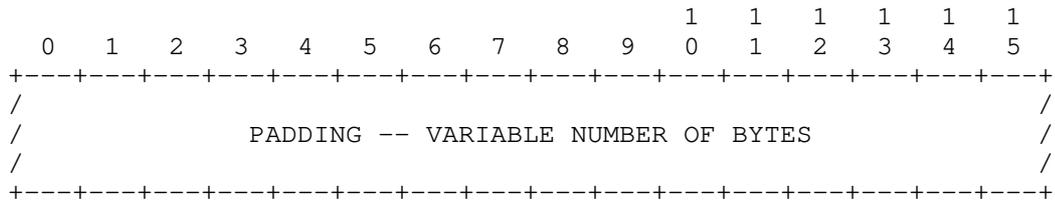
In the case of a DSO request message that results in a nonzero RCODE value, the responder MAY append a Retry Delay TLV to the response, indicating the time interval during which the initiator SHOULD NOT attempt this operation again.

The indicated time interval during which the initiator SHOULD NOT retry applies only to the failed operation, not to the DSO Session as a whole.

7.3. Encryption Padding TLV

The Encryption Padding TLV (DSO-TYPE=3) can only be used as an Additional or Response Additional TLV. It is only applicable when the DSO Transport layer uses encryption such as TLS.

The DSO-DATA for the Padding TLV is optional and is a variable length field containing non-specified values. A DSO-LENGTH of 0 essentially provides for 4 bytes of padding (the minimum amount).



As specified for the EDNS(0) Padding Option [RFC7830] the PADDING bytes SHOULD be set to 0x00. Other values MAY be used, for example, in cases where there is a concern that the padded message could be subject to compression before encryption. PADDING bytes of any value MUST be accepted in the messages received.

The Encryption Padding TLV may be included in either a DSO request message, response, or both. As specified for the EDNS(0) Padding Option [RFC7830] if a DSO request message is received with an Encryption Padding TLV, then the DSO response MUST also include an Encryption Padding TLV.

The length of padding is intentionally not specified in this document and is a function of current best practices with respect to the type and length of data in the preceding TLVs [I-D.ietf-dprive-padding-policy].

## 8. Summary Highlights

This section summarizes some noteworthy highlights about various aspects of the DSO protocol.

### 8.1. QR bit and MESSAGE ID

In DSO Request Messages the QR bit is 0 and the MESSAGE ID is nonzero.

In DSO Response Messages the QR bit is 1 and the MESSAGE ID is nonzero.

In DSO Unidirectional Messages the QR bit is 0 and the MESSAGE ID is zero.

The table below illustrates which combinations are legal and how they are interpreted:

|      | MESSAGE ID zero            | MESSAGE ID nonzero   |
|------|----------------------------|----------------------|
| QR=0 | DSO unidirectional Message | DSO Request Message  |
| QR=1 | Invalid - Fatal Error      | DSO Response Message |

## 8.2. TLV Usage

The table below indicates, for each of the three TLVs defined in this document, whether they are valid in each of ten different contexts.

The first five contexts are DSO requests or DSO unidirectional messages from client to server, and the corresponding responses from server back to client:

- o C-P - Primary TLV, sent in DSO Request message, from client to server, with nonzero MESSAGE ID indicating that this request MUST generate response message.
- o C-U - Primary TLV, sent in DSO Unidirectional message, from client to server, with zero MESSAGE ID indicating that this request MUST NOT generate response message.
- o C-A - Additional TLV, optionally added to a DSO request message or DSO unidirectional message from client to server.
- o CRP - Response Primary TLV, included in response message sent back to the client (in response to a client "C-P" request with nonzero MESSAGE ID indicating that a response is required) where the DSO-TYPE of the Response TLV matches the DSO-TYPE of the Primary TLV in the request.
- o CRA - Response Additional TLV, included in response message sent back to the client (in response to a client "C-P" request with nonzero MESSAGE ID indicating that a response is required) where the DSO-TYPE of the Response TLV does not match the DSO-TYPE of the Primary TLV in the request.

The second five contexts are their counterparts in the opposite direction: DSO requests or DSO unidirectional messages from server to client, and the corresponding responses from client back to server.

- o S-P - Primary TLV, sent in DSO Request message, from server to client, with nonzero MESSAGE ID indicating that this request MUST generate response message.
- o S-U - Primary TLV, sent in DSO Unidirectional message, from server to client, with zero MESSAGE ID indicating that this request MUST NOT generate response message.
- o S-A - Additional TLV, optionally added to a DSO request message or DSO unidirectional message from server to client.

- o SRP - Response Primary TLV, included in response message sent back to the server (in response to a server "S-P" request with nonzero MESSAGE ID indicating that a response is required) where the DSO-TYPE of the Response TLV matches the DSO-TYPE of the Primary TLV in the request.
- o SRA - Response Additional TLV, included in response message sent back to the server (in response to a server "S-P" request with nonzero MESSAGE ID indicating that a response is required) where the DSO-TYPE of the Response TLV does not match the DSO-TYPE of the Primary TLV in the request.

|            | C-P | C-U | C-A | CRP | CRA | S-P | S-U | S-A | SRP | SRA |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| KeepAlive  | X   |     |     | X   |     |     | X   |     |     |     |
| RetryDelay |     |     |     |     | X   |     | X   |     |     | X   |
| Padding    |     |     | X   |     | X   |     |     | X   |     | X   |

Note that some of the columns in this table are currently empty. The table provides a template for future TLV definitions to follow. It is recommended that definitions of future TLVs include a similar table summarizing the contexts where the new TLV is valid.

## 9. Additional Considerations

### 9.1. Service Instances

We use the term service instance to refer to software running on a host which can receive connections on some set of IP address and port tuples. What makes the software an instance is that regardless of which of these tuples the client uses to connect to it, the client is connected to the same software, running on the same node (but see Section 9.2), and will receive the same answers and the same keying information.

Service instances are identified from the perspective of the client. If the client is configured with IP addresses and port number tuples, it has no way to tell if the service offered at one tuple is the same server that is listening on a different tuple. So in this case, the client treats each such tuple as if it references a separate service instance.

In some cases a client is configured with a hostname and a port number (either implicitly, where the port number is omitted and assumed, or explicitly, as in the case of DNS SRV records). In these cases, the (hostname, port) tuple uniquely identifies the service instance (hostname comparisons are case-insensitive [RFC1034]).

It is possible that two hostnames might point to some common IP addresses; this is a configuration error which the client is not obliged to detect. The effect of this could be that after being told to disconnect, the client might reconnect to the same server because it is represented as a different service instance.

Implementations SHOULD NOT resolve hostnames and then perform matching of IP address(es) in order to evaluate whether two entities should be determined to be the "same service instance".

## 9.2. Anycast Considerations

When an anycast service is configured on a particular IP address and port, it must be the case that although there is more than one physical server responding on that IP address, each such server can be treated as equivalent. What we mean by "equivalent" here is that both servers can provide the same service and, where appropriate, the same authentication information, such as PKI certificates, when establishing connections.

If a change in network topology causes packets in a particular TCP connection to be sent to an anycast server instance that does not know about the connection, the new server will automatically terminate the connection with a TCP reset, since it will have no record of the connection, and then the client can reconnect or stop using the connection, as appropriate.

If after the connection is re-established, the client's assumption that it is connected to the same service is violated in some way, that would be considered to be incorrect behavior in this context. It is however out of the possible scope for this specification to make specific recommendations in this regard; that would be up to follow-on documents that describe specific uses of DNS stateful operations.

### 9.3. Connection Sharing

As previously specified for DNS over TCP [RFC7766]:

To mitigate the risk of unintentional server overload, DNS clients **MUST** take care to minimize the number of concurrent TCP connections made to any individual server. It is **RECOMMENDED** that for any given client/server interaction there **SHOULD** be no more than one connection for regular queries, one for zone transfers, and one for each protocol that is being used on top of TCP (for example, if the resolver was using TLS). However, it is noted that certain primary/secondary configurations with many busy zones might need to use more than one TCP connection for zone transfers for operational reasons (for example, to support concurrent transfers of multiple zones).

A single server may support multiple services, including DNS Updates [RFC2136], DNS Push Notifications [I-D.ietf-dnssd-push], and other services, for one or more DNS zones. When a client discovers that the target server for several different operations is the same service instance (see Section 9.1), the client **SHOULD** use a single shared DSO Session for all those operations.

This requirement has two benefits. First, it reduces unnecessary connection load on the DNS server. Second, it avoids paying the TCP slow start penalty when making subsequent connections to the same server.

However, server implementers and operators should be aware that connection sharing may not be possible in all cases. A single host device may be home to multiple independent client software instances that don't coordinate with each other. Similarly, multiple independent client devices behind the same NAT gateway will also typically appear to the DNS server as different source ports on the same client IP address. Because of these constraints, a DNS server **MUST** be prepared to accept multiple connections from different source ports on the same client IP address.

#### 9.4. Operational Considerations for Middlebox

Where an application-layer middlebox (e.g., a DNS proxy, forwarder, or session multiplexer) is in the path, care must be taken to avoid a configuration in which DSO traffic is mis-handled. The simplest way to avoid such problems is to avoid using middleboxes. When this is not possible, middleboxes should be evaluated to make sure that they behave correctly.

Correct behavior for middleboxes consists of one of:

- o The middlebox does not forward DSO messages, and responds to DSO messages with a response code other than NOERROR or DSOTYPENI.
- o The middlebox acts as a DSO server and follows this specification in establishing connections.
- o There is a 1:1 correspondence between incoming and outgoing connections, such that when a connection is established to the middlebox, it is guaranteed that exactly one corresponding connection will be established from the middlebox to some DNS resolver, and all incoming messages will be forwarded without modification or reordering. An example of this would be a NAT forwarder or TCP connection optimizer (e.g. for a high-latency connection such as a geosynchronous satellite link).

Middleboxes that do not meet one of the above criteria are very likely to fail in unexpected and difficult-to-diagnose ways. For example, a DNS load balancer might unbundle DNS messages from the incoming TCP stream and forward each message from the stream to a different DNS server. If such a load balancer is in use, and the DNS servers it points implement DSO and are configured to enable DSO, DSO session establishment will succeed, but no coherent session will exist between the client and the server. If such a load balancer is pointed at a DNS server that does not implement DSO or is configured not to allow DSO, no such problem will exist, but such a configuration risks unexpected failure if new server software is installed which does implement DSO.

It is of course possible to implement a middlebox that properly supports DSO. It is even possible to implement one that implements DSO with long-lived operations. This can be done either by maintaining a 1:1 correspondence between incoming and outgoing connections, as mentioned above, or by terminating incoming sessions at the middlebox, but maintaining state in the middlebox about any long-lived that are requested. Specifying this in detail is beyond the scope of this document.

### 9.5. TCP Delayed Acknowledgement Considerations

Most modern implementations of the Transmission Control Protocol (TCP) include a feature called "Delayed Acknowledgement" [RFC1122].

Without this feature, TCP can be very wasteful on the network. For illustration, consider a simple example like remote login, using a very simple TCP implementation that lacks delayed acks. When the user types a keystroke, a data packet is sent. When the data packet arrives at the server, the simple TCP implementation sends an immediate acknowledgement. Mere milliseconds later, the server process reads the one byte of keystroke data, and consequently the simple TCP implementation sends an immediate window update. Mere milliseconds later, the server process generates the character echo, and sends this data back in reply. The simple TCP implementation then sends this data packet immediately too. In this case, this simple TCP implementation sends a burst of three packets almost instantaneously (ack, window update, data).

Clearly it would be more efficient if the TCP implementation were to combine the three separate packets into one, and this is what the delayed ack feature enables.

With delayed ack, the TCP implementation waits after receiving a data packet, typically for 200 ms, and then send its ack if (a) more data packet(s) arrive (b) the receiving process generates some reply data, or (c) 200 ms elapses without either of the above occurring.

With delayed ack, remote login becomes much more efficient, generating just one packet instead of three for each character echo.

The logic of delayed ack is that the 200 ms delay cannot do any significant harm. If something at the other end were waiting for something, then the receiving process should generate the reply that the thing at the end is waiting for, and TCP will then immediately send that reply (and the ack and window update). And if the receiving process does not in fact generate any reply for this particular message, then by definition the thing at the other end cannot be waiting for anything, so the 200 ms delay is harmless.

This assumption may be true, unless the sender is using Nagle's algorithm, a similar efficiency feature, created to protect the network from poorly written client software that performs many rapid small writes in succession. Nagle's algorithm allows these small writes to be combined into larger, less wasteful packets.

Unfortunately, Nagle's algorithm and delayed ack, two valuable efficiency features, can interact badly with each other when used together [NagleDA].

DSO request messages elicit responses; DSO unidirectional messages and DSO response messages do not.

For DSO request messages, which do elicit responses, Nagle's algorithm and delayed ack work as intended.

For DSO messages that do not elicit responses, the delayed ack mechanism causes the ack to be delayed by 200 ms. The 200 ms delay on the ack can in turn cause Nagle's algorithm to prevent the sender from sending any more data for 200 ms until the awaited ack arrives. On an enterprise GigE backbone with sub-millisecond round-trip times, a 200 ms delay is enormous in comparison.

When this issues is raised, there are two solutions that are often offered, neither of them ideal:

1. Disable delayed ack. For DSO messages that elicit no response, removing delayed ack avoids the needless 200 ms delay, and sends back an immediate ack, which tells Nagle's algorithm that it should immediately grant the sender permission to send its next packet. Unfortunately, for DSO messages that *do* elicit a response, removing delayed ack removes the efficiency gains of combining acks with data, and the responder will now send two or three packets instead of one.
2. Disable Nagle's algorithm. When acks are delayed by the delayed ack algorithm, removing Nagle's algorithm prevents the sender from being blocked from sending its next small packet immediately. Unfortunately, on a network with a higher round-trip time, removing Nagle's algorithm removes the efficiency gains of combining multiple small packets into fewer larger ones, with the goal of limiting the number of small packets in flight at any one time.

For DSO messages that elicit a response, delayed ack and Nagle's algorithm do the right thing.

The problem here is that with DSO messages that elicit no response, the TCP implementation is stuck waiting, unsure if a response is about to be generated, or whether the TCP implementation should go ahead and send an ack and window update.

The solution is networking APIs that allow the receiver to inform the TCP implementation that a received message has been read, processed,

and no response for this message will be generated. TCP can then stop waiting for a response that will never come, and immediately go ahead and send an ack and window update.

For implementations of DSO, disabling delayed ack is NOT RECOMMENDED, because of the harm this can do to the network.

For implementations of DSO, disabling Nagle's algorithm is NOT RECOMMENDED, because of the harm this can do to the network.

At the time that this document is being prepared for publication, it is known that at least one TCP implementation provides the ability for the recipient of a TCP message to signal that it is not going to send a response, and hence the delayed ack mechanism can stop waiting. Implementations on operating systems where this feature is available SHOULD make use of it.

## 10. IANA Considerations

## 10.1. DSO OPCODE Registration

The IANA is requested to record the value [TBA1] (tentatively 6) for the DSO OPCODE in the DNS OPCODE Registry. DSO stands for DNS Stateful Operations.

## 10.2. DSO RCODE Registration

The IANA is requested to record the value [TBA2] (tentatively 11) for the DSOTYPENI error code in the DNS RCODE Registry. The DSOTYPENI error code ("DSO-TYPE Not Implemented") indicates that the receiver does implement DNS Stateful Operations, but does not implement the specific DSO-TYPE of the primary TLV in the DSO request message.

## 10.3. DSO Type Code Registry

The IANA is requested to create the 16-bit DSO Type Code Registry, with initial (hexadecimal) values as shown below:

| Type      | Name   | Early Data | Status   | Reference |
|-----------|--|------------|----------|-----------|
| 0000      | Reserved   | NO         | Standard | RFC-TBD   |
| 0001      | KeepAlive  | OK         | Standard | RFC-TBD   |
| 0002      | RetryDelay   | NO         | Standard | RFC-TBD   |
| 0003      | EncryptionPadding                                    | NA         | Standard | RFC-TBD   |
| 0004-003F | Unassigned, reserved for DSO session-management TLVs | NO         |          |           |
| 0040-F7FF | Unassigned   | NO         |          |           |
| F800-FBFF | Experimental/local use                               | NO         |          |           |
| FC00-FFFF | Reserved for future expansion                        | NO         |          |           |

The meanings of the fields are as follows:

Type: the 16-bit DSO type code

Name: the human-readable name of the TLV

Early Data: If OK, this TLV may be sent as early data in a TLS 0-RTT ([RFC8446] Section 2.3) initial handshake. If NA, the TLV may appear as a secondary TLV in a DSO message that is send as early data.

Status: IETF Document status (or "External" if not documented in an IETF document).

Reference: A stable reference to the document in which this TLV is defined.

DSO Type Code zero is reserved and is not currently intended for allocation.

Registrations of new DSO Type Codes in the "Reserved for DSO session-management" range 0004-003F and the "Reserved for future expansion" range FC00-FFFF require publication of an IETF Standards Action document [RFC8126].

Any document defining a new TLV which lists a value of "OK" in the 0-RTT column must include a threat analysis for the use of the TLV in the case of TLS 0-RTT. See Section 11.1 for details.

Requests to register additional new DSO Type Codes in the "Unassigned" range 0040-F7FF are to be recorded by IANA after Expert Review [RFC8126]. The expert review should validate that the requested type code is specified in a way that conforms to this specification, and that the intended use for the code would not be addressed with an experimental/local assignment.

DSO Type Codes in the "experimental/local" range F800-FBFF may be used as Experimental Use or Private Use values [RFC8126] and may be used freely for development purposes, or for other purposes within a single site. No attempt is made to prevent multiple sites from using the same value in different (and incompatible) ways. There is no need for IANA to review such assignments (since IANA does not record them) and assignments are not generally useful for broad interoperability. It is the responsibility of the sites making use of "experimental/local" values to ensure that no conflicts occur within the intended scope of use.

## 11. Security Considerations

If this mechanism is to be used with DNS over TLS, then these messages are subject to the same constraints as any other DNS-over-

TLS messages and MUST NOT be sent in the clear before the TLS session is established.

The data field of the "Encryption Padding" TLV could be used as a covert channel.

When designing new DSO TLVs, the potential for data in the TLV to be used as a tracking identifier should be taken into consideration, and should be avoided when not required.

When used without TLS or similar cryptographic protection, a malicious entity maybe able to inject a malicious unidirectional DSO Retry Delay Message into the data stream, specifying an unreasonably large RETRY DELAY, causing a denial-of-service attack against the client.

The establishment of DSO sessions has an impact on the number of open TCP connections on a DNS server. Additional resources may be used on the server as a result. However, because the server can limit the number of DSO sessions established and can also close existing DSO sessions as needed, denial of service or resource exhaustion should not be a concern.

#### 11.1. TLS 0-RTT Considerations

DSO permits zero round-trip operation using TCP Fast Open [RFC7413] with TLS 1.3 [RFC8446] 0-RTT to reduce or eliminate round trips in session establishment. TCP Fast Open is only permitted in combination with TLS 0-RTT. In the rest of this section we refer to TLS 1.3 early data in a TLS 0-RTT initial handshake message, whether or not it is included in a TCP SYN packet with early data using the TCP Fast Open option, as "early data."

A DSO message may or may not be permitted to be sent as early data. The definition for each TLV that can be used as a primary TLV is required to state whether or not that TLV is permitted as early data. Only response-requiring messages are ever permitted as early data, and only clients are permitted to send any DSO message as early data, unless there is an implicit session (see Section 5.1).

For DSO messages that are permitted as early data, a client MAY include one or more such messages as early data without having to wait for a DSO response to the first DSO request message to confirm successful establishment of a DSO session.

However, unless there is an implicit session, a client MUST NOT send DSO unidirectional messages until after a DSO Session has been mutually established.

Similarly, unless there is an implicit session, a server MUST NOT send DSO request messages until it has received a response-requiring DSO request message from a client and transmitted a successful NOERROR response for that request.

Caution must be taken to ensure that DSO messages sent as early data are idempotent, or are otherwise immune to any problems that could be result from the inadvertent replay that can occur with zero round-trip operation.

It would be possible to add a TLV that requires the server to do some significant work, and send that to the server as initial data in a TCP SYN packet. A flood of such packets could be used as a DoS attack on the server. None of the TLVs defined here have this property.

If a new TLV is specified that does have this property, that TLV must be specified as not permitted in 0-RTT messages. This prevents work from being done until a round-trip has occurred from the server to the client to verify that the source address of the packet is reachable.

Documents that define new TLVs must state whether each new TLV may be sent as early data. Such documents must include a threat analysis in the security considerations section for each TLV defined in the document that may be sent as early data. This threat analysis should be done based on the advice given in [RFC8446] Section 2.3, 8 and Appendix E.5.

## 12. Acknowledgements

Thanks to Stephane Bortzmeyer, Tim Chown, Ralph Droms, Paul Hoffman, Jan Komissar, Edward Lewis, Allison Mankin, Rui Paulo, David Schinazi, Manju Shankar Rao, Bernie Volz and Bob Harold for their helpful contributions to this document.

## 13. References

### 13.1. Normative References

- [RFC1034] Mockapetris, P., "Domain names - concepts and facilities", STD 13, RFC 1034, DOI 10.17487/RFC1034, November 1987, <<https://www.rfc-editor.org/info/rfc1034>>.
- [RFC1035] Mockapetris, P., "Domain names - implementation and specification", STD 13, RFC 1035, DOI 10.17487/RFC1035, November 1987, <<https://www.rfc-editor.org/info/rfc1035>>.

- [RFC1918] Rekhter, Y., Moskowitz, B., Karrenberg, D., de Groot, G., and E. Lear, "Address Allocation for Private Internets", BCP 5, RFC 1918, DOI 10.17487/RFC1918, February 1996, <<https://www.rfc-editor.org/info/rfc1918>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC2136] Vixie, P., Ed., Thomson, S., Rekhter, Y., and J. Bound, "Dynamic Updates in the Domain Name System (DNS UPDATE)", RFC 2136, DOI 10.17487/RFC2136, April 1997, <<https://www.rfc-editor.org/info/rfc2136>>.
- [RFC6891] Damas, J., Graff, M., and P. Vixie, "Extension Mechanisms for DNS (EDNS(0))", STD 75, RFC 6891, DOI 10.17487/RFC6891, April 2013, <<https://www.rfc-editor.org/info/rfc6891>>.
- [RFC7766] Dickinson, J., Dickinson, S., Bellis, R., Mankin, A., and D. Wessels, "DNS Transport over TCP - Implementation Requirements", RFC 7766, DOI 10.17487/RFC7766, March 2016, <<https://www.rfc-editor.org/info/rfc7766>>.
- [RFC7830] Mayrhofer, A., "The EDNS(0) Padding Option", RFC 7830, DOI 10.17487/RFC7830, May 2016, <<https://www.rfc-editor.org/info/rfc7830>>.
- [RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <<https://www.rfc-editor.org/info/rfc8126>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.

## 13.2. Informative References

- [I-D.ietf-dnsop-no-response-issue]  
Andrews, M. and R. Bellis, "A Common Operational Problem in DNS Servers - Failure To Respond.", draft-ietf-dnsop-no-response-issue-12 (work in progress), November 2018.

- [I-D.ietf-dnssd-mdns-relay]  
Lemon, T. and S. Cheshire, "Multicast DNS Discovery Relay", draft-ietf-dnssd-mdns-relay-01 (work in progress), July 2018.
- [I-D.ietf-dnssd-push]  
Pusateri, T. and S. Cheshire, "DNS Push Notifications", draft-ietf-dnssd-push-16 (work in progress), November 2018.
- [I-D.ietf-doh-dns-over-https]  
Hoffman, P. and P. McManus, "DNS Queries over HTTPS (DoH)", draft-ietf-doh-dns-over-https-14 (work in progress), August 2018.
- [I-D.ietf-dprive-padding-policy]  
Mayrhofer, A., "Padding Policy for EDNS(0)", draft-ietf-dprive-padding-policy-06 (work in progress), July 2018.
- [NagleDA] Cheshire, S., "TCP Performance problems caused by interaction between Nagle's Algorithm and Delayed ACK", May 2005,  
<<http://www.stuartcheshire.org/papers/nagledelayedack/>>.
- [RFC1122] Braden, R., Ed., "Requirements for Internet Hosts - Communication Layers", STD 3, RFC 1122, DOI 10.17487/RFC1122, October 1989,  
<<https://www.rfc-editor.org/info/rfc1122>>.
- [RFC2132] Alexander, S. and R. Droms, "DHCP Options and BOOTP Vendor Extensions", RFC 2132, DOI 10.17487/RFC2132, March 1997,  
<<https://www.rfc-editor.org/info/rfc2132>>.
- [RFC5382] Guha, S., Ed., Biswas, K., Ford, B., Sivakumar, S., and P. Srisuresh, "NAT Behavioral Requirements for TCP", BCP 142, RFC 5382, DOI 10.17487/RFC5382, October 2008,  
<<https://www.rfc-editor.org/info/rfc5382>>.
- [RFC6762] Cheshire, S. and M. Krochmal, "Multicast DNS", RFC 6762, DOI 10.17487/RFC6762, February 2013,  
<<https://www.rfc-editor.org/info/rfc6762>>.
- [RFC6763] Cheshire, S. and M. Krochmal, "DNS-Based Service Discovery", RFC 6763, DOI 10.17487/RFC6763, February 2013,  
<<https://www.rfc-editor.org/info/rfc6763>>.

- [RFC7413] Cheng, Y., Chu, J., Radhakrishnan, S., and A. Jain, "TCP Fast Open", RFC 7413, DOI 10.17487/RFC7413, December 2014, <<https://www.rfc-editor.org/info/rfc7413>>.
- [RFC7828] Wouters, P., Abley, J., Dickinson, S., and R. Bellis, "The edns-tcp-keepalive EDNS0 Option", RFC 7828, DOI 10.17487/RFC7828, April 2016, <<https://www.rfc-editor.org/info/rfc7828>>.
- [RFC7857] Penno, R., Perreault, S., Boucadair, M., Ed., Sivakumar, S., and K. Naito, "Updates to Network Address Translation (NAT) Behavioral Requirements", BCP 127, RFC 7857, DOI 10.17487/RFC7857, April 2016, <<https://www.rfc-editor.org/info/rfc7857>>.
- [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>>.
- [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>>.

## Authors' Addresses

Ray Bellis  
Internet Systems Consortium, Inc.  
950 Charter Street  
Redwood City CA 94063  
USA

Phone: +1 (650) 423-1200  
Email: [ray@isc.org](mailto:ray@isc.org)

Stuart Cheshire  
Apple Inc.  
One Apple Park Way  
Cupertino CA 95014  
USA

Phone: +1 (408) 996-1010  
Email: [cheshire@apple.com](mailto:cheshire@apple.com)

John Dickinson  
Sinodun Internet Technologies  
Magadalen Centre  
Oxford Science Park  
Oxford OX4 4GA  
United Kingdom

Email: jad@sinodun.com

Sara Dickinson  
Sinodun Internet Technologies  
Magadalen Centre  
Oxford Science Park  
Oxford OX4 4GA  
United Kingdom

Email: sara@sinodun.com

Ted Lemon  
Nibbhaya Consulting  
P.O. Box 958  
Brattleboro VT 05302-0958  
USA

Email: mellon@fugue.com

Tom Pusateri  
Unaffiliated  
Raleigh NC 27608  
USA

Phone: +1 (919) 867-1330  
Email: pusateri@bangj.com