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DHCPv6 Failover Protocol

Abstract

DHCPv6 as defined in "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)" (RFC 3315) does not offer server redundancy. This document defines a protocol implementation to provide DHCPv6 failover, a mechanism for running two servers with the capability for either server to take over clients' leases in case of server failure or network partition. It meets the requirements for DHCPv6 failover detailed in "DHCPv6 Failover Requirements" (RFC 7031).

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc8156.

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1. Introduction

This document defines a DHCPv6 failover protocol, which is a mechanism for running two DHCPv6 servers [RFC3315] with the capability for either server to take over clients' leases in case of server failover or network partition. For a general overview of DHCPv6 failover problems, use cases, benefits, and shortcomings, see [RFC7031].

The failover protocol provides a means for cooperating DHCP servers to work together to provide a service to DHCP clients with availability that is increased beyond the availability that could be provided by a single DHCP server operating alone. It is designed to protect DHCP clients against server unreachability, including server failure and network partition. It is possible to deploy exactly two servers that are able to continue providing a lease for an IPv6 address [RFC3315] or on an IPv6 prefix [RFC3633] without the DHCP client experiencing lease expiration or a reassignment of a lease to a different IPv6 address or prefix in the event of failure by one or the other of the two servers.

The failover protocol defines an active-passive mode, sometimes also called a "hot standby" model. This means that during normal operation one server is active (i.e., it actively responds to clients' requests) while the second is passive (i.e., it receives clients' requests but responds only to those specifically directed to it). The secondary server maintains a copy of the binding database and is ready to take over all incoming queries in case the primary server fails.

The failover protocol is designed to provide lease stability for leases with valid lifetimes beyond a short period. The DHCPv6 failover protocol MUST NOT be used for new leases shorter than 30 seconds. Leases reaching the end of their lifetimes are not affected by this restriction.

The failover protocol fulfills all DHCPv6 failover requirements defined in [RFC7031].

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. Glossary

This is a supplemental glossary that should be used in combination with the definitions in Section 2 of RFC 7031 [RFC7031].

- Absolute Time

  "Absolute time" refers to the time in seconds since midnight January 1, 2000 UTC, modulo 2^32.

- Address Lease

  "Address lease" refers to a lease involving an IPv6 address. Typically used when it is necessary to distinguish the lease for an IPv6 address from a lease for a DHCP prefix. See the definitions for "delegated prefix" and "prefix lease" below.

- auto-partner-down

  "auto-partner-down" refers to a capability where a failover server will move from COMMUNICATIONS-INTERRUPTED state to PARTNER-DOWN state automatically, without operator intervention.

- Available (Lease or Prefix)

  A lease or delegable prefix is available if it could be allocated for use by a DHCP client. It is available on the main server when it is in the FREE state and available on the secondary server when it is in the FREE-BACKUP state. The term "available" is sometimes used when it would be awkward to say "FREE on the primary server and FREE-BACKUP on the secondary server".

- Binding-Status

  A lease can hold a variety of states (see Section 5.5.1 for a list); these are also referred to as the "binding-status" of the lease.

- Delegable Prefix

  "Delegable prefix" refers to a prefix from which other prefixes may be delegated, using the mechanisms described in [RFC3633]. A prefix that has been delegated is known as a "delegated prefix" or a "prefix lease".

- Delegated Prefix

  A delegated prefix is a prefix that has been delegated to a DHCP client as described in [RFC3633]. Depending on the context, a delegated prefix may also be described as a "prefix lease" when it is necessary to distinguish it from an "address lease".

- DHCP Prefix

  A DHCP prefix is part of the IPv6 address space configured to be managed by a DHCP server.

- Failover Endpoint

  The failover protocol permits a unique failover "endpoint" for each failover relationship in which a failover server participates. The failover relationship is defined by a relationship name and includes

  * the failover partner IP address,

  * the role this server takes with respect to that partner (primary or secondary), and

  * the prefixes from which addresses can be leased, as well as prefixes from which other prefixes can be delegated (delegable prefixes), that are associated with that relationship.

  The failover endpoint can take actions and hold unique states. Typically, there is one failover endpoint per partner (server), although there may be more.

- Failover Communication

  "Failover communication" refers to all messages exchanged between partners.

- Independent Allocation

  "Independent allocation" refers to an allocation algorithm that splits the available pool of address leases between the primary and secondary servers. It is used for IPv6 address allocations. See Section 4.2.1.

- Lease

  A lease is an association of a DHCP client with an IPv6 address or delegated prefix. This might refer to either an existing association or a potential association.

- MCLT (Maximum Client Lead Time)

  The fundamental relationship on which much of the correctness of the failover protocol depends is that the lease expiration time known to a DHCP client MUST NOT be greater by more than the MCLT beyond the later of the partner lifetime acknowledged by that server's failover partner or the current time (i.e., now). See Section 4.4.

- Partner

  The other DHCP server that participates in a failover relationship is referred to as the "partner". When the role (primary or secondary) is not important, the other server is referred to as a "failover partner" or sometimes simply "partner".

- Prefix Lease

  A prefix lease is a lease involving a prefix that is delegated or could be delegated, as opposed to a lease for a single IPv6 address. A prefix lease can also be described as a "delegated prefix".

- Primary Server

  The primary server is the first of the two DHCP servers that participate in a failover relationship. When both servers are operating, this server handles most of the client traffic. Its failover partner is referred to as the "secondary server".

- Proportional Allocation

  "Proportional allocation" is an allocation algorithm that splits the delegable prefixes between the primary and secondary servers and maintains a more or less fixed proportion of the delegable prefixes between both servers. See Section 4.2.2.

- Renew Responsive

  A server that is "renew responsive" will respond to valid DHCP client messages that are directed to it by having an OPTION_SERVERID option in the message that contains the DHCP Unique Identifier (DUID) of the renew responsive server. See [RFC3315].

- Responsive

  A server that is responsive will respond to all valid DHCP client messages.

- Secondary Server

  The secondary server is the second of the two DHCP servers that participate in a failover relationship. Its failover partner is referred to as the "primary server" (as defined above). When both servers are operating, this server (the secondary) typically does not handle client traffic and acts as a backup to the primary server. However, it will respond to RENEW requests directed specifically to it.

- Server

  "Server" refers to a DHCP server that implements DHCPv6 failover. "Server" and "failover endpoint" are synonymous only if the server participates in only one failover relationship.

- State

  The term "state" is used in two ways in this document. A failover endpoint is always in some state, and there are a series of states that a failover endpoint can move through. See Section 8 for details of the failover endpoint states. A lease also has a state, and this is sometimes referred to as a "binding-status". See Section 5.5.1 for a list of the states a lease can hold.

- Unresponsive

  A server that is unresponsive will not respond to DHCP client messages.

4. Failover Concepts and Mechanisms

The following concepts and mechanisms are necessary for the operation of the failover protocol. They are not currently employed by DHCPv6 [RFC3315]. The failover protocol provides support for all of these concepts and mechanisms.

4.1. Required Server Configuration

Servers frequently have several kinds of leases available on a particular network segment. The failover protocol assumes that both the primary server and the secondary server are configured identically with regard to the prefixes and links involved in DHCP. For delegable prefixes (involved in proportional allocation), the primary server is responsible for allocating to the secondary server the correct proportion of the available delegable prefixes. IPv6 addresses (involved in independent allocation) are allocated to the primary and secondary servers algorithmically and do not require an explicit message transfer to be distributed.

4.2. IPv6 Address and Delegable Prefix Allocation

Currently, there are two allocation algorithms defined: one for address leases and one for prefix leases.

4.2.1. Independent Allocation

In this allocation scheme, which is used for allocating individual IPv6 addresses, available IPv6 addresses are permanently (until server configuration changes) split between servers. Available IPv6 addresses are split between the primary and secondary servers as part of initial connection establishment. Once IPv6 addresses are allocated to each server, there is no need to reassign them. The IPv6 address allocation is algorithmic in nature and does not require a message exchange for each server to know which IPv6 addresses it has been allocated. This algorithm is simpler than proportional allocation, since it does not require a rebalancing mechanism. It also assumes that the pool assigned to each server will never be depleted.

Once each server is assigned a pool of IPv6 addresses during initial connection establishment, it may allocate its assigned IPv6 addresses to clients. Once a client releases a lease or its lease on an IPv6 address expires, the returned IPv6 address returns to the pool for the server that leased it. A lease on an IPv6 address can be renewed by a responsive server or by a renew responsive server. When an IPv6 address goes PENDING-FREE (see Section 7.2), it is owned by whichever server it is allocated to by the independent allocation algorithm.

IPv6 addresses, which use the independent allocation approach, will be ignored when a server processes a POOLREQ message.

During COMMUNICATIONS-INTERRUPTED events, a partner MAY continue extending existing address leases as requested by clients. An operational partner MUST NOT lease IPv6 addresses that were assigned to its downed partner and later expired or that were released or declined by a client. When it is in PARTNER-DOWN state, a server MUST allocate new leases from its own pool. It MUST NOT use its partner's pool to allocate new leases.

4.2.1.1. Independent Allocation Algorithm

For each address that can be allocated, the primary server MUST allocate only IPv6 addresses when the low-order bit (i.e., bit 127) is equal to 1, and the secondary server MUST allocate only the IPv6 addresses when the low-order bit (i.e., bit 127) is equal to 0.

4.2.2. Proportional Allocation

In this allocation scheme, each server has its own pool of prefixes available for delegation, known as "delegable prefixes". These delegable prefixes may be prefixes from which other prefixes can be delegated, or they may be prefixes that are the correct size for delegation but are not, at present, delegated to a particular client. Remaining delegable prefixes are split between the primary and secondary servers in a configured proportion. Note that a delegated prefix (also known as a "prefix lease") is not "owned" by a particular server. Only a delegable prefix that is available is owned by a particular server -- once it has been delegated (leased) to a client, it becomes a prefix lease and is not owned by either failover partner. When it finally becomes available again, it will be initially owned by the primary server, and it may or may not be allocated to the secondary server by the primary server.

The flow of a delegable prefix is as follows: initially, the delegable prefix is part of a set of delegable prefixes, all of which are initially owned by the primary server. A delegable prefix may be allocated to the secondary server, and it is then owned by the secondary server. Either server can allocate and delegate prefixes out of the delegable prefixes that they own. Once these prefixes are delegated (leased) to clients, the servers cease to own them, and they are owned by the clients to which they have been delegated (leased). When the client releases the delegated prefix or the lease on it expires, the prefix will again become available, will again be a delegable prefix, and will be owned by the primary.

A server delegates prefixes only from its own pool of delegable prefixes in all states except for PARTNER-DOWN. In PARTNER-DOWN state, the operational partner can delegate prefixes from either pool (both its own, and its partner's after some time constraints have elapsed). The operational partner SHOULD allocate from its own pool before using its partner's pool. The allocation and maintenance of these pools of delegable prefixes are important, since the goal is to maintain a more or less constant ratio of delegable prefixes between the two servers.

Each server knows which delegable prefixes are in its own pool as well as which are in its partner's pool, so that it can allocate delegable prefixes from its partner's pool without communication with its partner if that becomes necessary.

The initial allocation of delegable prefixes from the primary to the secondary when the servers first integrate is triggered by the POOLREQ message from the secondary to the primary. This is followed (at some point) by the POOLRESP message, where the primary tells the secondary that it received and processed the POOLREQ message. The primary sends the allocated delegable prefixes to the secondary as prefix leases via BNDUPD messages. The POOLRESP message may be sent before, during, or at the completion of the BNDUPD message exchanges that were triggered by the POOLREQ message. The POOLREQ/POOLRESP message exchange is a trigger to the primary to perform a scan of its database and to ensure that the secondary has enough delegable prefixes (based on some configured ratio).

The delegable prefixes are sent to the secondary as prefix leases using the BNDUPD message containing an OPTION_IAPREFIX with a state of FREE-BACKUP, which indicates that the prefix lease is now available for allocation by the secondary. Once the message is sent, the primary MUST NOT use these prefixes for allocation to DHCP clients (except when the server is in PARTNER-DOWN state).

The POOLREQ/POOLRESP message exchange initiated by the secondary is valid at any time both partners remain in contact, and the primary server SHOULD, whenever it receives the POOLREQ message, scan its database of delegable prefixes and determine if the secondary needs more delegable prefixes from any of the delegable prefixes that it currently owns.

In order to support a reasonably dynamic balance of the leases between the failover partners, the primary server needs to do additional work to ensure that the secondary server has as many delegable prefixes as it needs (but that it doesn't have more than it needs).

The primary server SHOULD examine the balance of delegable prefixes between the primary and secondary for a particular prefix whenever the number of possibly delegable prefixes for either the primary or secondary changes by more than a predetermined amount. Typically, this comparison would not involve actually comparing the count of existing instances of delegable prefixes but would instead involve determining the number of prefixes that could be delegated given the address ranges of the delegable prefixes allocated to each server. The primary server SHOULD adjust the delegable prefix balance as required to ensure the configured delegable prefix balance, except that the primary server SHOULD employ some threshold mechanism to such a balance adjustment in order to minimize the overhead of maintaining this balance.

The primary server can, at any time, send an available delegable prefix to the secondary using a BNDUPD message with the state FREE-BACKUP. The primary server can attempt to take an available delegable prefix away from the secondary by sending a BNDUPD message with the state FREE. If the secondary accepts the BNDUPD message, then the lease is now available to the primary and not available to the secondary. Of course, the secondary MUST reject that BNDUPD message if it has already allocated that lease to a DHCP client.

4.2.2.1. Reallocating Leases

When the server is in PARTNER-DOWN state, there is a waiting period after which a delegated prefix can be reallocated to another client. For delegable prefixes that are "available" when the server enters PARTNER-DOWN state, the period is the MCLT from the entry into PARTNER-DOWN state. For delegated prefixes that are not available when the server enters PARTNER-DOWN state, the period is the MCLT after the later of the following times: the acked-partner-lifetime, the partner-lifetime (if any), the expiration-time, or the entry into PARTNER-DOWN time.

In any other state, a server cannot reallocate a delegated prefix from one client to another without first notifying its partner (through a BNDUPD message) and receiving acknowledgement (through a BNDREPLY message) that its partner is aware that the first client is not using the lease.

Specifically, an "available" delegable prefix on a server may be allocated to any client. A prefix that was delegated (leased) to a client and that expired or was released by that client would take on a new state -- EXPIRED or RELEASED, respectively. The partner server would then be notified that this delegated prefix was EXPIRED or RELEASED through a BNDUPD message. When the sending server received the BNDREPLY message for that delegated prefix showing that it was

FREE, it would move the lease from EXPIRED or RELEASED to FREE, and the prefix would be available for allocation by the primary server to any clients.

A server MAY reallocate a delegated prefix in the EXPIRED or RELEASED state to the same client with no restrictions, provided it has not sent a BNDUPD message regarding the delegated prefix to its partner. This situation would exist if the prefix lease expired or was released after the transition into PARTNER-DOWN state, for instance.

4.3. Lazy Updates

[RFC7031] includes the requirement that failover must not introduce significant performance impact on server response times (see Sections 7 and 5.2.2 of [RFC7031]). In order to realize this requirement, a server implementing the failover protocol must be able to respond to a DHCP client without waiting to update its failover partner whenever the binding database changes. The "lazy update" mechanism allows a server to allocate a new lease or extend an existing lease, respond to the DHCP client, and then update its failover partner as time permits.

Although the "lazy update" mechanism does not introduce additional delays in server response times, it introduces other difficulties. The key problem with lazy update is that when a server fails after updating a DHCP client with a particular valid lifetime but before updating its failover partner, the failover partner will eventually believe that the client's lease has expired -- even though the DHCP client still retains a valid lease on that address or prefix. It is also possible that the failover partner will have no record at all of the lease being assigned to the DHCP client. Both of these issues are dealt with by using the MCLT when allocating or extending leases (see Section 4.4).

4.4. Maximum Client Lead Time (MCLT)

In order to handle problems introduced by lazy updates (see Section 4.3), a period of time known as the "Maximum Client Lead Time" (MCLT) is defined and must be known to both the primary server and the secondary server. Proper use of this time interval places an upper bound on the difference allowed between the valid lifetime provided to a DHCP client by a server and the valid lifetime known by that server's failover partner.

The MCLT is typically much less than the valid lifetime that a server has been configured to offer a client, and so some strategy must exist to allow a server to offer the configured valid lifetime to a client. During a lazy update, the updating server updates its

failover partner with a partner lifetime that is longer than the valid lifetime previously given to the DHCP client and that is longer than the valid lifetime that the server has been configured to give a client. This allows the server to give the configured valid lifetime to the client the next time the client renews its lease, since the time that it will give to the client will not be longer than the MCLT beyond the partner lifetime acknowledged by its partner or the current time.

The fundamental relationship on which the failover protocol depends is as follows: the lease expiration time known to a DHCP client MUST NOT be greater by more than the MCLT beyond the later of the partner lifetime acknowledged by that server's failover partner or the current time.

The remainder of this section makes the above fundamental relationship more explicit.

The failover protocol requires a DHCP server to deal with several different lease intervals and places specific restrictions on their relationships. The purpose of these restrictions is to allow the partner to be able to make certain assumptions in the absence of an ability to communicate between servers.

In the following explanation, all of the lifetimes are "valid" lifetimes, in the context of [RFC3315].

The different times are as follows:

desired lifetime:
: The desired lifetime is the lease interval that a DHCP server would like to give to a DHCP client in the absence of any restrictions imposed by the failover protocol. Its determination is outside of the scope of the failover protocol. Typically, this is the result of external configuration of a DHCP server.

actual lifetime:
: The actual lifetime is the lease interval that a DHCP server gives out to a DHCP client. It may be shorter than the desired lifetime (as explained below).

partner lifetime:
: The partner lifetime is the lease expiration interval the local server sends to its partner in a BNDUPD message.

acknowledged partner lifetime:
The acknowledged partner lifetime is the partner lifetime the partner server has most recently acknowledged in a BNDREPLY message.

4.4.1. MCLT Example

The following example demonstrates the MCLT concept in practice. The values used are arbitrarily chosen and are not a recommendation for actual values. The MCLT in this case is 1 hour. The desired lifetime is 3 days, and its renewal time is half the lifetime.

When a server makes an offer for a new lease on an IPv6 address to a DHCP client, it determines the desired lifetime (in this case, 3 days). It then examines the acknowledged partner lifetime (which, in this case, is zero) and determines the remainder of the time left to run, which is also zero. It adds the MCLT to this value. Since the actual lifetime cannot be allowed to exceed the remainder of the current acknowledged partner lifetime plus the MCLT, the offer made to the client is for the remainder of the current acknowledged partner lifetime (i.e., zero) plus the MCLT. Thus, the actual lifetime is 1 hour (the MCLT).

Once the server has sent the REPLY to the DHCP client, it will update its failover partner with the lease information using a BNDUPD message. The partner lifetime will be composed of the T1 fraction (1/2) of the actual lifetime added to the desired lifetime. Thus, the failover partner is updated using a BNDUPD message with a partner lifetime of 1/2 hour + 3 days.

When the primary server receives a BNDREPLY to its update of the secondary server's (partner's) partner lifetime, it records that as the acknowledged partner lifetime. A server MUST NOT send a BNDREPLY message in response to a BNDUPD message until it is sure that the information in the BNDUPD message has been updated in its lease database. See Section 7.5.2. Thus, the primary server in this case can be sure that the secondary server has recorded the partner lifetime in its stable storage when the primary server receives a BNDREPLY message from the secondary server.

When the DHCP client attempts to renew at T1 (approximately 1/2 hour from the start of the lease), the primary server again determines the desired lifetime, which is still 3 days. It then compares this with the original acknowledged partner lifetime (1/2 hour + 3 days) and adjusts for the time passed since the secondary was last updated (1/2 hour). Thus, the remaining time for the acknowledged partner

interval is 3 days. Adding the MCLT to this yields 3 days plus 1 hour, which is more than the desired lifetime of 3 days. So, the client may have its lease renewed for the desired lifetime -- 3 days.

When the primary DHCP server updates the secondary DHCP server after the DHCP client's renewal REPLY is complete, it will calculate the partner lifetime as the T1 fraction of the actual client lifetime (1/2 of 3 days = 1.5 days). To this it will add the desired lifetime of 3 days, yielding a total partner lifetime of 4.5 days. In this way, the primary attempts to have the secondary always "lead" the client in its understanding of the client's lifetime so as to be able to always offer the client the desired lifetime.

Once the initial actual client lifetime of the MCLT has passed, the failover protocol operates effectively like DHCP does today in its behavior concerning lifetimes. However, the guarantee that the actual client lifetime will never exceed the partner server's remaining acknowledged partner lifetime by more than the MCLT allows full recovery from a variety of DHCP server failures.

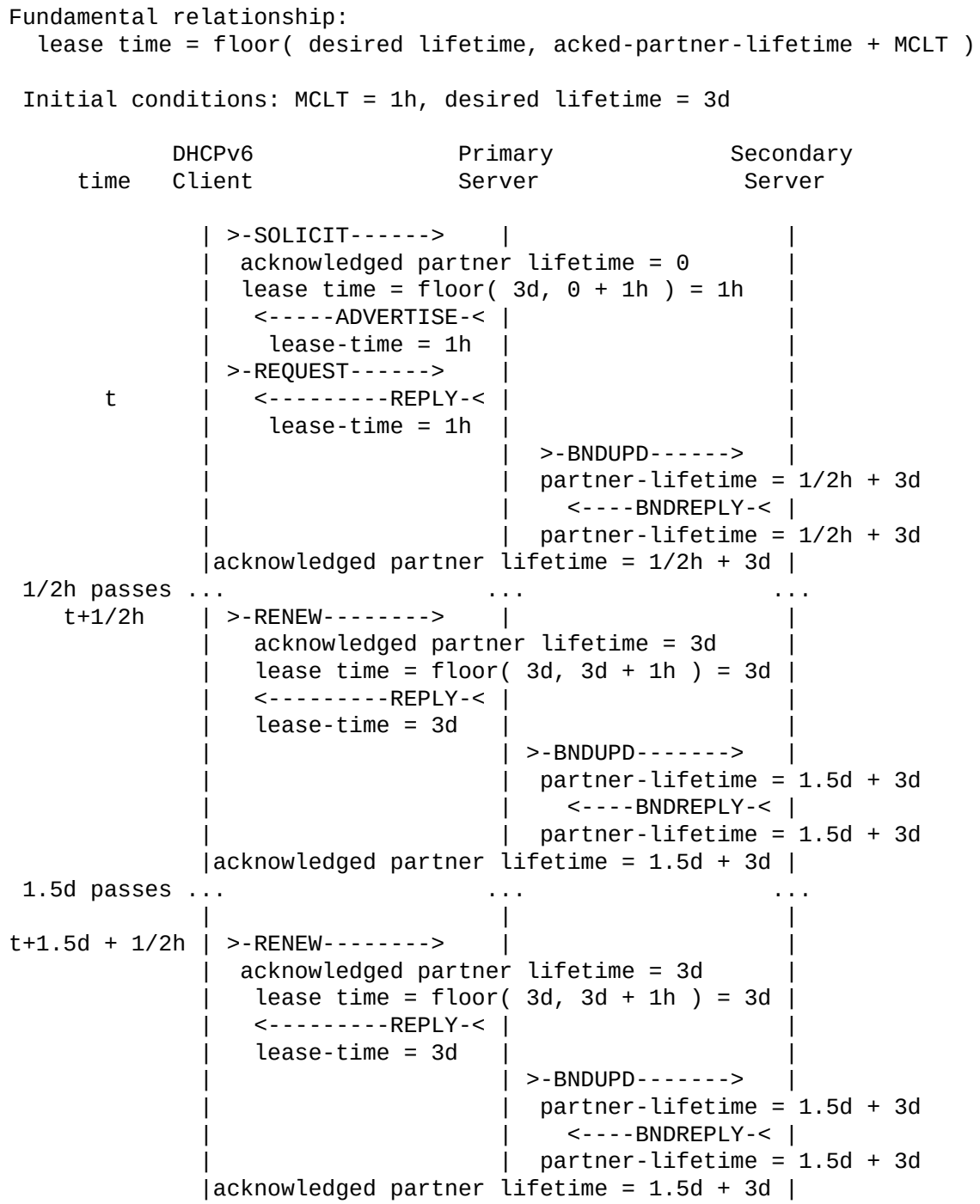


Figure 1: MCLT Example

5. Message and Option Definitions

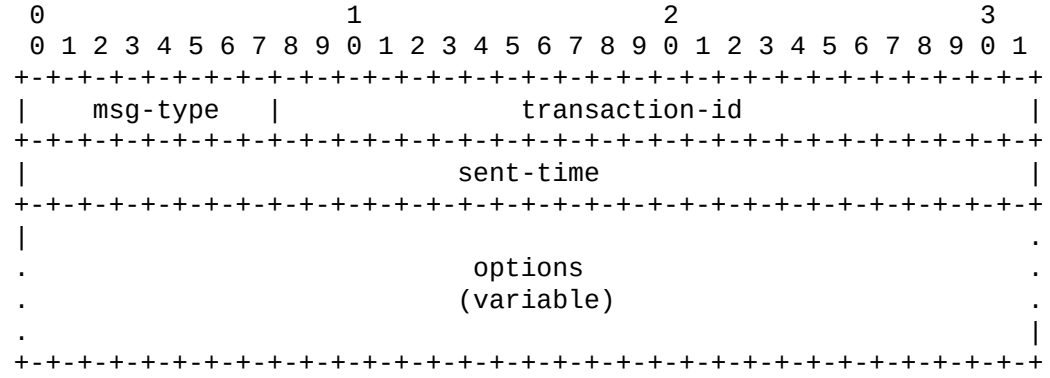
5.1. Message Framing for TCP

Failover communication is conducted over a TCP connection established between the partners. The failover protocol uses the framing format specified in Section 5.1 of "DHCPv6 Bulk Leasequery" [RFC5460] but uses different message types with a different message format, as described in Section 5.2 of this document. The TCP connection between failover servers is made to a specific port -- the dhcp-failover port, port 647. All information is sent over the connection as typical DHCP messages that convey DHCP options, following the format defined in Section 22.1 of [RFC3315].

5.2. Failover Message Format

All failover messages defined below share a common format with a fixed-size header and a variable format area for options. All values in the message header and in any included options are in network byte order.

The following diagram illustrates the format (which is compatible with the format described in Section 6 of [RFC3315]) of DHCP messages exchanged between failover partners:



msg-type — Identifies the DHCP message type; the available message types are listed below.

transaction-id — The transaction-id for this message exchange.

sent-time	The time the message was transmitted (set as close to transmission as practical), in seconds since midnight (UTC), January 1, 2000, modulo 2^32. Used to determine the time skew of the failover partners.
options	Options carried in this message. These options are all defined in the "Option Codes" sub-registry of the "Dynamic Host Configuration Protocol for IPv6 (DHCPv6)" registry. A number of existing DHCPv6 options are used, and several more are defined in this document.

5.3. Messages

The following sections list the new message types defined for failover communication.

5.3.1. BNDUPD

The binding update message, BNDUPD (24), is used to send the binding lease changes to the partner. At most one OPTION_CLIENT_DATA option may appear in a BNDUPD message. Note that not all data in a BNDUPD message is sent in an OPTION_CLIENT_DATA option. Information about delegable prefixes not currently allocated to a particular client is sent in BNDUPD messages but not within OPTION_CLIENT_DATA options. The partner is expected to respond with a BNDREPLY message.

5.3.2. BNDREPLY

The binding acknowledgement message, BNDREPLY (25), is used for confirmation of the received BNDUPD message. It may contain a positive or negative response (e.g., due to a detected lease conflict).

5.3.3. POOLREQ

The pool request message, POOLREQ (26), is used by the secondary server to request allocation of delegable prefixes from the primary server. The primary responds with a POOLRESP message.

5.3.4. POOLRESP

The pool response message, POOLRESP (27), is used by the primary server to indicate that it has received the secondary server's request to ensure that delegable prefixes are balanced between the primary and secondary servers. It does not indicate that all of the BNDUPD messages that might be created from any rebalancing have been sent or responded to; it only indicates reception and acceptance of the task of ensuring that the balance is examined and corrected as necessary.

5.3.5. UPDREQ

The update request message, UPDREQ (28), is used by one server to request that its partner send all binding database changes that have not yet been confirmed. The partner is expected to respond with zero or more BNDUPD messages, followed by an UPDDONE message that signals that all of the BNDUPD messages have been sent and a corresponding BNDREPLY message has been received for each of them.

5.3.6. UPDREQALL

The update request all message, UPDREQALL (29), is used by one server to request that all binding database information present in the other server be sent to the requesting server, in order for the requesting server to recover from a total loss of its binding database. A server receiving this request responds with zero or more BNDUPD messages, followed by an UPDDONE message that signals that all of the BNDUPD messages have been sent and a corresponding BNDREPLY message has been received for each of them.

5.3.7. UPDDONE

The update done message, UPDDONE (30), is used by the server responding to an UPDREQ or UPDREQALL message to indicate that all requested updates have been sent by the responding server and acked by the requesting server.

5.3.8. CONNECT

The connect message, CONNECT (31), is used by the primary server to establish a failover connection with the secondary server and to transmit several important configuration attributes between the servers. The partner is expected to confirm by responding with a CONNECTREPLY message.

5.3.9. CONNECTREPLY

The connect acknowledgement message, CONNECTREPLY (32), is used by the secondary server to respond to a CONNECT message from the primary server.

5.3.10. DISCONNECT

The disconnect message, DISCONNECT (33), is used by either server when closing a connection and shutting down. No response is required for this message. The DISCONNECT message SHOULD contain an OPTION_STATUS_CODE option with an appropriate status. Often, this will be ServerShuttingDown. See Section 5.6. A server SHOULD include a descriptive message as to what caused the disconnect message.

5.3.11. STATE

The state message, STATE (34), is used by either server to inform its partner about a change of failover state. In some cases, it may be used to also inform the partner about the current state, e.g., after connection is established in the COMMUNICATIONS-INTERRUPTED or PARTNER-DOWN states.

5.3.12. CONTACT

The contact message, CONTACT (35), is used by either server to ensure that its partner continues to see the connection as operational. It MUST be transmitted periodically over every established connection if other message traffic is not flowing, and it MAY be sent at any time. See Section 6.5.

5.4. Transaction-id

The initiator of a message exchange MUST set the transaction-id (see Section 5.2). This means that all of the messages above except BNDREPLY, POOLRESP, UPDDONE, and CONNECTREPLY must set the transaction-id. The transaction-id MUST be unique among all currently outstanding messages sent to the failover partner. A straightforward way to ensure this is to simply use an incrementing value, with one caveat: The UPDREQ and UPDREQALL messages may be separated by a considerable time prior to the receipt of an UPDDONE message. While the usual pattern of message exchange would have the partner doing the vast majority of message initiation, it is remotely possible that the partner that initiated the UPDREQ or UPDREQALL messages might also send enough messages to wrap the 24-bit transaction-id and duplicate the transaction-id of the outstanding UPDREQ or UPDREQALL messages. Thus, it is important to ensure that

the transaction-id of a currently outstanding UPDREQ or UPDREQALL message is not replicated in any message initiated prior to the receipt of the corresponding UPDDONE message.

5.5. Options

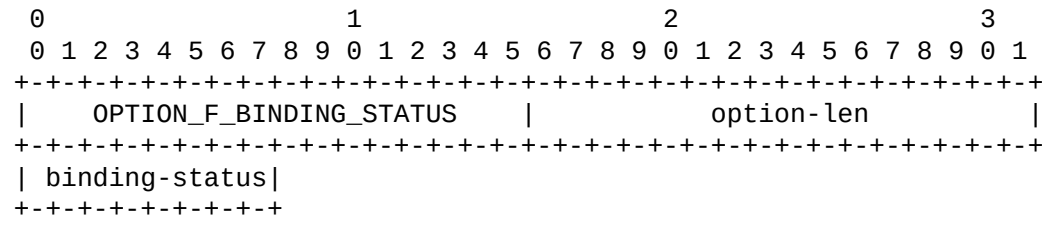
The following new options are defined.

5.5.1. OPTION_F_BINDING_STATUS

The binding-status is an implementation-independent representation of the status (or the state) of a lease on an IPv6 address or prefix.

This is an unsigned byte.

The code for this option is 114.



option-code	OPTION_F_BINDING_STATUS (114)
option-len	1
binding-status	The binding-status. See below:

Value	binding-status
0	reserved
1	ACTIVE
2	EXPIRED
3	RELEASED
4	PENDING-FREE
5	FREE
6	FREE-BACKUP
7	ABANDONED
8	RESET

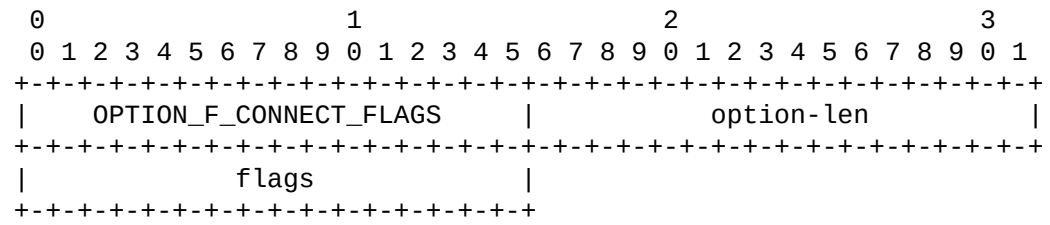
The binding-status values are discussed in Section 7.2.

5.5.2. OPTION_F_CONNECT_FLAGS

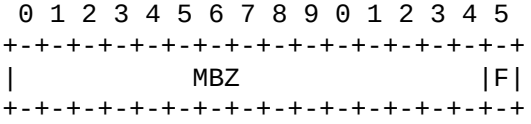
This option provides flags that indicate attributes of the connecting server.

This option consists of an unsigned 16-bit integer in network byte order.

The code for this option is 115.



option-code	OPTION_F_CONNECT_FLAGS (115)
option-len	2
flags	flag bits. See below:



The bits (numbered from the most significant bit in network byte order) are used as follows:

0-14: MBZ
Must be zero.

15 (F): FIXED_PD_LENGTH
Set to 1 to indicate that all prefixes delegated from a given delegable prefix have the same prefix length (size). If this is not set, the prefixes delegated from one delegable prefix may have different sizes.

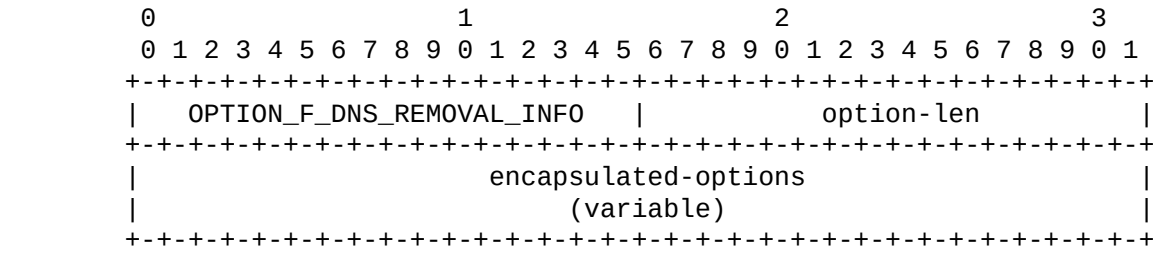
If the FIXED_PD_LENGTH bit is not set, it indicates that prefixes of a range of sizes can be delegated from a given delegable prefix. Note that if the FIXED_PD_LENGTH bit is set, each delegable prefix may have its own fixed size -- this flag does not imply that all prefixes delegated will be the same size, but rather that all prefixes delegated from the same delegable prefix will be the same size.

If the FIXED_PD_LENGTH bit is set, the length used for each prefix is specified independently of the failover protocol but must be known to both failover partners. It might be specified in the configuration for each delegable prefix, or it might be fixed for the entire server.

5.5.3. OPTION_F_DNS_REMOVAL_INFO

This option contains the information necessary to remove a DNS name that was entered by the failover partner.

The code for this option is 116.



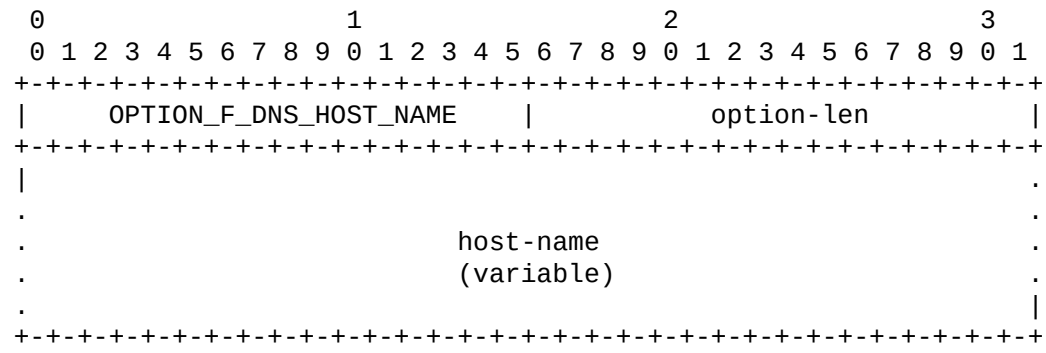
option-code	OPTION_F_DNS_REMOVAL_INFO (116)
option-len	variable
options	Three possible encapsulated options: OPTION_F_DNS_HOST_NAME OPTION_F_DNS_ZONE_NAME OPTION_F_DNS_FLAGS

5.5.3.1. OPTION_F_DNS_HOST_NAME

This option contains the hostname that was entered into the DNS by the failover partner.

This is a DNS name encoded using the format specified in [RFC1035], as also specified in Section 8 of [RFC3315].

The code for this option is 117.



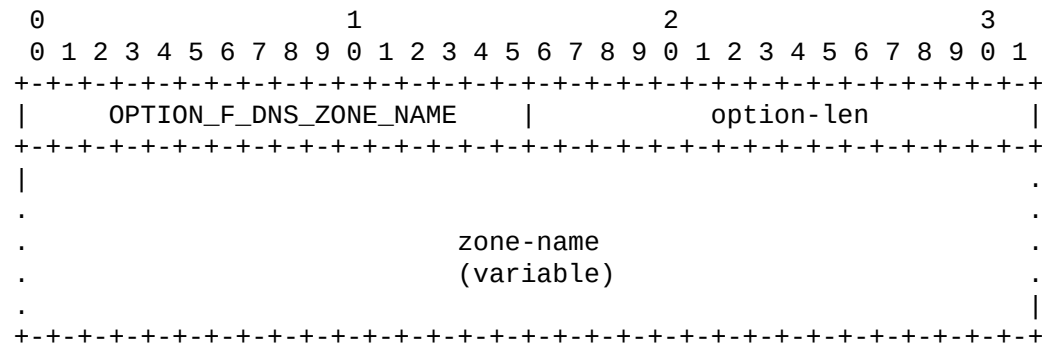
option-code OPTION_F_DNS_HOST_NAME (117)
option-len length of host-name
host-name hostname encoded per RFC 1035

5.5.3.2. OPTION_F_DNS_ZONE_NAME

This option contains the zone name that was entered into the DNS by the failover partner.

This is a DNS name encoded using the format specified in [RFC1035], as also specified in Section 8 of [RFC3315].

The code for this option is 118.



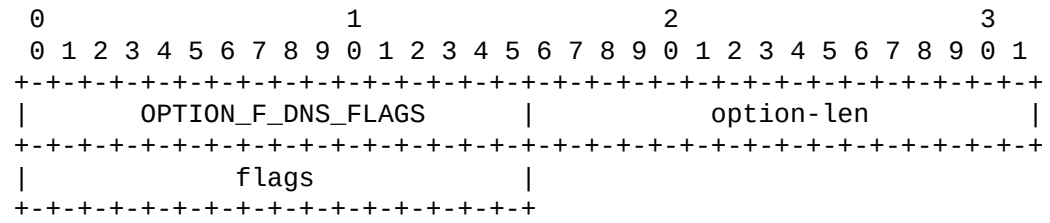
```
option-code       OPTION_F_DNS_ZONE_NAME (118)
option-len        length of zone-name
zone-name         zone name encoded per RFC 1035
```

5.5.3.3. OPTION_F_DNS_FLAGS

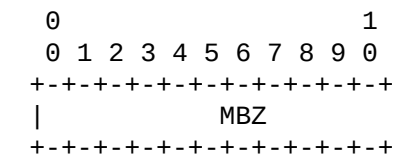
This option provides flags that indicate what needs to be done to remove this DNS name.

This option consists of an unsigned 16-bit integer in network byte order.

The code for this option is 119.




```
option-code       OPTION_F_DNS_FLAGS (119)
option-len        2
flags             flag bits.  See below:
```



The bits (numbered from the most significant bit in network byte order) are used as follows:

```
0-11:   MBZ
        Must be zero.
12 (U): USING_REQUESTED_FQDN
        Set to 1 to indicate that the name used came from the
        Fully Qualified Domain Name (FQDN) that was received
        from the client.
13 (S): SYNTHESIZED_NAME
        Set to 1 to indicate that the name was synthesized
        based on some algorithm.
14 (R): REV_UPTODATE
        Set to 1 to indicate that the reverse zone is up to date.
15 (F): FWD_UPTODATE
        Set to 1 to indicate that the forward zone is up to date.
```

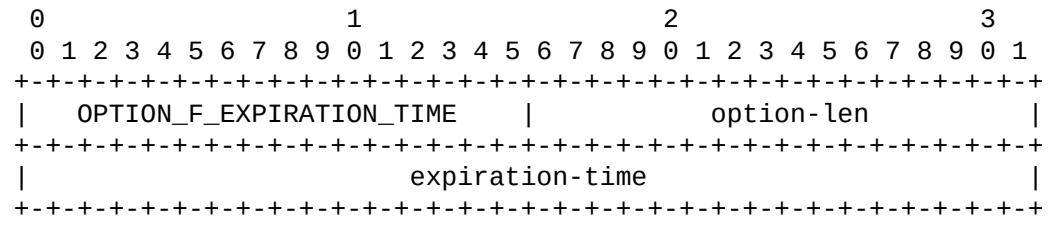
If both the U bit and the S bit are unset, then the name must have been provided from some alternative configuration, such as client registration in some database accessible to the DHCP server.

5.5.4. OPTION_F_EXPIRATION_TIME

This option specifies the greatest lifetime that this server has ever acked to its partner in a BNDREPLY message for a particular lease or prefix. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 120.



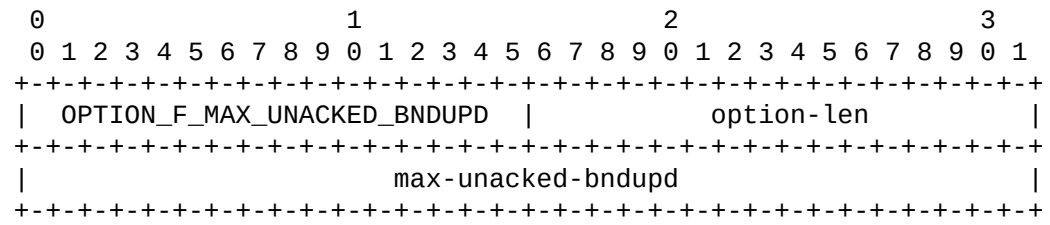
option-code	OPTION_F_EXPIRATION_TIME (120)
option-len	4
expiration-time	The expiration time. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.5.5. OPTION_F_MAX_UNACKED_BNDUPD

This option specifies the maximum number of BNDUPD messages that this server is prepared to accept over the TCP connection without causing the TCP connection to block.

This is an unsigned 32-bit integer in network byte order.

The code for this option is 121.



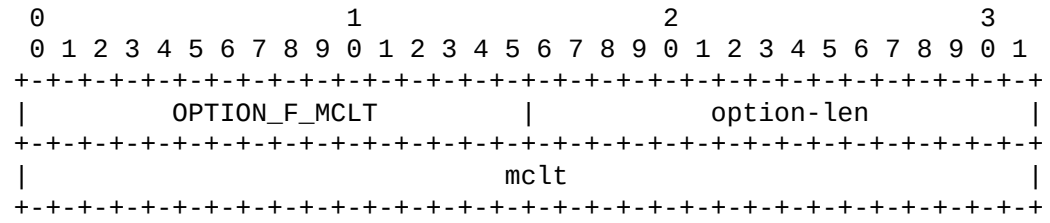
option-code	OPTION_F_MAX_UNACKED_BNDUPD (121)
option-len	4
max-unacked-bndupd	Maximum number of unacked BNDUPD messages allowed

5.5.6. OPTION_F_MCLT

The Maximum Client Lead Time (MCLT) is the upper bound on the difference allowed between the valid lifetime provided to a DHCP client by a server and the valid lifetime known by that server's failover partner. It is an interval, measured in seconds. See Section 4.4.

This is an unsigned 32-bit integer in network byte order.

The code for this option is 122.



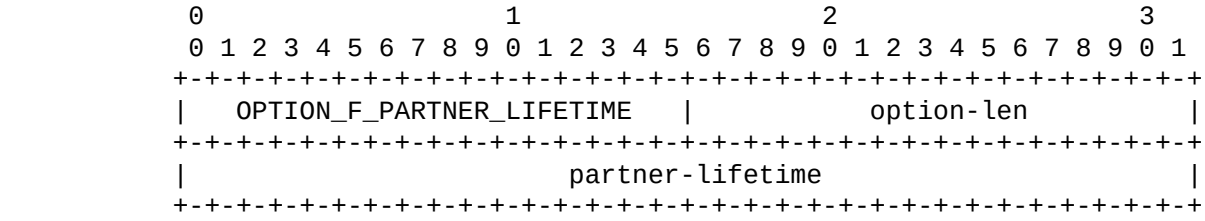
option-code	OPTION_F_MCLT (122)
option-len	4
mclt	The MCLT, in seconds

5.5.7. OPTION_F_PARTNER_LIFETIME

This option specifies the time after which the partner can consider an IPv6 address expired and is able to reuse the IPv6 address. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 123.



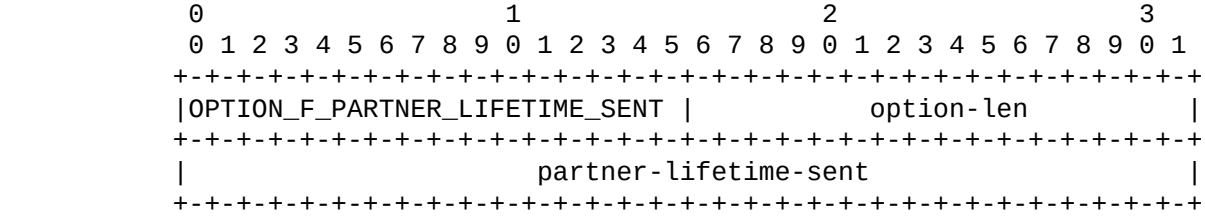
option-code	OPTION_F_PARTNER_LIFETIME (123)
option-len	4
partner-lifetime	The partner lifetime. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.5.8. OPTION_F_PARTNER_LIFETIME_SENT

This option indicates the time that was received in an OPTION_F_PARTNER_LIFETIME option (Section 5.5.7). This is an exact duplicate (echo) of the time received in the OPTION_F_PARTNER_LIFETIME option; it is not adjusted in any way. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 124.



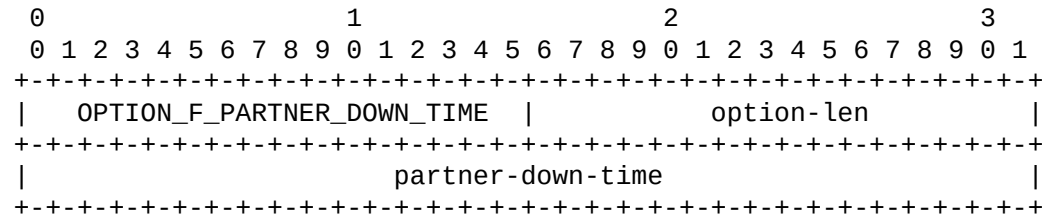
option-code	OPTION_F_PARTNER_LIFETIME_SENT (124)
option-len	4
partner-lifetime-sent	The partner-lifetime received in an OPTION_F_PARTNER_LIFETIME option. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.5.9. OPTION_F_PARTNER_DOWN_TIME

This option specifies the time that the server most recently lost communications with its failover partner. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 125.



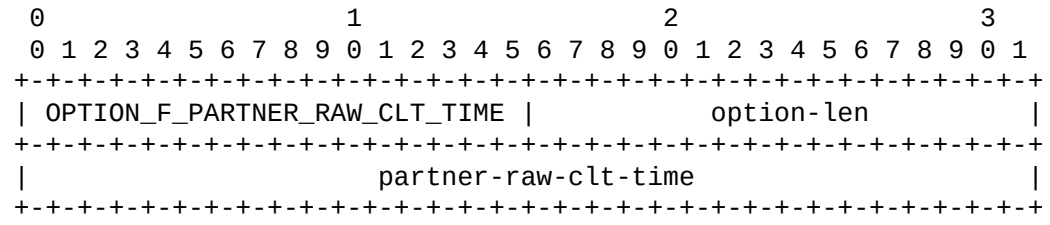
option-code	OPTION_F_PARTNER_DOWN_TIME (125)
option-len	4
partner-down-time	Contains the PARTNER-DOWN time. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.5.10. OPTION_F_PARTNER_RAW_CLT_TIME

This option specifies the time when the partner most recently interacted with the DHCP client associated with this IPv6 address or prefix. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 126.



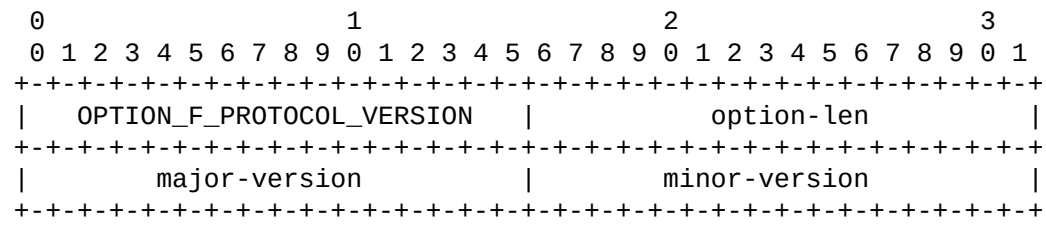
option-code	OPTION_F_PARTNER_RAW_CLT_TIME (126)
option-len	4
partner-raw-clt-time	Contains the partner-raw-clt-time. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.5.11. OPTION_F_PROTOCOL_VERSION

The protocol version allows one failover partner to determine the version of the protocol being used by the other partner, to allow for changes and upgrades in the future. Two components are provided, to allow large and small changes to be represented in one 32-bit number. The intent is that large changes would result in an increment of the value of major-version, while small changes would result in an increment of the value of minor-version. As subsequent updates and extensions of this document can define changes to these values in any way deemed appropriate, no attempt is made to further define "large" and "small" in this document.

This option consists of two unsigned 16-bit integers in network byte order.

The code for this option is 127.



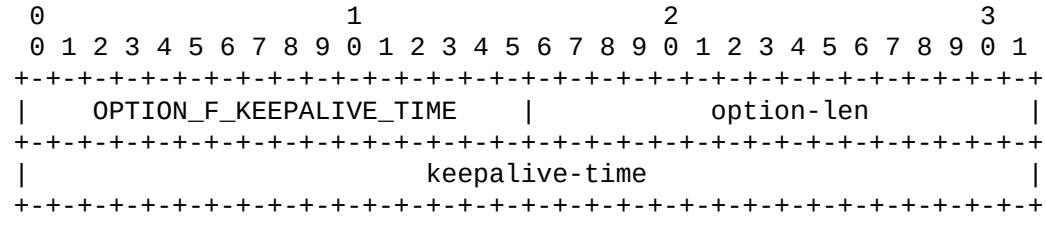
option-code	OPTION_F_PROTOCOL_VERSION (127)
option-len	4
major-version	The major version of the protocol. Initially 1.
minor-version	The minor version of the protocol. Initially 0.

5.5.12. OPTION_F_KEEPALIVE_TIME

This option specifies the number of seconds (an interval) within which the server must receive a message from its partner, or it will assume that communications from the partner are not "OK".

This is an unsigned 32-bit integer in network byte order.

The code for this option is 128.

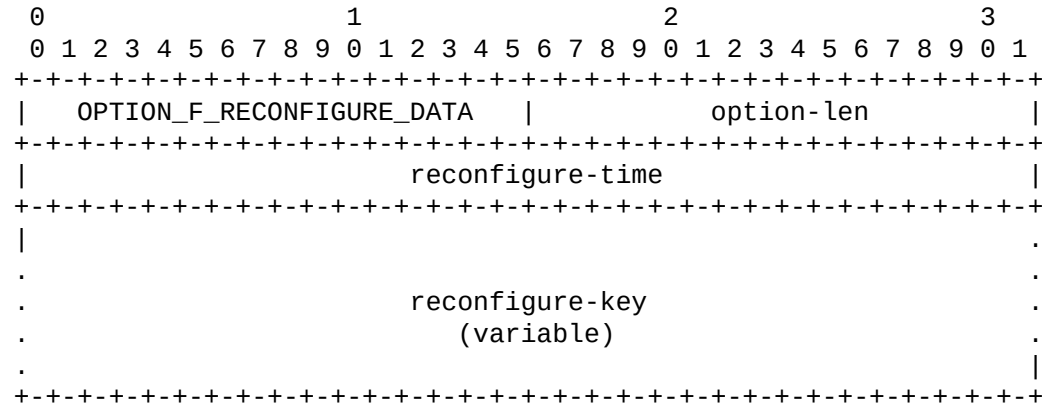


option-code	OPTION_F_KEEPALIVE_TIME (128)
option-len	4
receive-time	The keepalive-time. An interval of seconds.

5.5.13. OPTION_F_RECONFIGURE_DATA

This option contains the information necessary for one failover partner to use the reconfigure-key created on the other failover partner.

The code for this option is 129.



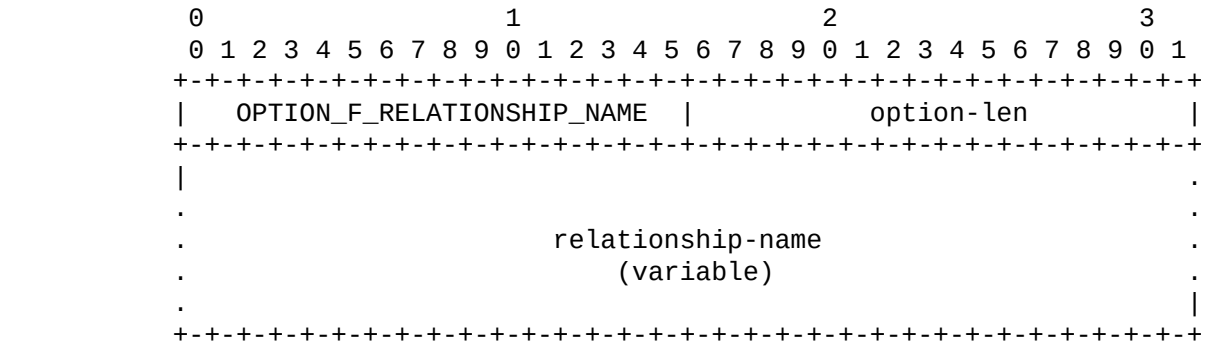
option-code	OPTION_F_RECONFIGURE_DATA (129)
option-len	4 + length of reconfigure-key
reconfigure-time	Time at which reconfigure-key was created. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).
reconfigure-key	The reconfigure key

5.5.14. OPTION_F_RELATIONSHIP_NAME

This option specifies a name for this failover relationship. It is used to distinguish between relationships when there are multiple failover relationships between two failover servers.

This is a UTF-8 encoded text string suitable for display to an end user. It MUST NOT be null-terminated.

The code for this option is 130.



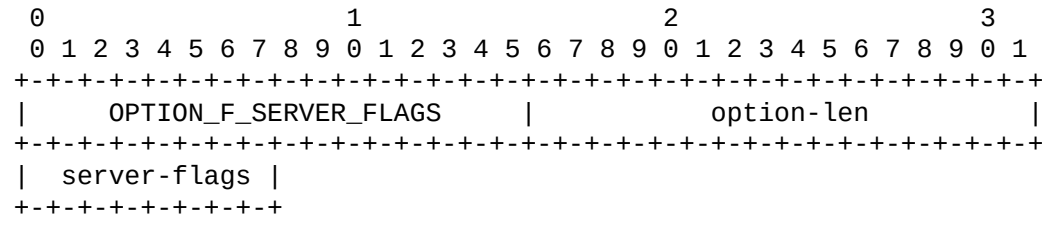
option-code	OPTION_F_RELATIONSHIP_NAME (130)
option-len	length of relationship-name
relationship-name	A UTF-8 encoded text string suitable for display to an end user. MUST NOT be null-terminated.

5.5.15. OPTION_F_SERVER_FLAGS

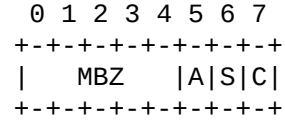
The OPTION_F_SERVER_FLAGS option specifies information associated with the failover endpoint sending the option.

This is an unsigned byte.

The code for this option is 131.



option-code OPTION_F_SERVER_FLAGS (131)
option-len 1
server-flags The server flags. See below:



The bits (numbered from the most significant bit in network byte order) are used as follows:

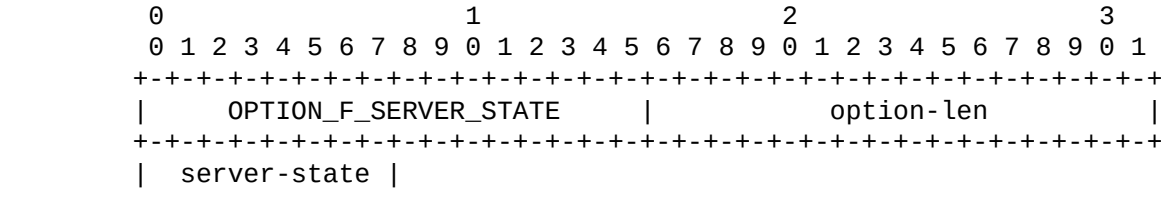
0-4: MBZ
Must be zero.
5 (A): ACK_STARTUP
Set to 1 to indicate that the OPTION_F_SERVER_FLAGS option that was most recently received contained the STARTUP bit set.
6 (S): STARTUP
MUST be set to 1 whenever the server is in STARTUP state.
7 (C): COMMUNICATED
Set to 1 to indicate that the sending server has communicated with its partner.

5.5.16. OPTION_F_SERVER_STATE

The OPTION_F_SERVER_STATE option specifies the endpoint state of the server sending the option.

This is an unsigned byte.

The code for this option is 132.



option-code OPTION_F_SERVER_STATE (132)
option-len 1
server-state Failover endpoint state

Value	Server State	
0	reserved	
1	STARTUP	Startup state (1)
2	NORMAL	Normal state
3	COMMUNICATIONS-INTERRUPTED	Communications interrupted
4	PARTNER-DOWN	Partner down
5	POTENTIAL-CONFLICT	Synchronizing
6	RECOVER	Recovering bindings from partner
7	RECOVER-WAIT	Waiting out MCLT after RECOVER
8	RECOVER-DONE	Interlock state prior to NORMAL
9	RESOLUTION-INTERRUPTED	Comm. failed during resolution
10	CONFLICT-DONE	Primary resolved its conflicts

These states are discussed in detail in Section 8.

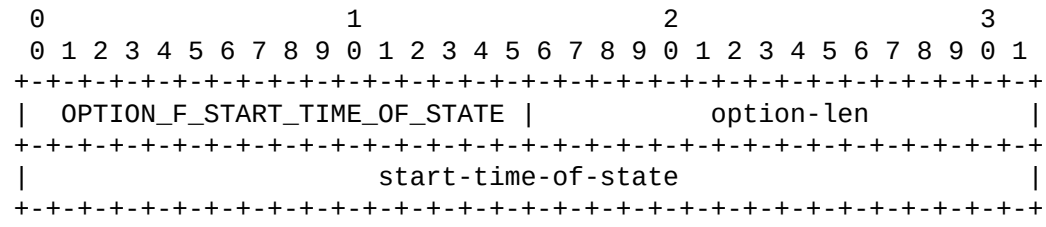
(1) The STARTUP state is never sent to the partner server; it is indicated by the STARTUP bit in the OPTION_F_SERVER_FLAGS option (see Section 8.3).

5.5.17. OPTION_F_START_TIME_OF_STATE

The OPTION_F_START_TIME_OF_STATE option specifies the time at which the associated state began to hold its current value. When this option appears in a STATE message, the state to which it refers is the server endpoint state. When it appears in an IA_NA-options, IA_TA-options, or IA_PD-options field, the state to which it refers is the binding-status value in the OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD option, respectively. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

This is an unsigned 32-bit integer in network byte order.

The code for this option is 133.



option-code	OPTION_F_START_TIME_OF_STATE (133)
option-len	4
start-time-of-state	The start time of the current state. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

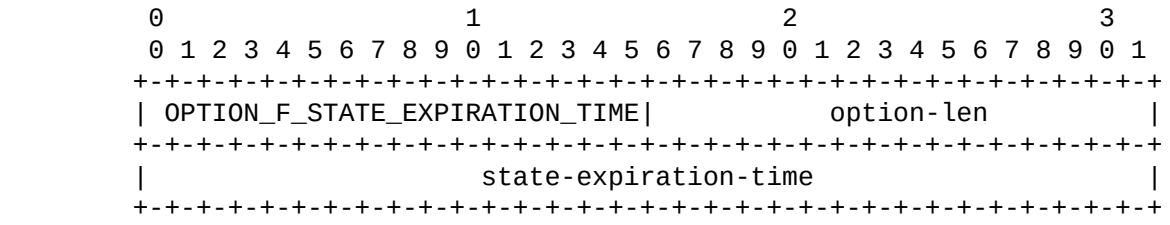
5.5.18. OPTION_F_STATE_EXPIRATION_TIME

The OPTION_F_STATE_EXPIRATION_TIME option specifies the time at which the current state of this lease will expire. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

Note that states other than ACTIVE may have a time associated with them. In particular, EXPIRED might have a time associated with it, in the event that some sort of "grace period" existed where the lease would not be reused for a period after the lease expired. The ABANDONED state might have a time associated with it, in the event that the servers participating in failover had a time after which an ABANDONED lease might be placed back into a pool for allocation to a client. In general, if there is an OPTION_STATE_EXPIRATION_TIME associated with a particular state, that indicates that the associated state will expire and move to a different state at that time.

This is an unsigned 32-bit integer in network byte order.

The code for this option is 134.



option-code	OPTION_F_STATE_EXPIRATION_TIME (134)
option-len	4
state-expiration-time	The time at which the current state of the lease will expire. This MUST be an absolute time (i.e., seconds since midnight January 1, 2000 UTC, modulo 2^32).

5.6. Status Codes

The following new status codes are defined to be used in the OPTION_STATUS_CODE option.

AddressInUse (16)
: One client on one server has leases that are in conflict with the leases that the client has on another server. Alternatively, the address could be associated with a different Identity Association Identifier (IAID) on each server.

ConfigurationConflict (17)
: The configuration implied by the information in a BNDUPD message (e.g., the IPv6 address or prefix address) is in direct conflict with the information known to the receiving server.

MissingBindingInformation (18)
: There is insufficient information in a BNDUPD message to effectively process it.

OutdatedBindingInformation (19)
: The information in a server's binding database conflicts with the information found in an incoming BNDUPD message and the server believes that the information in its binding database more accurately reflects reality.

ServerShuttingDown (20)
: The server is undergoing an operator-directed or otherwise planned shutdown.

DNSUpdateNotSupported (21)
A server receives a BNDUPD message with DNS update information included and the server doesn't support DNS update.

ExcessiveTimeSkew (22)
A server detects that the time skew between its current time and its partner's current time is greater than 5 seconds.

6. Connection Management

Communication between failover partners takes place over a long-lived TCP connection. This connection is always initiated by the primary server, and if the long-lived connection is lost it is the responsibility of the primary server to attempt to reconnect to the secondary server. The detailed process used by the primary server when initiating a connection and by the secondary server when responding to a connection attempt as documented in Section 6.1 is followed each time a connection is established, regardless of any previous connection between the failover partners.

6.1. Creating Connections

Every primary server implementing the failover protocol MUST periodically attempt to create a TCP connection to the dhcp-failover port (647) of all of its configured partners, where the period is implementation dependent and SHOULD be configurable. In the event that a connection has been rejected by a CONNECTREPLY message with an OPTION_STATUS_CODE option contained in it or a DISCONNECT message, a server SHOULD reduce the frequency with which it attempts to connect to that server, but it MUST continue to attempt to connect periodically.

Every secondary server implementing the failover protocol MUST listen for TCP connection attempts on the dhcp-failover port (647) from a primary server.

After a primary server successfully establishes a TCP connection to a secondary server, it MUST continue the connection process as described in Section 8.2 of [RFC7653]. In the language of that section, the primary failover server operates as the "requestor" and the secondary failover server operates as the "DHCP server". The message that is sent over the newly established connection is a CONNECT message, instead of an ACTIVELEASEQUERY message.

When a secondary server receives a connection attempt, the only information that the secondary server has is the IP address of the partner initiating a connection. If it has any relationships with the connecting server for which it is a secondary server, it should

operate as described in Section 9.1 of [RFC7653], with the exception that instead of waiting for an Active Leasequery message it will wait for a CONNECT message. Once it has received the CONNECT message, it will use the information in that message to determine which relationship this connection is to service.

If it has no secondary relationships with the connecting server, it MUST drop the connection.

To summarize -- a primary server MUST use a connection that it has initiated in order to send a CONNECT message. Every server that is a secondary server in a relationship MUST listen for CONNECT messages from the primary server.

When the CONNECT and CONNECTREPLY exchange successfully produces a working failover connection, the next message sent over a new connection is a STATE message. See Section 6.3. Upon the receipt of the STATE message, the receiver can consider communications "OK".

6.1.1. Sending a CONNECT Message

The CONNECT message is sent with information about the failover configuration on the primary server. The message MUST contain at least the following information in the options area:

- OPTION_F_PROTOCOL_VERSION containing the protocol version that the primary server will use when sending failover messages.

- OPTION_F_MCLT containing the configured MCLT.

- OPTION_F_KEEPALIVE_TIME containing the number of seconds (an interval) within which the server must receive a message from its partner, or it will assume that communications from the partner are not "OK".

- OPTION_F_MAX_UNACKED_BNDUPD containing the maximum number of BNDUPD messages that this server is prepared to accept over the failover connection without causing the connection to block. This implements application-level flow control over the connection, so that a flood of BNDUPD messages does not cause the connection to block and thereby prevent other messages from being transmitted over the connection and received by the failover partner.

- OPTION_F_RELATIONSHIP_NAME containing the name of the failover relationship to which this connection applies. If there is no OPTION_F_RELATIONSHIP_NAME in the CONNECT message, it indicates that there is only a single relationship between this pair of primary and secondary servers.

- OPTION_F_CONNECT_FLAGS containing information about certain attributes of the connecting servers.

6.1.2. Receiving a CONNECT Message

A server receiving a CONNECT message must process the information in the message and decide whether or not to accept the connection. The processing is performed as follows:

- sent-time - The secondary server checks the sent-time to see if it is within 5 seconds of its current time. See Section 7.1. If it is not, return ExcessiveTimeSkew in the OPTION_STATUS_CODE to reject the CONNECT message.

- OPTION_F_PROTOCOL_VERSION - The secondary server decides if the protocol version of the primary server is supported by the secondary server. If it is not, return NotSupported in the OPTION_STATUS_CODE to reject the CONNECT message.

- OPTION_F_MCLT - Use this MCLT supplied by the primary server. Remember this MCLT, and use it until a different MCLT is supplied by some subsequent CONNECT message.

- OPTION_F_KEEPALIVE_TIME - Remember the keepalive-time as the FO_KEEPALIVE_TIME (Section 6.5) when implementing the Unreachability Detection algorithm described in Section 6.6.

- OPTION_F_MAX_UNACKED_BNDUPD - Ensure that the maximum amount of unacked BNDUPD messages queued to the primary server never exceeds the value in the OPTION_F_MAX_UNACKED_BNDUPD option.

- OPTION_F_CONNECT_FLAGS - Ensure that the secondary server can process information from the primary server as specified in the flags. For example, if the secondary server cannot process prefix delegation with variable-sized prefixes delegated from the same delegable prefix and the primary server says that it can, the secondary should reject the connection.

A CONNECT message SHOULD always be followed by a CONNECTREPLY message, to either (1) accept the connection or (2) reject the connection by including an OPTION_STATUS_CODE option with a status-code indicating the reason for the rejection. If accepting the connection attempt, then send a CONNECTREPLY message with the following information:

- OPTION_F_PROTOCOL_VERSION containing the protocol version being used by the secondary server when sending failover messages.

- OPTION_F_MCLT containing the MCLT currently in use on the secondary server. This MUST equal the MCLT that was in the OPTION_F_MCLT option in the CONNECT message.

- OPTION_F_KEEPALIVE_TIME containing the number of seconds (an interval) within which the server must receive a message from its partner, or it will assume that communications from the partner are not "OK".

- OPTION_F_MAX_UNACKED_BNDUPD containing the maximum number of BNDUPD messages that this server is prepared to accept over the failover connection without causing the connection to block. This implements application-level flow control over the connection, so that a flood of BNDUPD messages does not cause the connection to block and thereby prevent other messages from being transmitted over the connection and received by the failover partner.

- OPTION_F_CONNECT_FLAGS containing information describing the attributes of the secondary server that the primary needs to know about.

After sending a CONNECTREPLY message to accept the primary server's CONNECT message, the secondary server MUST send a STATE message (see Section 6.3).

6.1.3. Receiving a CONNECTREPLY Message

A server receiving a CONNECTREPLY message must process the information in the message and decide whether or not to continue to employ the connection. The processing is performed as follows:

- OPTION_F_PROTOCOL_VERSION - The primary server decides if the protocol version in use by the secondary server is supported by the primary server. If it is not, send a DISCONNECT message and drop the connection. If it is supported, continue processing. It is possible that the primary and secondary servers will each be sending different versions of the protocol to the other server.

The extent to which this is supported will be defined partly by as-yet-unknown differences in the protocols that the versions represent and partly by the capabilities of the two implementations involved in the failover relationship.

- OPTION_F_MCLT - Compare the MCLT received with the configured MCLT. If they are different, send a DISCONNECT message and drop the connection.

- OPTION_F_KEEPALIVE_TIME - Remember the keepalive-time as the FO_KEEPALIVE_TIME (Section 6.5) when implementing the Unreachability Detection algorithm described in Section 6.6.

- OPTION_F_MAX_UNACKED_BNDUPD - Ensure that the maximum amount of unacked BNDUPD messages queued to the secondary server never exceeds the value in the OPTION_F_MAX_UNACKED_BNDUPD option.

- OPTION_F_CONNECT_FLAGS - Ensure that the primary server can process information from the secondary server as specified in the flags. For example, if the primary server cannot process prefix delegation with variable-sized prefixes delegated from the same delegable prefix and the secondary server says that it can, the primary should drop the connection.

After receiving a CONNECTREPLY message that accepted the primary server's CONNECT message, the primary server MUST send a STATE message (see Section 6.3).

6.2. Endpoint Identification

A failover endpoint is always associated with a set of DHCP prefixes that are configured on the DHCP server where the endpoint appears. A DHCP prefix MUST NOT be associated with more than one failover endpoint.

The failover protocol SHOULD be configured with one failover relationship between each pair of failover servers. In this case, there is one failover endpoint for that relationship on each failover partner. This failover relationship MUST have a unique name.

Any failover endpoint can take actions and hold unique states.

This document frequently describes the behavior of the failover protocol in terms of primary and secondary servers, not primary and secondary failover endpoints. However, it is important to remember that every "server" described in this document is in reality a failover endpoint that resides in a particular process and that several failover endpoints may reside in the same server process.

It is not the case that there is a unique failover endpoint for each prefix that participates in a failover relationship. On one server, there is (typically) one failover endpoint per partner, regardless of how many prefixes are managed by that combination of partner and role. On a particular server, any given prefix that participates in failover will be associated with exactly one failover endpoint.

When a connection is received from the partner, the unique failover endpoint to which the message is directed is determined solely by the IPv6 address of the partner, the relationship name, and the role of the receiving server.

6.3. Sending a STATE Message

A server MUST send a STATE message to its failover partner whenever the state of the failover endpoint changes. Sending the occasional duplicate STATE message will not cause any problems; note, however, that not updating the failover partner with information about a failover endpoint state change can, in many cases, cause the entire failover protocol to be inoperative.

The STATE message is sent with information about the endpoint state of the failover relationship. The STATE message MUST contain at least the following information in the options area:

- OPTION_F_SERVER_STATE containing the state of this failover endpoint.
- OPTION_F_SERVER_FLAGS containing the flag values associated with this failover endpoint.
- OPTION_F_START_TIME_OF_STATE containing the time when this became the state of this failover endpoint.
- OPTION_F_PARTNER_DOWN_TIME containing the time that this failover endpoint went into PARTNER-DOWN state if this server is in PARTNER-DOWN state. If this server isn't in PARTNER-DOWN state, do not include this option.

The server sending a STATE message SHOULD ensure that this information is written to stable storage prior to enqueuing it to its failover partner.

6.4. Receiving a STATE Message

A server receiving a STATE message must process the information in the message and decide how to react to the information. The processing is performed as follows:

- OPTION_F_SERVER_STATE - If this represents a change in state for the failover partner, react according to the instructions in Section 8.1. If the state is not PARTNER-DOWN, clear any memory of the partner-down-time.

- OPTION_F_SERVER_FLAGS - Remember these flags in an appropriate data area so they can be referenced later.

- OPTION_F_START_TIME_OF_STATE - Remember this information in an appropriate data area so it can be referenced later.

- OPTION_F_PARTNER_DOWN_TIME - If the value of the OPTION_F_SERVER_STATE is PARTNER-DOWN, remember this information in an appropriate data area so it can be referenced later.

A server receiving a STATE message SHOULD ensure that this information is written to stable storage.

6.5. Connection Maintenance Parameters

The following parameters and timers are used to ensure the integrity of the connections between two failover servers.

Parameter	Default	Description
FO_KEEPALIVE_TIMER	timer	counts down to time connection assumed dead due to lack of messages
FO_KEEPALIVE_TIME	60	maximum time server will consider connection still up with no messages
FO_CONTACT_PER_KEEPALIVE_TIME	4	number of CONTACT messages to send during partner's FO_KEEPALIVE_TIME period
FO_SEND_TIMER	timer	counts down to time to send next CONTACT message

FO_SEND_TIME	15	maximum time to wait between sending CONTACT messages if no other traffic. Created from partner's FO_KEEPALIVE_TIME divided by FO_CONTACT_PER_KEEPALIVE_TIME

6.6. Unreachability Detection

Each partner MUST maintain an FO_SEND_TIMER for each failover connection. The FO_SEND_TIMER for a particular connection is reset to FO_SEND_TIME every time any message is transmitted on that connection, and the timer counts down once per second. If the timer reaches zero, a CONTACT message is transmitted on that connection and the timer for that connection is reset to FO_SEND_TIME. The CONTACT message may be transmitted at any time. An implementation MAY use additional mechanisms to detect partner unreachability.

The FO_SEND_TIME is initialized from the configured FO_KEEPALIVE_TIME divided by FO_CONTACT_PER_KEEPALIVE_TIME. When a CONNECT or CONNECTREPLY message is received on a connection, the received OPTION_F_KEEPALIVE_TIME option is checked, and the value in that option is used to calculate the FO_SEND_TIME for that connection by dividing the value received by the configured FO_CONTACT_PER_KEEPALIVE_TIME.

Each partner MUST maintain an FO_KEEPALIVE_TIMER for each failover connection. This timer is initialized to FO_KEEPALIVE_TIME and counts down once per second. It is reset to FO_KEEPALIVE_TIME whenever a message is received on that connection. If it ever reaches zero, that connection is considered dead. In addition, the FO_KEEPALIVE_TIME for that connection MUST be sent to the failover partner on every CONNECT or CONNECTREPLY message in the OPTION_F_KEEPALIVE_TIME option.

7. Binding Updates and Acks

7.1. Time Skew

Partners exchange information about known lease states. To reliably compare a known lease state with an update received from a partner, servers must be able to reliably compare the times stored in the known lease state with the times received in the update. The failover protocol adopts the simple approach of requiring that the failover partners use some mechanism to synchronize the clocks on the two servers to within an accuracy of roughly 5 seconds.

A mechanism to measure and track relative time differences between servers is necessary to ensure this synchronization. To do so, each message contains the time of the transmission in the sent-time field of the message (see Section 5.2). The transmitting server MUST set this as close to the actual transmission as possible. The receiving partner MUST store its own timestamp of reception as close to the actual reception as possible. The received timestamp information is then compared with the local timestamp.

7.2. Information Model

In most DHCP servers, a lease on an IPv6 address or a prefix can take on several different binding-status values, sometimes also called "lease states". While no two DHCP server implementations will have exactly the same possible binding-status values, [RFC3315] enforces some commonality among the general semantics of the binding-status values used by various DHCP server implementations.

In order to transmit binding database updates between one server and another using the failover protocol, some common binding-status values must be defined. It is not expected that these values correspond to any actual implementation of DHCPv6 in a DHCP server, but rather that the binding-status values defined in this document should be convertible back and forth between those defined below and those in use by many DHCP server implementations.

The lease binding-status values defined for the failover protocol are listed below. Unless otherwise noted below, there MAY be client information associated with each of these binding-status values.

ACTIVE - The lease is assigned to a client. Client identification data MUST appear.

EXPIRED - This value indicates that a client's binding on a given lease has expired. When the partner acks the BNDUPD message of an expired lease, the server sets its internal state to PENDING-FREE. Client identification SHOULD appear.

RELEASED - This value indicates that a client sent a RELEASE message. When the partner acks the BNDUPD message of a released lease, the server sets its internal state to PENDING-FREE. Client identification SHOULD appear.

PENDING-FREE - Once a lease is expired or released, its state becomes PENDING-FREE. Depending on which algorithm was used to allocate a given lease, PENDING-FREE may mean either FREE or FREE-BACKUP. Implementations do not have to implement this PENDING-FREE state but may choose to switch to the destination state directly. For clarity of representation, this transitional PENDING-FREE state is treated as a separate state.

FREE - This value is used when a DHCP server needs to communicate that a lease is unused by any client, but it was not just released, expired, or reset by a network administrator. When the partner acks the BNDUPD message of a FREE lease, the server marks the lease as available for assignment by the primary server. Note that on a secondary server running in PARTNER-DOWN state, after waiting the MCLT, the lease MAY be allocated to a client by the secondary server. Client identification MAY appear and indicates, as a hint, the last client to have used this lease.

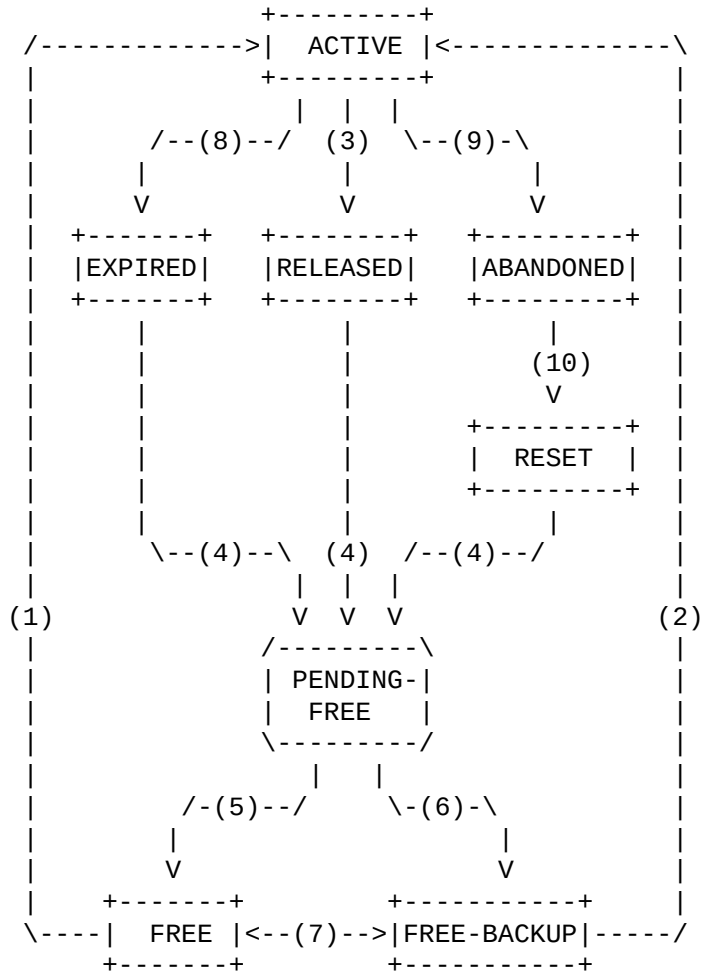
FREE-BACKUP - This value indicates that this lease can be allocated by the secondary server to a client at any time. Note that on the primary server running in PARTNER-DOWN state, after waiting the MCLT, the lease MAY be allocated to a client by the primary server if the proportional algorithm was used. Client identification MAY appear and indicates, as a hint, the last client to have used this lease.

ABANDONED - This value indicates that a lease is considered unusable by the DHCP system. The primary reason for entering such a state is the reception of a DECLINE message for the lease. Client identification MAY appear.

RESET - This value indicates that this lease was made available by an operator command. This is a distinct state so that the reason that the lease became FREE can be determined. Client identification MAY appear.

Which binding-status values are associated with a timeout is implementation dependent. Some binding-status values, such as ACTIVE, will have a timeout value in all implementations, while others, such as ABANDONED, will have a timeout value in some implementations and not in others. In some implementations, a binding-status value may be associated with a timeout in some circumstances and not in others. The receipt of a BNDUPD message with a particular binding-status value and an OPTION_F_STATE_EXPIRATION_TIME indicates that this particular binding-status value is associated with a timeout.

The lease state machine is presented in Figure 2. Most states are stationary, i.e., the lease stays in a given state until an external event triggers transition to another state. The only transitive state is PENDING-FREE. Once it is reached, the state machine immediately transitions to either FREE or FREE-BACKUP state.



PENDING-FREE transition

Figure 2: Lease State Machine

Transitions between states will result from the following events:

(1) The primary server allocates a lease.

(2) The secondary server allocates a lease.

(3) The client sends RELEASE, and the lease is released.

(4) The partner acknowledges the state change. This transition MAY also occur if the server is in PARTNER-DOWN state and the MCLT has passed since the entry into RELEASED, EXPIRED, or RESET states.

(5) The lease belongs to a pool that is governed by proportional allocation, or independent allocation is used and this lease belongs to the primary server's pool.

(6) The lease belongs to a pool that is governed by independent allocation, and the lease belongs to the secondary server.

(7) A pool rebalance event occurs (POOLREQ/POOLRESP messages are exchanged). Delegable prefixes belonging to the primary server can be assigned to the secondary server's pool (transition from FREE to FREE-BACKUP) or vice versa.

(8) The lease has expired.

(9) A DECLINE message is received, or a lease is deemed unusable for other reasons.

(10) An administrative action is taken to restore an abandoned lease to a usable state. This transition MAY occur due to implementation-specific handling of an ABANDONED lease. One possible example of this is a Neighbor Discovery or ICMPv6 Echo check to see if the address is still in use.

The lease that is no longer in use (due to expiration or release) becomes PENDING-FREE. Depending on what allocation algorithm is used, the lease that is no longer in use returns to the primary pool (FREE) or the secondary pool (FREE-BACKUP). The conditions for specific transitions are depicted in Figure 3.

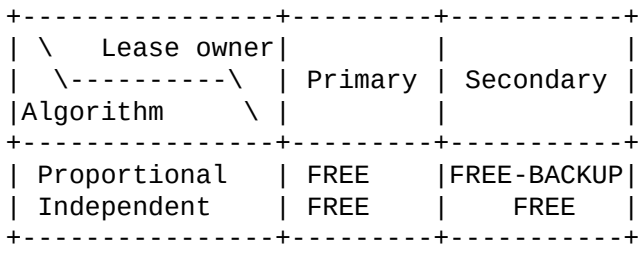


Figure 3: PENDING-FREE State Transitions

7.3. Times Required for Exchanging Binding Updates

Each server must keep track of the following specific times beyond those required by the base DHCP specification [RFC3315].

expiration-time
: The greatest lifetime that this server has ever acked to its failover partner in a BNDREPLY message.

acked-partner-lifetime
: The greatest lifetime that the failover partner has ever acked to this server in a BNDREPLY message.

partner-lifetime
: The time value that will be sent (or that has been sent) to the partner to indicate the time after which the partner can consider the lease expired. When a BNDUPD message is received, this value can be updated from the received OPTION_F_EXPIRATION_TIME.

client-last-transaction-time
: The time when this server most recently interacted with the client associated with this lease.

partner-raw-clt-time
: The time when the partner most recently interacted with the client associated with this lease. This time remains exactly as it was received by this server and MUST NOT be adjusted in any way.

start-time-of-state
: The time when the binding-status of this lease was changed to its current value.

state-expiration-time
: The time when the current state of this lease will expire.

7.4. Sending Binding Updates

Every BNDUPD message contains information about either (1) a single client binding in an OPTION_CLIENT_DATA option that includes IAADDR or IAPREFIX options associated with that client or (2) a single prefix lease in an OPTION_IAPREFIX option for prefixes that are currently not associated with any clients.

All information about a particular client binding MUST be contained in a single OPTION_CLIENT_DATA option (see Section 4.1.2.2 of [RFC5007]). The OPTION_CLIENT_DATA option contains at least the data shown below in its client-options section:

- OPTION_CLIENTID containing the DUID of the client most recently associated with this lease MUST appear.

- OPTION_LQ_BASE_TIME containing the absolute time that the information was placed in this OPTION_CLIENT_DATA option (see Section 6.3.1 of [RFC7653]) MUST appear.

- OPTION_VSS (see Section 3.4 of [RFC6607]). This option MUST NOT appear if the information in this OPTION_CLIENT_DATA option is associated with the global, default VPN. This option MUST appear if the information in this OPTION_CLIENT_DATA option is associated with a VPN other than the global, default VPN. Support of [RFC6607] is not required, and if it is not supported, then an OPTION_VSS MUST NOT appear. If [RFC6607] is supported, then an OPTION_VSS MUST appear if and only if a VPN other than the global, default VPN is used.

- OPTION_F_RECONFIGURE_DATA containing the time and reconfigure key, if any.

- OPTION_LQ_RELAY_DATA containing information described in Section 4.1.2.4 of [RFC5007], if any exists.

- OPTION_IA_NA or OPTION_IA_TA for an IPv6 address, or OPTION_IA_PD for an IPv6 prefix. More than one of either of these options MAY appear if more than one of them are associated with this client. At least one of an OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD must appear.
  - IAID - Identity Association used by the client, while obtaining a given lease. Note that (1) one client may use many IAIDs simultaneously and (2) IAIDs for OPTION_IA_NA, OPTION_IA_TA, and OPTION_IA_PD are orthogonal number spaces.
  - T1 time sent to client.
  - T2 time sent to client.
  - Inside of the IA_NA-options, IA_TA-options, or IA_PD-options sections:
    - OPTION_IAADDR for an IPv6 address or an OPTION_IAPREFIX for an IPv6 prefix MUST appear.
      - IPv6 address or IPv6 prefix (with length).
      - Preferred lifetime sent to client.
      - Valid lifetime sent to client.
      - Inside of the IAaddr-options or IAprefix-options:
        - OPTION_F_BINDING_STATUS containing the binding-status MUST appear.
        - OPTION_F_START_TIME_OF_STATE containing the start-time-of-state MUST appear.
        - OPTION_F_STATE_EXPIRATION_TIME (absolute) containing the state-expiration-time*.
        - OPTION_CLT_TIME (relative) containing the client-last-transaction-time. See [RFC5007] for a description of this option.
        - OPTION_F_PARTNER_LIFETIME (absolute) containing the partner-lifetime*.
        - OPTION_F_PARTNER_RAW_CLT_TIME (absolute) containing the partner-raw-clt-time.

- o OPTION_F_EXPIRATION_TIME (absolute) containing the expiration-time*.

- o OPTION_CLIENT_FQDN containing the FQDN information associated with this lease and client, if any.

Information about a prefix lease is contained in a single OPTION_IAPREFIX option. Only a single OPTION_IAPREFIX option may appear in a BNDUPD message outside of an OPTION_CLIENT_DATA option. In detail:

- o OPTION_IAPREFIX for a prefix lease.
  - * IPv6 prefix (with length).
  - * Inside of the IAprefix-options section:
    - + OPTION_VSS (see Section 3.4 of [RFC6607]). This option MUST NOT appear if the information in this OPTION_IAPREFIX option is associated with the global, default VPN. This option MUST appear if the information in this OPTION_IAPREFIX option is associated with a VPN other than the global, default VPN. Support of [RFC6607] is not required, and if it is not supported, then an OPTION_VSS MUST NOT appear. If [RFC6607] is supported, then an OPTION_VSS MUST appear if and only if a VPN other than the global, default VPN is used.
    - + OPTION_LQ_BASE_TIME containing the absolute time that this information was placed in this OPTIONS_IAPREFIX option (see Section 6.3.1 of [RFC7653]) MUST appear.
    - + OPTION_F_BINDING_STATUS containing the binding-status MUST appear.
    - + OPTION_F_START_TIME_OF_STATE containing the start-time-of-state MUST appear.
    - + OPTION_F_STATE_EXPIRATION_TIME (absolute) containing the state-expiration-time*.
    - + OPTION_F_PARTNER_LIFETIME (absolute) containing the partner-lifetime*.
    - + OPTION_F_EXPIRATION_TIME (absolute) containing the expiration-time*.

Items marked with a single asterisk (*) MUST appear only if the value in the OPTION_F_BINDING_STATUS is associated with a timeout; otherwise, it MUST NOT appear. See Section 7.2 for details.

The OPTION_CLT_TIME MUST, if it appears, be the time that the server last interacted with the DHCP client. It MUST NOT be, for instance, the time that the lease expired if there has been no interaction with the DHCP client in question.

A server SHOULD be prepared to clean up DNS information once the lease expires or is released. See Section 9 for a detailed discussion about DNS update. Another reason the partner may be interested in keeping additional data is to enable better support for Leasequery [RFC5007], Bulk Leasequery [RFC5460], or Active Leasequery [RFC7653], some of which feature queries based on Relay-ID, link address, or Remote-ID.

7.5. Receiving Binding Updates

7.5.1. Monitoring Time Skew

The sent-time from the failover message is compared with the current time of the receiving server as recorded when it received the message. The difference is noted, and if it is greater than 5 seconds the receiving server SHOULD drop the connection. A message SHOULD be logged to signal the reason for the connection being dropped.

Any time can be before, after, or essentially the same as another time. Any time that ends up being +/- 5 seconds of another time SHOULD be considered to be representing the same time when performing a comparison between two times.

7.5.2. Acknowledging Reception

Upon acceptance of a binding update, the server MUST notify its partner that it has processed the binding update (and updated its lease state database if necessary) by sending a BNDREPLY message. A server MUST NOT send the BNDREPLY message before its binding database is updated.

7.5.3. Processing Binding Updates

When a BNDUPD message is received, it MUST contain either a single OPTION_CLIENT_DATA option or a single OPTION_IAPREFIX option.

When analyzing a BNDUPD message from a partner server, if there is insufficient information in the BNDUPD message to process it, then it is rejected with an OPTION_STATUS_CODE of "MissingBindingInformation".

The server receiving a BNDUPD message from its partner must evaluate the received information in each OPTION_CLIENT_DATA or IAPREFIX option to see if it is consistent with the server's already-known state and, if it is not, decide to accept or reject the information. Section 7.5.4 provides details regarding how the server makes this determination.

A server receiving a BNDUPD message MUST respond to the sender of that message with a BNDREPLY message that contains the same transaction-id as the BNDUPD message. This BNDREPLY message MUST contain either a single OPTION_CLIENT_DATA option or a single OPTION_IAPREFIX option, corresponding to whatever was received in the BNDUPD message.

An OPTION_CLIENT_DATA option or an OPTION_IAPREFIX option in the BNDREPLY message that is accepted SHOULD NOT contain an OPTION_STATUS_CODE unless a status message needs to be sent to the failover partner, in which case it SHOULD include an OPTION_STATUS_CODE option with a status-code indicating success and whatever message is needed.

To indicate rejection of the information in an OPTION_CLIENT_DATA option or an OPTION_IAPREFIX option, an OPTION_STATUS_CODE SHOULD be included with a status-code indicating an error in the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option in the BNDREPLY message.

7.5.4. Accept or Reject?

The first task in processing the information in an OPTION_CLIENT_DATA option or OPTION_IAPREFIX option is to extract the client information (if any) and lease information out of the option and to access the address lease or prefix lease information in the server's binding database.

If an OPTION_VSS option is specified in the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option and the VPN specified in the OPTION_VSS option does not appear in the configuration of the receiving server,

then reject the entire OPTION_CLIENT_DATA option or OPTION_IAPREFIX option by including an OPTION_STATUS_CODE option with a status-code of "ConfigurationConflict".

If the lease specified in the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option is not a lease associated with the failover endpoint that received the OPTION_CLIENT_DATA option, then reject it by including an OPTION_STATUS_CODE option with a status-code of "ConfigurationConflict".

In general, acceptance or rejection is based on the comparison of two different time values -- one from the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option in the BNDUPD message, and one from the receiving server's binding database associated with the address or prefix lease found in the BNDUPD message. The time for the BNDUPD message where the OPTION_F_BINDING_STATUS is ACTIVE, EXPIRED, or RELEASED is the OPTION_CLT_TIME if one appears, or the OPTION_F_START_TIME_OF_STATE if one does not. For other binding-status values, the time for the BNDUPD message is the later of (1) the OPTION_CLT_TIME if one appears or (2) the OPTION_F_START_TIME_OF_STATE. The time for the lease in the server's binding database is the client-last-transaction-time if one appears, or the start-time-of-state if one does not.

The basic approach is to compare these times, and if the one from the BNDUPD message is clearly later, then accept the information in the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option. If the one from the server's binding database is clearly later, then reject the information in the BNDUPD message. The challenge comes when they are essentially the same (i.e., +/- 5 seconds). In this case, they are considered identical, despite the minor differences. Figure 4 shows a table containing the rules for dealing with all of these situations.

	binding-status in received OPTION_CLIENT_DATA or OPTION_IAPREFIX				
binding-status in receiving server's lease state DB	ACTIVE	EXPIRED	RELEASED	FREE FREE-BACKUP	RESET ABANDONED
ACTIVE	accept(3)	time(1)	accept	time(1)	accept
EXPIRED	accept	accept	accept	accept	accept
RELEASED	accept	accept	accept	accept	accept
FREE/FREE-BACKUP	accept	accept	accept	accept	accept
RESET	time(2)	accept	accept	accept	accept
ABANDONED	accept	accept	accept	accept	accept

Figure 4: Conflict Resolution

accept: If the time value in the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option is later than the time value in the server's binding database, accept it, else reject it.

time(1): If the current time is later than the receiving server's state-expiration-time, accept it, else reject it.

time(2): If the OPTION_CLT_TIME value (if it appears) in the OPTION_CLIENT_DATA is later than the start-time-of-state in the receiving server's binding, accept it, else reject it.

accept,time(1),time(2): If rejecting, use a status-code of "OutdatedBindingInformation".

accept(3): If the clients in an OPTION_CLIENT_DATA option and in a receiving server's binding differ, then if time(2) or the receiving server is a secondary accept it, else reject it with a status-code of "AddressInUse". If the clients match, accept the update.

The lease update may be accepted or rejected. If a lease is rejected with "OutdatedBindingInformation", then the flag in the lease that indicates that the partner should be updated with the information in this lease SHOULD be set; otherwise, it SHOULD NOT be changed. If this flag was previously not set, then an update MAY be transmitted immediately to the partner (though the BNDREPLY to this BNDUPD message SHOULD be sent first). If this flag was previously set, an update SHOULD NOT be transmitted immediately to the partner. In this case, an update will be sent during the next periodic scan, but not immediately, thus preventing a possible update storm should the servers be unable to agree. Ultimately, the server with the most recent binding information should have its update accepted by its partner.

7.5.5. Accepting Updates

When the information in an OPTION_CLIENT_DATA option or OPTION_IAPREFIX option has been accepted, some of that information is stored in the receiving server's binding database, and a corresponding OPTION_CLIENT_DATA option or OPTION_IAPREFIX option is entered into a BNDREPLY message. The information to enter into the OPTION_CLIENT_DATA option or OPTION_IAPREFIX option in the BNDREPLY message is described in Section 7.6.

The information contained in an accepted OPTION_CLIENT_DATA option is stored in the receiving server's binding database as follows:

1. The OPTION_CLIENTID is used to find the client.

2. The other data contained in the top level of the OPTION_CLIENT_DATA option is stored with the client as appropriate.

3. For each of the OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD options in the OPTION_CLIENT_DATA option and for each of the OPTION_IAADDR or OPTION_IAPREFIX options in the IA_* options:

    a. OPTION_F_BINDING_STATUS is stored as the binding-status.

    b. OPTION_F_PARTNER_LIFETIME is stored in the expiration-time.

    c. OPTION_F_STATE_EXPIRATION_TIME is stored in the state-expiration-time.

    d. OPTION_CLT_TIME [RFC5007] is stored in the partner-raw-clt-time.

    e. OPTION_F_PARTNER_RAW_CLT_TIME replaces the client-last-transaction-time if it is later than the current client-last-transaction-time.

    f. OPTION_F_EXPIRATION_TIME replaces the partner-lifetime if it is later than the current partner-lifetime.

The information contained in an accepted single OPTION_IAPREFIX option that is not contained in an OPTION_CLIENT_DATA option is stored in the receiving server's binding database as follows:

1. The IPv6 prefix is used to find the prefix.

2. Inside of the IAprefix-options section:

    a. OPTION_F_BINDING_STATUS is stored as the binding-status.

    b. OPTION_F_PARTNER_LIFETIME (if any) is stored in the expiration-time.

    c. OPTION_F_STATE_EXPIRATION_TIME (if any) is stored in the state-expiration-time.

d. OPTION_F_EXPIRATION_TIME (if any) replaces the partner-lifetime if it is later than the current partner-lifetime.

7.6. Sending Binding Replies

A server MUST respond to every BNDUPD message with a BNDREPLY message. The BNDREPLY message MUST contain an OPTION_CLIENT_DATA option if the BNDUPD message contained an OPTION_CLIENT_DATA option, or it MUST contain an OPTION_IAPREFIX option if the BNDUPD message contained an OPTION_IAPREFIX option. The BNDREPLY message MUST have the same transaction-id as the BNDUPD message to which it is a response.

Acceptance or rejection of all of or a particular part of the BNDUPD message is signaled with an OPTION_STATUS_CODE option. An OPTION_STATUS_CODE option containing a status-code representing an error is significant, while an OPTION_STATUS_CODE option whose status-code contains success is considered informational but does not affect the processing of the BNDREPLY message when it is received by the server that sent the BNDUPD message.

Rejection of all of or part of the information in a BNDUPD message is signaled in a BNDREPLY message by using the OPTION_STATUS_CODE message with an error in the status-code field. This rejection can take place at either of two levels -- the top level of the option hierarchy or the bottom level of the option hierarchy:

1. Entire BNDUPD: The OPTION_STATUS_CODE containing an error is present in the outermost option of the BNDREPLY message -- either the single OPTION_CLIENT_DATA option or the single OPTION_IAPREFIX option. An example of this sort of error might be that an OPTION_VSS option was present and specified a VPN that might not exist in the receiving server.

2. Single address or prefix: The OPTION_STATUS_CODE containing an error is present in a single IAADDR or IAPREFIX option that is itself contained in an OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD option. An example of this sort of error might be that a particular IPv6 address was specified in an IAADDR option that doesn’t appear in the receiving server’s configuration.

Rejection occurring at either of these levels indicates rejection of all of the information contained in the option (including any other options contained in that option) where the OPTION_STATUS_CODE option containing an error appears. The converse is not true -- an OPTION_STATUS_CODE option containing success does not signify that all of the contained information has been accepted.

If the BNDREPLY message contains an OPTION_CLIENT_DATA option, then the OPTION_CLIENT_DATA option MUST contain at least the data shown below in its client-options section:

- OPTION_CLIENTID containing the DUID of the client most recently associated with this IPv6 address.

- OPTION_VSS from the BNDUPD message, if any.

- OPTION_IA_NA or OPTION_IA_TA for an IPv6 address or OPTION_IA_PD for an IPv6 prefix. More than one of either of these options MAY appear if there are more than one of them associated with this client.

  * Inside of the IA_NA-options, IA_TA-options, or IA_PD-options sections:

    + OPTION_IAADDR for an IPv6 address or an OPTION_IAPREFIX for an IPv6 prefix.

      - IPv6 address or IPv6 prefix (with length).

      - Inside of the IAaddr-options or IAprefix-options:

        o OPTION_STATUS_CODE containing an error code, or containing a success code if a message is required. An OPTION_STATUS_CODE option SHOULD NOT appear with a success code unless a message associated with the success code needs to be included. The lack of an OPTION_STATUS_CODE option is an indication of success.

        o OPTION_F_BINDING_STATUS containing the binding-status received in the BNDUPD message.

        o OPTION_F_STATE_EXPIRATION_TIME (absolute) containing the state-expiration-time received in the BNDUPD message.

        o OPTION_F_PARTNER_LIFETIME_SENT (absolute) containing a duplicate of the OPTION_F_PARTNER_LIFETIME received in the BNDUPD message.

If the BNDREPLY message contains a single OPTION_IAPREFIX option not contained in an OPTION_CLIENT_DATA option, then the OPTION_IAPREFIX option MUST contain at least the data shown below:

- IPv6 prefix (with length).
- IAprefix-options:
  - OPTION_VSS from the BNDUPD message, if any.
  - OPTION_STATUS_CODE containing an error code, or containing a success code if a message is required. If the information in the corresponding OPTION_IAPREFIX in the BNDUPD message was accepted and no status message was required (which is the usual case), no OPTION_STATUS_CODE option appears.
  - OPTION_F_BINDING_STATUS containing the binding-status received in the BNDREPLY message.
  - OPTION_F_STATE_EXPIRATION_TIME (absolute) containing the state-expiration-time received in the BNDREPLY message.
  - OPTION_F_PARTNER_LIFETIME_SENT (absolute) containing a duplicate of the OPTION_F_PARTNER_LIFETIME received in the BNDREPLY message.

7.7. Receiving Binding Acks

When a BNDREPLY message is received, the overall OPTION_CLIENT_DATA option or the overall OPTION_IAPREFIX option may contain an OPTION_STATUS_CODE containing an error that represents a rejection of the entire BNDUPD message. An enclosed OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD option may also contain an OPTION_STATUS_CODE containing an error that indicates that everything in the containing option has been rejected. Alternatively, an individual IAADDR or IAPREFIX option may contain an OPTION_STATUS_CODE option containing an error that indicates that the IAADDR or IAPREFIX option has been rejected. An OPTION_STATUS_CODE containing a success code has no bearing on the acceptance status of the BNDREPLY message at any level.

Receipt of a rejection (or a part of a BNDREPLY message that has been rejected) requires no processing, other than remembering that it has been encountered.

The information contained in the BNDREPLY message in an OPTION_CLIENT_DATA that represents an acceptance is stored with the appropriate client and lease, as follows:

1. The OPTION_CLIENTID is used to find the client.

2. For each of the OPTION_IA_NA, OPTION_IA_TA, or OPTION_IA_PD options in the OPTION_CLIENT_DATA option and for each of the OPTION_IAADDR or OPTION_IAPREFIX options they contain:

    a. OPTION_F_PARTNER_LIFETIME_SENT is stored in the acked-partner-lifetime.

    b. The partner-lifetime is set to 0 to indicate that no more information needs to be sent to the partner.

Alternatively, the BNDREPLY message may contain a single OPTION_IAPREFIX option not contained in an OPTION_CLIENT_DATA option, representing information concerning a single prefix lease. If the IAprefix-options section of the OPTION_IAPREFIX option contains an OPTION_STATUS_CODE representing an error, then it is considered a rejection of the corresponding BNDUPD message. If the OPTION_IAPREFIX option does not contain an OPTION_STATUS_CODE option or if the OPTION_STATUS_CODE option contains a success status, then the three items in the following list are stored in the lease state database, in the section associated with the prefix lease represented by the OPTION_IAPREFIX option.

1. OPTION_F_BINDING_STATUS containing the binding-status received in the BNDREPLY message.

2. OPTION_F_STATE_EXPIRATION_TIME (absolute) containing the state-expiration-time received in the BNDREPLY message.

3. OPTION_F_PARTNER_LIFETIME_SENT (absolute) containing a duplicate of the OPTION_F_PARTNER_LIFETIME received in the BNDREPLY message.

7.8. BNDUPD/BNDREPLY Data Flow

Figure 5 shows the relationship of the times described in Section 7.3 to the options used to transmit them. It also relates the times on one failover partner to the other failover partner.

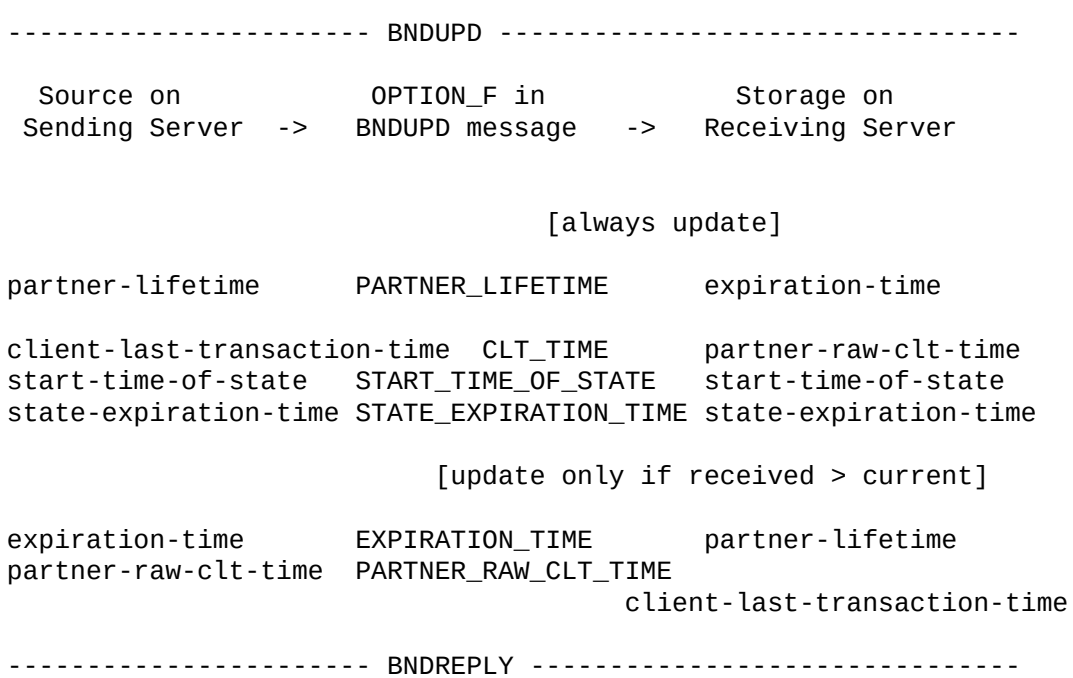


Figure 5: BNDUPD and BNDREPLY Time Handling

8. Endpoint States

8.1. State Machine Operation

Each server (or, more accurately, failover endpoint) can take on a variety of failover states. These states play a crucial role in determining the actions that a server will perform when processing a request from a DHCP client as well as dealing with changing external conditions (e.g., loss of connection to a failover partner).

The failover state in which a server is running controls the following behaviors:

- Responsiveness - the server is either responsive to DHCP client requests, renew responsive, or unresponsive.

- Allocation Pool - which pool of addresses (or prefixes) can be used for advertisement on receipt of a SOLICIT or allocation on receipt of a REQUEST, RENEW, or REBIND message.

- MCLT - ensure that valid lifetimes are not beyond what the partner has acked plus the MCLT (unless the failover state doesn't require this restriction).

A server will transition from one failover state to another based on the specific values held by the following state variables:

- Current failover state.

- Communications status ("OK" or not "OK").

- Partner's failover state (if known).

Whenever any of the above state variables change state, the state machine is invoked, which may then trigger a change in the current failover state. Thus, whenever the communications status changes, the state machine processing is invoked. This may or may not result in a change in the current failover state.

Whenever a server transitions to a new failover state, the new state MUST be communicated to its failover partner in a STATE message if the communications status is "OK". In addition, whenever a server makes a transition into a new state, it MUST record the new state, its current understanding of its partner's state, and the time at which it entered the new state in stable storage.

The state transition diagram below (Figure 6) gives a condensed view of the state machine. If there are any differences between text describing a particular state and the information shown in Figure 6, the text should be considered authoritative.

In Figure 6, the terms "responsive", "r-responsive", and "unresponsive" appear in the states and refer to whether the server in the indicated state is allowed to be responsive, renew responsive, or unresponsive, respectively. The "+", "-", or "*" in the upper right corner of each state is a notation about whether communication is ongoing with the other server, with "+" meaning that communications are "OK", "-" meaning that communications are interrupted, and "*" meaning that communications may be either "OK" or interrupted.

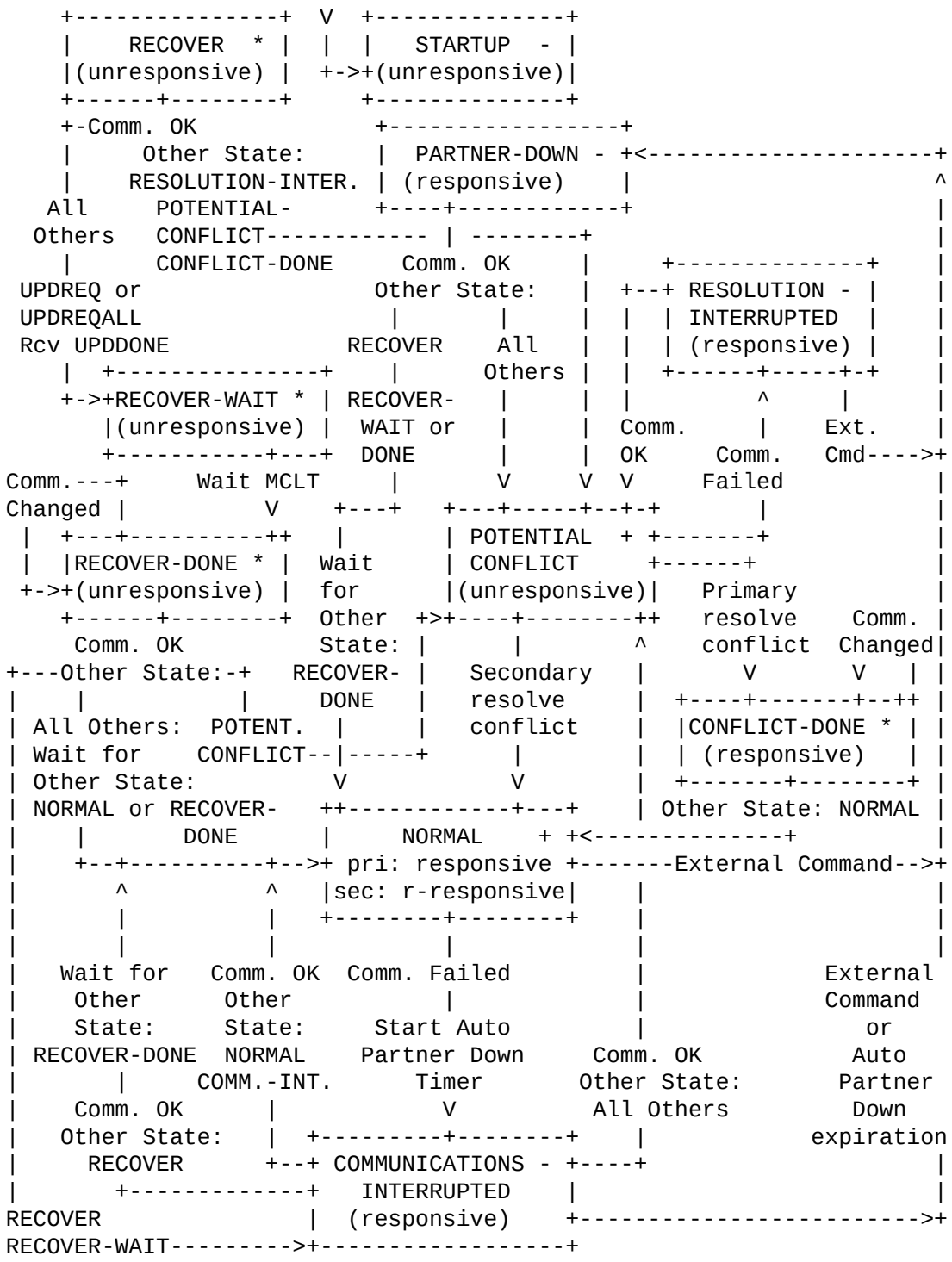


Figure 6: Failover Endpoint State Machine

8.2. State Machine Initialization

The state machine is characterized by storage (in stable storage) of at least the following information:

- Current failover state.
- Previous failover state.
- Start time of current failover state.
- Partner's failover state.
- Start time of partner's failover state.
- Time most recent message received from partner.

The state machine is initialized by reading these data items from stable storage and restoring their values from the information saved. If there is no information in stable storage concerning these items, then they should be initialized as follows:

- Current failover state: Primary: PARTNER-DOWN, Secondary: RECOVER.
- Previous failover state: None.
- Start time of current failover state: Current time.
- Partner's failover state: None until reception of STATE message.
- Start time of partner's failover state: None until reception of STATE message.
- Time most recent message received from partner: None until message received.

8.3. STARTUP State

The STARTUP state affords an opportunity for a server to probe its partner server before starting to service DHCP clients. When in the STARTUP state, a server attempts to learn its partner's state and determine (using that information if it is available) what state it should enter.

The STARTUP state is not shown with any specific state transitions in the state machine diagram (Figure 6) because the processing during the STARTUP state can cause the server to transition to any of the other states, so that specific state transition arcs would only obscure other information.

8.3.1. Operation in STARTUP State

The server MUST NOT be responsive to DHCP clients in STARTUP state.

Whenever a STATE message is sent to the partner while in STARTUP state, the STARTUP flag MUST be set in the OPTION_F_SERVER_FLAGS option and the previously recorded failover state MUST be placed in the OPTION_F_SERVER_STATE option, each of which is included in the STATE message.

8.3.2. Transition out of STARTUP State

The algorithm below is followed every time the server initializes itself and enters STARTUP state.

The variables PREVIOUS-STATE and CURRENT-STATE are defined for use in the algorithm description below. PREVIOUS-STATE is simply for storage of a state, while CURRENT-STATE not only stores the current state but also changes the current state of the failover endpoint to whatever state is set in CURRENT-STATE.

Step 1: If there is any record of a previous failover state in stable storage for this server, then set the PREVIOUS-STATE to the last recorded value in stable storage and the TIME-OF-FAILURE to the time the server failed or a time beyond which the server could not have been operating, and go to Step 2.

If there is no record of any previous failover state in stable storage for this server, then set the PREVIOUS-STATE to RECOVER, and set the TIME-OF-FAILURE to 0. This will allow two servers that already have lease information to synchronize themselves prior to operating.

In some cases, an existing server will be commissioned as a failover server and brought back into operation when its partner is not yet available. In this case, the newly commissioned failover server will not operate until its partner comes online -- but it has operational responsibilities as a DHCP server nonetheless. To properly handle this situation, a server SHOULD be configurable in such a way as to move directly into PARTNER-DOWN state after the startup period expires if it has been unable to contact its partner during the startup period.

Step 2: Implementations will differ in the ways that they deal with the state machine for failover endpoint states. In many cases, state transitions will occur when communications go from "OK" to failed or from failed to "OK", and some implementations will implement a portion of their state machine processing based on these changes.

In these cases, during startup, if the PREVIOUS-STATE is one where communications were "OK", then set the PREVIOUS-STATE to the state that is the result of the communication failed state transition when in that state (if such a transition exists -- some states don’t have a communication failed state transition, since they allow both "communications OK" and "failed").

Step 3: Start the STARTUP state timer. The time that a server remains in the STARTUP state (absent any communications with its partner) is implementation dependent but SHOULD be short. It SHOULD be long enough for a TCP connection to a heavily loaded partner to be created across a slow network.

Step 4: If the server is a primary server, attempt to create a TCP connection to the failover partner. If the server is a secondary server, listen on the failover port and wait for the primary server to connect. See Section 6.1.

Step 5: Wait for "communications OK".

When and if communications become "OK", clear the STARTUP flag, and set the CURRENT-STATE to the PREVIOUS-STATE.

If the partner is in PARTNER-DOWN state and if the time at which it entered PARTNER-DOWN state (as received in the OPTION_F_START_TIME_OF_STATE option in the STATE message) is later than the last recorded time of operation of this server, then set CURRENT-STATE to RECOVER. If the time at which it entered PARTNER-DOWN state is earlier than the last recorded time of operation of this server, then set CURRENT-STATE to POTENTIAL-CONFLICT.

Then, transition to the CURRENT-STATE and take the "communications OK" state transition based on the CURRENT-STATE of this server and the partner.

Step 6: If the startup time expires prior to communications becoming "OK", the server SHOULD transition to PREVIOUS-STATE.

8.4. PARTNER-DOWN State

PARTNER-DOWN state is a state either server can enter. When in this state, the server assumes that it is the only server operating and serving the client base. If one server is in PARTNER-DOWN state, the other server MUST NOT be operating.

A server can enter PARTNER-DOWN state as a result of either (1) operator intervention (when an operator determines that the server's partner is, indeed, down) or (2) an optional auto-partner-down capability where PARTNER-DOWN state is entered automatically after a server has been in COMMUNICATIONS-INTERRUPTED state for a predetermined period of time.

8.4.1. Operation in PARTNER-DOWN State

The server MUST be responsive in PARTNER-DOWN state, regardless of whether it is primary or secondary.

It will allow renewal of all outstanding leases.

For delegable prefixes, the server will allocate leases from its own pool, and after a fixed period of time (the MCLT interval) has elapsed from entry into PARTNER-DOWN state, it may allocate delegable prefixes from the set of all available pools. The server MUST fully deplete its own pool before starting allocations from its downed partner's pool.

IPv6 addresses available for independent allocation by the other server (upon entering PARTNER-DOWN state) SHOULD NOT be allocated to a client. If one elects to do so anyway, they MUST NOT be allocated to a new client until the MCLT beyond the entry into PARTNER-DOWN state has elapsed.

A server in PARTNER-DOWN state MUST NOT allocate a lease to a DHCP client different from the client to which it was allocated at the time of entry into PARTNER-DOWN state until the MCLT beyond the maximum of the following times: client expiration time, most recently transmitted partner-lifetime, most recently received ack of the partner-time from the partner, and most recently acked partner-lifetime to the partner. If this time would be earlier than the current time plus the MCLT, then the time the server entered PARTNER-DOWN state plus the MCLT is used.

The server is not restricted by the MCLT when offering valid lifetimes while in PARTNER-DOWN state.

In the unlikely case when there are two servers operating in PARTNER-DOWN state, there is a chance that duplicate leases for the same prefix could be assigned. This leads to a POTENTIAL-CONFLICT (unresponsive) state when the servers reestablish contact. This issue of duplicate leases can be prevented as long as the server grants new leases from its own pool; therefore, the server operating in PARTNER-DOWN state MUST use its own pool first for new leases before assigning any leases from its downed partner's pool.

8.4.2. Transition out of PARTNER-DOWN State

When a server in PARTNER-DOWN state succeeds in establishing a connection to its partner, its actions are conditional on the state and flags received in the STATE message from the other server as part of the process of establishing the connection.

If the STARTUP bit is set in the OPTION_F_SERVER_FLAGS option of a received STATE message, a server in PARTNER-DOWN state MUST NOT take any state transitions based on reestablishing communications. If a server is in PARTNER-DOWN state, it ignores all STATE messages from its partner that have the STARTUP bit set in the OPTION_F_SERVER_FLAGS option of the STATE message.

If the STARTUP bit is not set in the OPTION_F_SERVER_FLAGS option of a STATE message received from its partner, then a server in PARTNER-DOWN state takes the following actions, based on the state of the partner as received in a STATE message (either immediately after establishing communications or at any time later when a new state is received):

- If the partner is in NORMAL, COMMUNICATIONS-INTERRUPTED, PARTNER-DOWN, POTENTIAL-CONFLICT, RESOLUTION-INTERRUPTED, or CONFLICT-DONE state, then transition to POTENTIAL-CONFLICT state.

- If the partner is in RECOVER or RECOVER-WAIT state, then stay in PARTNER-DOWN state.

- If the partner is in RECOVER-DONE state, then transition to NORMAL state.

8.5. RECOVER State

This state indicates that the server has no information in its stable storage or that it is reintegrating with a server in PARTNER-DOWN state after it has been down. A server in this state MUST attempt to refresh its stable storage from the other server.

8.5.1. Operation in RECOVER State

The server MUST NOT be responsive in RECOVER state.

A server in RECOVER state will attempt to reestablish communications with the other server.

8.5.2. Transition out of RECOVER State

If the other server is in POTENTIAL-CONFLICT, RESOLUTION-INTERRUPTED, or CONFLICT-DONE state when communications are reestablished, then the server in RECOVER state will move itself to POTENTIAL-CONFLICT state.

If the other server is in any other state, then the server in RECOVER state will request an update of missing binding information by sending an UPDREQ message. If the server has determined that it has lost its stable storage because it has no record of ever having talked to its partner even though its partner does have a record of communicating with it, it MUST send an UPDREQALL message; otherwise, it MUST send an UPDREQ message.

It will wait for an UPDDONE message, and upon receipt of that message it will transition to RECOVER-WAIT state.

If communication fails during the reception of the results of the UPDREQ or UPDREQALL message, the server will remain in RECOVER state and will reissue the UPDREQ or UPDREQALL message when communications are reestablished.

If an UPDDONE message isn't received within an implementation-dependent amount of time and no BNDUPD messages are being received, the connection SHOULD be dropped.

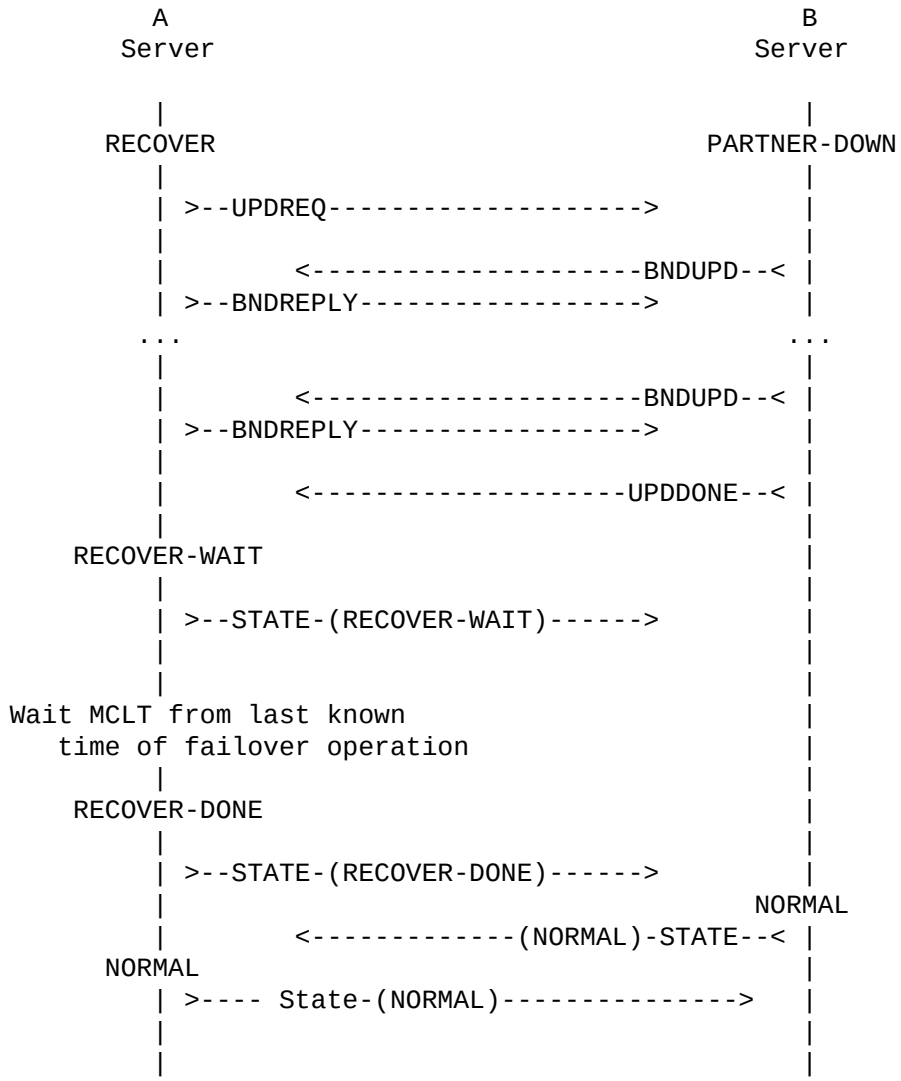


Figure 7: Transition out of RECOVER State

If at any time while a server is in RECOVER state communication fails, the server will stay in RECOVER state. When communications are restored, it will restart the process of transitioning out of RECOVER state.

8.6. RECOVER-WAIT State

This state indicates that the server has sent an UPDREQ or UPDREQALL message and has received the UPDDONE message indicating that it has received all outstanding binding update information. In the RECOVER-WAIT state, the server will wait for the MCLT in order to ensure that any processing that this server might have done prior to losing its stable storage will not cause future difficulties.

8.6.1. Operation in RECOVER-WAIT State

The server MUST NOT be responsive in RECOVER-WAIT state.

8.6.2. Transition out of RECOVER-WAIT State

Upon entry into RECOVER-WAIT state, the server MUST start a timer whose expiration is set to a time equal to the time the server went down (the TIME-OF-FAILURE from Section 8.3.2), if known, or the time the server started (if the TIME-OF-FAILURE is unknown), plus the MCLT. When this timer expires, the server will transition into RECOVER-DONE state.

This allows any IPv6 addresses or prefixes that were allocated by this server prior to the loss of its client binding information in stable storage to contact the other server or to time out.

If the server has never before run failover, then there is no need to wait in this state, and the server MAY transition immediately to RECOVER-DONE state. However, to determine if this server has run failover, it is vital that the information provided by the partner be utilized, since the stable storage of this server may have been lost.

If communication fails while a server is in RECOVER-WAIT state, it has no effect on the operation of this state. The server SHOULD continue to operate its timer, and if the timer expires during the period where communications with the other server have failed, then the server SHOULD transition to RECOVER-DONE state. This is rare -- failover state transitions are not usually made while communications are interrupted, but in this case there is no reason to inhibit this transition.

8.7. RECOVER-DONE State

This state exists to allow an interlocked transition for one server from RECOVER state and another server from PARTNER-DOWN or COMMUNICATIONS-INTERRUPTED state into NORMAL state.

8.7.1. Operation in RECOVER-DONE State

A server in RECOVER-DONE state SHOULD be renew responsive and MAY respond to RENEW requests but MUST only change the state of a lease that appears in the RENEW request. It MUST NOT allocate any additional leases when in RECOVER-DONE state and should only respond to RENEW requests where it already has a record of the lease.

8.7.2. Transition out of RECOVER-DONE State

When a server in RECOVER-DONE state determines that its partner server has entered NORMAL or RECOVER-DONE state, it will transition into NORMAL state.

If the partner server enters RECOVER or RECOVER-WAIT state, this server transitions to COMMUNICATIONS-INTERRUPTED.

If the partner server enters POTENTIAL-CONFLICT state, this server enters POTENTIAL-CONFLICT state as well.

If communication fails while in RECOVER-DONE state, a server will stay in RECOVER-DONE state.

8.8. NORMAL State

NORMAL state is the state used by a server when it is communicating with the other server and any required resynchronization has been performed. While some binding database synchronization is performed in NORMAL state, potential conflicts are resolved prior to entry into NORMAL state, as is binding database data loss.

When entering NORMAL state, a server will send to the other server all currently unacknowledged binding updates as BNDUPD messages.

When the above process is complete, if the server entering NORMAL state is a secondary server, then it will request delegable prefixes for allocation using the POOLREQ message.

8.8.1. Operation in NORMAL State

The primary server is responsive in NORMAL state. The secondary is renew responsive in NORMAL state.

When in NORMAL state, a primary server will operate in the following manner:

Valid lifetime calculations
: As discussed in Section 4.4, the lease interval given to a DHCP client can never be more than the MCLT greater than the most recently acknowledged partner lifetime received from the failover partner or the current time, whichever is later.

  As long as a server adheres to this constraint, the specifics of the lease interval that it gives to a DHCP client or the value of the partner lifetime sent to its failover partner are implementation dependent.

Lazy update of partner server
: After sending a REPLY that includes a lease update to a client, the server servicing a DHCP client request attempts to update its partner with the new binding information. See Section 4.3.

Reallocation of leases between clients
: Whenever a client binding is released or expires, a BNDUPD message must be sent to the partner, setting the binding state to RELEASED or EXPIRED. However, until a BNDREPLY is received for this message, the lease cannot be allocated to another client. It cannot be allocated to the same client again if a BNDUPD message was sent; otherwise, it can. See Section 4.2.2.1 for details.

In NORMAL state, each server receives binding updates from its partner server in BNDUPD messages (see Section 7.5.5). It records these in its binding database in stable storage and then sends a corresponding BNDREPLY message to its partner server (see Section 7.6).

8.8.2. Transition out of NORMAL State

If a server in NORMAL state receives an external command informing it that its partner is down, it will transition immediately into PARTNER-DOWN state. Generally, this would be an unusual situation, where some external agency knew the partner server was down prior to the failover server discovering it on its own.

If a server in NORMAL state fails to receive acks to messages sent to its partner for an implementation-dependent period of time, it MAY move into COMMUNICATIONS-INTERRUPTED state. This situation might occur if the partner server was capable of maintaining the TCP connection between the server and also capable of sending a CONTACT message periodically but was (for some reason) incapable of processing BNDUPD messages.

If it is determined that communications are not "OK" (as defined in Section 6.6), then the server should transition into COMMUNICATIONS-INTERRUPTED state.

If a server in NORMAL state receives any messages from its partner where the partner has changed state from that expected by the server in NORMAL state, then the server should transition into COMMUNICATIONS-INTERRUPTED state and take the appropriate state transition from there. For example, it would be expected that the partner would transition from POTENTIAL-CONFLICT state into NORMAL state but not that the partner would transition from NORMAL state into POTENTIAL-CONFLICT state.

If a server in NORMAL state receives a DISCONNECT message from its partner, then the server should transition into COMMUNICATIONS-INTERRUPTED state.

8.9. COMMUNICATIONS-INTERRUPTED State

A server goes into COMMUNICATIONS-INTERRUPTED state whenever it is unable to communicate with its partner. Primary and secondary servers cycle automatically (without administrative intervention) between NORMAL state and COMMUNICATIONS-INTERRUPTED state as the network connection between them fails and recovers, or as the partner server cycles between operational and non-operational. No allocation of duplicate leases can occur while the servers cycle between these states.

When a server enters COMMUNICATIONS-INTERRUPTED state, if it has been configured to support an automatic transition out of COMMUNICATIONS-INTERRUPTED state and into PARTNER-DOWN state (i.e., auto-partner-down has been configured), then a timer is started for the length of the configured auto-partner-down period.

A server transitioning into the COMMUNICATIONS-INTERRUPTED state from the NORMAL state SHOULD raise an alarm condition to alert administrative staff to a potential problem in the DHCP subsystem.

8.9.1. Operation in COMMUNICATIONS-INTERRUPTED State

In this state, a server MUST respond to all DHCP client requests. When allocating new leases, each server allocates from its own pool, where the primary MUST allocate only FREE delegable prefixes and the secondary MUST allocate only FREE-BACKUP delegable prefixes, and each server allocates from its own independent IPv6 address ranges. When responding to RENEW messages, each server will allow continued renewal of a DHCP client's current lease, regardless of whether that lease was given out by the receiving server or not, although the renewal period MUST NOT exceed the MCLT beyond the later of (1) the partner lifetime already acknowledged by the other server or (2) now.

However, since the server cannot communicate with its partner in this state, the acknowledged partner lifetime will not be updated, despite continued RENEW message processing. This is likely to eventually cause the actual lifetimes to converge to the MCLT (unless this is greater than the desired lease time, which would be unusual).

The server should continue to try to establish a connection with its partner.

8.9.2. Transition out of COMMUNICATIONS-INTERRUPTED State

If the auto-partner-down timer expires while a server is in COMMUNICATIONS-INTERRUPTED state, it will transition immediately into PARTNER-DOWN state.

If a server in COMMUNICATIONS-INTERRUPTED state receives an external command informing it that its partner is down, it will transition immediately into PARTNER-DOWN state.

If communications with the other server are restored, then the server in COMMUNICATIONS-INTERRUPTED state will transition into another state based on the state of the partner:

- NORMAL or COMMUNICATIONS-INTERRUPTED: Transition into NORMAL state.
- RECOVER: Stay in COMMUNICATIONS-INTERRUPTED state.
- RECOVER-DONE: Transition into NORMAL state.
- PARTNER-DOWN, POTENTIAL-CONFLICT, CONFLICT-DONE, or RESOLUTION-INTERRUPTED: Transition into POTENTIAL-CONFLICT state.

Figure 8 illustrates the transition from NORMAL state to COMMUNICATIONS-INTERRUPTED state and then back to NORMAL state again.

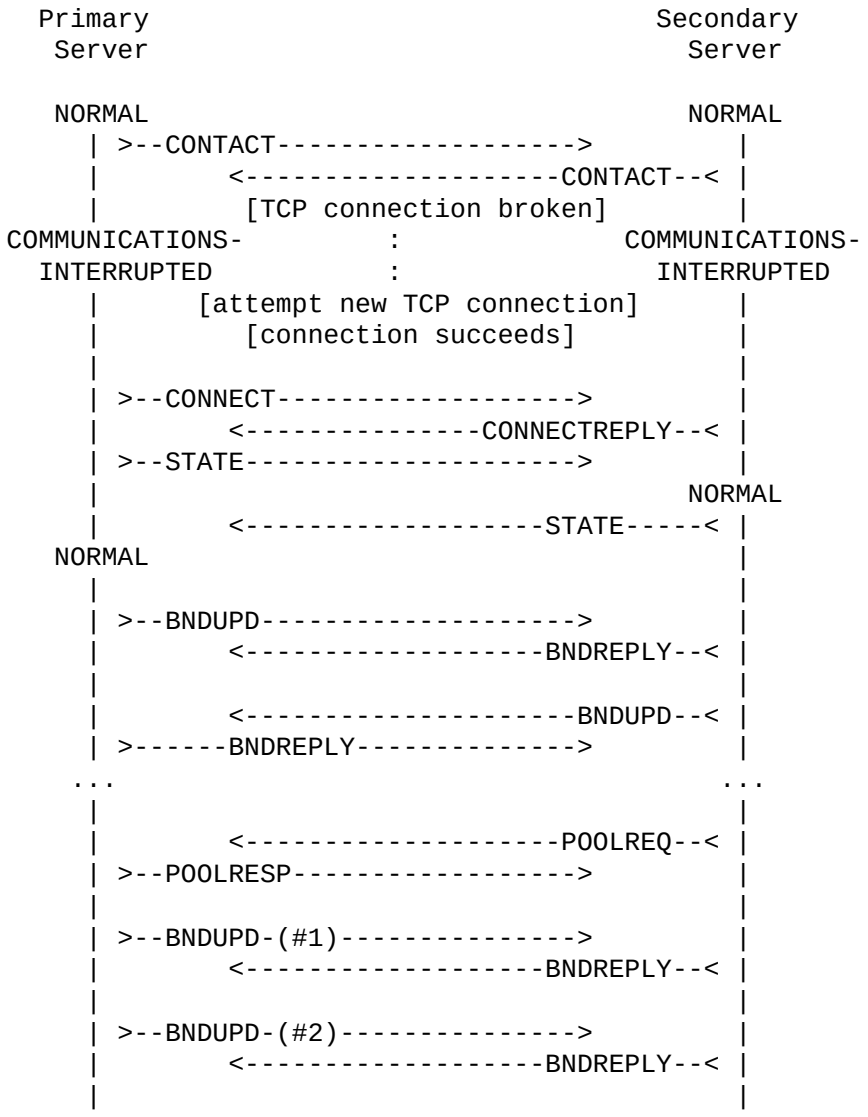


Figure 8: Transition from NORMAL State to COMMUNICATIONS-INTERRUPTED State and Back

8.10. POTENTIAL-CONFLICT State

This state indicates that the two servers are attempting to reintegrate with each other but at least one of them was running in a state that did not guarantee that automatic reintegration would be possible. In POTENTIAL-CONFLICT state, the servers may determine that the same lease has been offered and accepted by two different clients.

A goal of the failover protocol is to minimize the possibility that POTENTIAL-CONFLICT state is ever entered.

When a primary server enters POTENTIAL-CONFLICT state, it should request that the secondary send it all updates that the primary server has not yet acknowledged by sending an UPDREQ message to the secondary server.

A secondary server entering POTENTIAL-CONFLICT state will wait for the primary to send it an UPDREQ message.

8.10.1. Operation in POTENTIAL-CONFLICT State

Any server in POTENTIAL-CONFLICT state MUST NOT process any incoming DHCP requests.

8.10.2. Transition out of POTENTIAL-CONFLICT State

If communication with the partner fails while in POTENTIAL-CONFLICT state, then the server will transition to RESOLUTION-INTERRUPTED state.

Whenever either server receives an UPDDONE message from its partner while in POTENTIAL-CONFLICT state, it MUST transition to a new state. The primary MUST transition to CONFLICT-DONE state, and the secondary MUST transition to NORMAL state. This will cause the primary server to leave POTENTIAL-CONFLICT state prior to the secondary, since the primary sends an UPDREQ message and receives an UPDDONE message before the secondary sends an UPDREQ message and receives its UPDDONE message.

When a secondary server receives an indication that the primary server has made a transition from POTENTIAL-CONFLICT to CONFLICT-DONE state, it SHOULD send an UPDREQ message to the primary server.

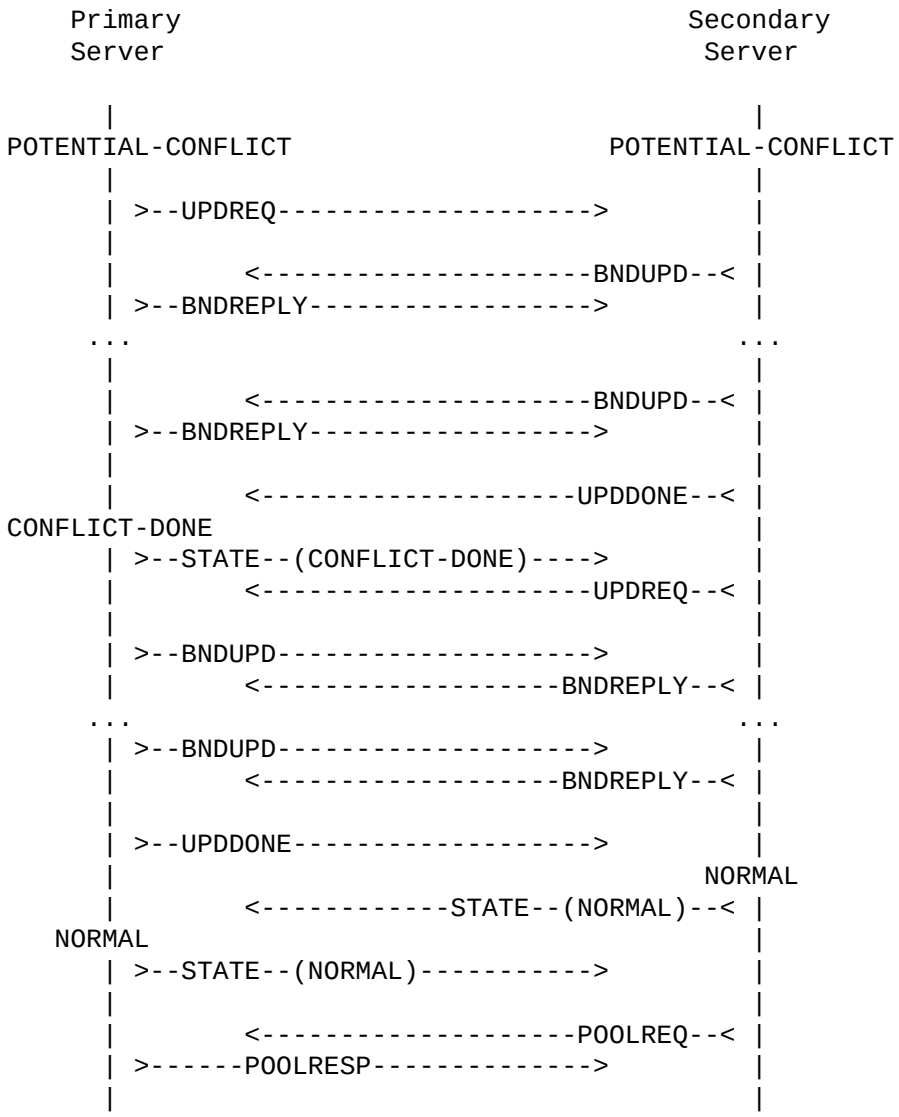


Figure 9: Transition out of POTENTIAL-CONFLICT State

8.11. RESOLUTION-INTERRUPTED State

This state indicates that the two servers were attempting to reintegrate with each other in POTENTIAL-CONFLICT state but communication failed prior to completion of reintegration.

The RESOLUTION-INTERRUPTED state exists because servers are not responsive in POTENTIAL-CONFLICT state, and if one server drops out of service while both servers are in POTENTIAL-CONFLICT state, the server that remains in service will not be able to process DHCP

client requests and there will be no DHCP server available to process client requests. The RESOLUTION-INTERRUPTED state is the state that a server moves to if its partner disappears while it is in POTENTIAL-CONFLICT state.

When a server enters RESOLUTION-INTERRUPTED state, it SHOULD raise an alarm condition to alert administrative staff of a problem in the DHCP subsystem.

8.11.1. Operation in RESOLUTION-INTERRUPTED State

In this state, a server MUST respond to all DHCP client requests. When allocating new leases, each server SHOULD allocate from its own pool (if that can be determined), where the primary SHOULD allocate only FREE leases and the secondary SHOULD allocate only FREE-BACKUP leases. When responding to renewal requests, each server will allow continued renewal of a DHCP client's current lease, independent of whether that lease was given out by the receiving server or not, although the renewal period MUST NOT exceed the MCLT beyond the later of (1) the partner lifetime already acknowledged by the other server or (2) now.

However, since the server cannot communicate with its partner in this state, the acknowledged partner lifetime will not be updated in any new bindings.

8.11.2. Transition out of RESOLUTION-INTERRUPTED State

If a server in RESOLUTION-INTERRUPTED state receives an external command informing it that its partner is down, it will transition immediately into PARTNER-DOWN state.

If communications with the other server are restored, then the server in RESOLUTION-INTERRUPTED state will transition into POTENTIAL-CONFLICT state.

8.12. CONFLICT-DONE State

This state indicates that during the process where the two servers are attempting to reintegrate with each other, the primary server has received all of the updates from the secondary server. It makes a transition into CONFLICT-DONE state so that it can be totally responsive to the client load. There is no operational difference between CONFLICT-DONE and NORMAL for the primary server, as in both states it responds to all clients' requests. The distinction between CONFLICT-DONE and NORMAL states is necessary in the event that a load-balancing extension is ever defined.

8.12.1. Operation in CONFLICT-DONE State

A primary server in CONFLICT-DONE state is fully responsive to all DHCP clients (similar to the situation in COMMUNICATIONS-INTERRUPTED state).

If communication fails, remain in CONFLICT-DONE state. If communication becomes "OK", remain in CONFLICT-DONE state until the conditions for transition out of CONFLICT-DONE state are satisfied.

8.12.2. Transition out of CONFLICT-DONE State

If communication with the partner fails while in CONFLICT-DONE state, then the server will remain in CONFLICT-DONE state.

When a primary server determines that the secondary server has made a transition into NORMAL state, the primary server will also transition into NORMAL state.

9. DNS Update Considerations

DHCP servers (and clients) can use "DNS update" as described in RFC 2136 [RFC2136] to maintain DNS name mappings as they maintain DHCP leases. Many different administrative models for DHCP-DNS integration are possible. Descriptions of several of these models, and guidelines that DHCP servers and clients should follow in carrying them out, are laid out in RFC 4704 [RFC4704].

The nature of the failover protocol introduces some issues concerning DNS updates that are not part of non-failover environments. This section describes these issues and defines the information that failover partners should exchange in order to ensure consistent behavior. The presence of this section should not be interpreted as a requirement that an implementation of the DHCPv6 failover protocol also support DNS updates.

The purpose of this discussion is to clarify the areas where the failover and DHCP DNS update protocols intersect for the benefit of implementations that support both protocols, not to introduce a new requirement into the DHCPv6 failover protocol. Thus, a DHCP server that implements the failover protocol MAY also support DNS updates, but if it does support DNS updates it SHOULD utilize the techniques described here in order to correctly distribute them between the failover partners. See RFC 4704 [RFC4704] as well as RFC 4703 [RFC4703] for information on how DHCP servers deal with potential conflicts when updating DNS even without failover.

From the standpoint of the failover protocol, there is no reason why a server that is utilizing the DNS update protocol to update a DNS server should not be a partner with a server that is not utilizing the DNS update protocol to update a DNS server. However, a server that is not able to support DNS update or is not configured to support DNS update SHOULD output a warning message when it receives BNDUPD messages that indicate that its failover partner is configured to support the DNS update protocol to update a DNS server. An implementation MAY consider this an error and refuse to accept the BNDUPD message by returning the status DNSUpdateNotSupported in an OPTION_STATUS_CODE option in the BNDREPLY message, or it MAY choose to operate anyway, having warned the administrator of the problem in some way.

9.1. Relationship between Failover and DNS Update

The failover protocol describes the conditions under which each failover server may renew a lease to its current DHCP client and describes the conditions under which it may grant a lease to a new DHCP client. An analogous set of conditions determines when a failover server should initiate a DNS update, and when it should attempt to remove records from the DNS. The failover protocol's conditions are based on the desired external behavior: avoiding duplicate address and prefix assignments, allowing clients to continue using leases that they obtained from one failover partner even if they can only communicate with the other partner, and allowing the secondary DHCP server to grant new leases even if it is unable to communicate with the primary server. The desired external DNS update behavior for DHCPv6 failover servers is similar to that described above for the failover protocol itself:

1. Allow timely DNS updates from the server that grants a lease to a client. Recognize that there is often a DNS update "lifecycle" that parallels the DHCP lease lifecycle. This is likely to include the addition of records when the lease is granted and the removal of DNS records when the lease is subsequently made available for allocation to a different client.

2. Communicate enough information between the two failover servers to allow one to complete the DNS update lifecycle even if the other server originally granted the lease.

3. Avoid redundant or overlapping DNS updates where both failover servers are attempting to perform DNS updates for the same lease-client binding.

4. Avoid situations where one partner is attempting to add resource records (RRs) related to a lease binding while the other partner is attempting to remove RRs related to the same lease binding.

While DHCPv6 servers configured for DNS update typically perform these operations on both the AAAA and the PTR RRs, this is not required. It is entirely possible that a DHCPv6 server could be configured to only update the DNS with PTR records, and the DHCPv6 clients could be responsible for updating the DNS with their own AAAA records. In this case, the discussions here would apply only to the PTR records.

9.2. Exchanging DNS Update Information

In order for either server to be able to complete a DNS update or to remove DNS records that were added by its partner, both servers need to know the FQDN associated with the lease-client binding. In addition, to properly handle DNS updates, additional information is required. All of the following information needs to be transmitted between the failover partners:

1. The FQDN that the client requested be associated with the lease. If the client doesn’t request a particular FQDN and one is synthesized by the failover server or if the failover server is configured to replace a client-requested FQDN with a different FQDN, then the server-generated value would be used.

2. The FQDN that was actually placed in the DNS for this lease. It may differ from the client-requested FQDN due to some form of disambiguation or other DHCP server configuration (as described above).

3. The status of any DNS update operations in progress or completed.

4. Information sufficient to allow the failover partner to remove the FQDN from the DNS, should that become necessary.

These data items are the minimum necessary set to reliably allow two failover partners to successfully share the responsibility to keep the DNS up to date with the leases allocated to clients.

This information would typically be included in BNDUPD messages sent from one failover partner to the other. Failover servers MAY choose not to include this information in BNDUPD messages if there has been no change in the status of any DNS update related to the lease.

The partner server receiving BNDUPD messages containing the DNS update information SHOULD compare the status information and the FQDN with the current DNS update information it has associated with the lease binding and update its notion of the DNS update status accordingly.

Some implementations will instead choose to send a BNDUPD message without waiting for the DNS update to complete and then will send a second BNDUPD message once the DNS update is complete. Other implementations will delay sending the partner a BNDUPD message until the DNS update has been acknowledged by the DNS server, or until some time limit has elapsed, in order to avoid sending a second BNDUPD message.

The FQDN option contains the FQDN that will be associated with the AAAA RR (if the server is performing a AAAA RR update for the client). The PTR RR can be generated automatically from the IPv6 address value. The FQDN may be composed in any of several ways, depending on server configuration and the information provided by the client in its DHCP messages. The client may supply a hostname that it would like the server to use in forming the FQDN, or it may supply the entire FQDN. The server may be configured to attempt to use the information the client supplies, it may be configured with an FQDN to use for the client, or it may be configured to synthesize an FQDN.

Since the server interacting with the client may not have completed the DNS update at the time it sends the first BNDUPD message about the lease binding, there may be cases where the FQDN in later BNDUPD messages does not match the FQDN included in earlier messages. For example, the responsive server may be configured to handle situations where two or more DHCP client FQDNs are identical by modifying the most-specific label in the FQDNs of some of the clients in an attempt to generate unique FQDNs for them (a process sometimes called "disambiguation"). Alternatively, at sites that use some or all of the information that clients supply to form the FQDN, it’s possible that a client’s configuration may be changed so that it begins to supply new data. The server interacting with the client may react by removing the DNS records that it originally added for the client and replacing them with records that refer to the client’s new FQDN. In such cases, the server SHOULD include the actual FQDN that was used in subsequent DNS update options in any BNDUPD messages exchanged between the failover partners. This server SHOULD include relevant information in its BNDUPD messages. This information may be necessary in order to allow the non-responsive partner to detect client configuration changes that change the hostname or FQDN data that the client includes in its DHCPv6 requests.

9.3. Adding RRs to the DNS

A failover server that is going to perform DNS updates SHOULD initiate the DNS update when it grants a new lease to a client. The server that did not grant the lease SHOULD NOT initiate a DNS update when it receives the BNDUPD message after the lease has been granted. The failover protocol ensures that only one of the partners will grant a lease to any individual client, so it follows that this requirement will prevent both partners from initiating updates simultaneously. The server initiating the update SHOULD follow the protocol in RFC 4704 [RFC4704]. The server may be configured to perform a AAAA RR update on behalf of its clients, or not. Ordinarily, a failover server will not initiate DNS updates when it renews leases. In two cases, however, a failover server MAY initiate a DNS update when it renews a lease to its existing client:

1. When the lease was granted before the server was configured to perform DNS updates, the server MAY be configured to perform updates when it next renews existing leases.

2. If a server is in PARTNER-DOWN state, it can conclude that its partner is no longer attempting to perform an update for the existing client. If the remaining server has not recorded that an update for the binding has been successfully completed, the server MAY initiate a DNS update. It may initiate this update immediately upon entry into PARTNER-DOWN state, it may perform this in the background, or it may initiate this update upon next hearing from the DHCP client.

Note that, regardless of the use of failover, there is a use case for updating the DNS on every lease renewal. If there is a concern that the information in the DNS does not match the information in the DHCP server, updating the DNS on lease renewal is one way to gradually ensure that the DNS has information that corresponds correctly to the information in the DHCP server.

9.4. Deleting RRs from the DNS

The failover server that makes a lease PENDING-FREE SHOULD initiate any DNS deletes if it has recorded that DNS records were added on behalf of the client.

A server not in PARTNER-DOWN state "makes a lease PENDING-FREE" when it initiates a BNDUPD message with a binding-status of FREE, FREE-BACKUP, EXPIRED, or RELEASED. Its partner confirms this status by acking that BNDUPD message, and upon receipt of the BNDREPLY message the server has "made the lease PENDING-FREE". Conversely, a server in PARTNER-DOWN state "makes a lease PENDING-FREE" when it sets the binding-status to FREE, since in PARTNER-DOWN state no communications with the partner are required.

It is at this point that it should initiate the DNS operations to delete RRs from the DNS. Its partner SHOULD NOT initiate DNS deletes for DNS records related to the lease binding as part of sending the BNDREPLY message. The partner MAY have issued BNDUPD messages with a binding-status of FREE, EXPIRED, or RELEASED previously, but the other server will have rejected these BNDUPD messages.

The failover protocol ensures that only one of the two partner servers will be able to make a lease PENDING-FREE. The server making the lease PENDING-FREE may be doing so while it is communicating in NORMAL state with its partner, or it may be in PARTNER-DOWN state. If a server is in PARTNER-DOWN state, it may be performing DNS deletes for RRs that its partner added originally. This allows a single remaining partner server to assume responsibility for all of the DNS update activity that the two servers were undertaking.

Another implication of this approach is that no DNS RR deletes will be performed while either server is in COMMUNICATIONS-INTERRUPTED state, since no leases are moved into the PENDING-FREE state during that period.

A failover server SHOULD ensure that a server failure while making a lease PENDING-FREE and initiating a DNS delete does not somehow leave the lease with an RR in the DNS with nothing recorded in the lease state database to trigger a DNS delete.

9.5. Name Assignment with No Update of DNS

In some cases, a DHCP server is configured to return a name to the DHCP client but not enter that name into the DNS. This is typically a name that it has discovered or generated from information it has received from the client. In this case, this name information SHOULD be communicated to the failover partner, if only to ensure that they will return the same name in the event the partner becomes the server with which the DHCP client begins to interact.

10. Security Considerations

DHCPv6 failover is an extension of a standard DHCPv6 protocol, so all security considerations from Section 23 of [RFC3315] and Section 15 of [RFC3633] related to the server apply.

The use of TCP introduces some additional concerns. Attacks that attempt to exhaust the DHCP server's available TCP connection resources can compromise the ability of legitimate partners to receive service. Malicious requestors who succeed in establishing connections but who then send invalid messages, partial messages, or no messages at all can also exhaust a server's pool of available connections.

DHCPv6 failover can operate in secure or insecure mode. Secure mode (using Transport Layer Security (TLS) [RFC5246]) would be indicated when the TCP connection between failover partners is open to external monitoring or interception. Insecure mode should only be used when the TCP connection between failover partners remains within a set of protected systems. Details of such protections are beyond the scope of this document. Failover servers MUST use the approach documented in Section 9.1 of [RFC7653] to decide whether or not to use TLS when connecting with the failover partner.

The threats created by using failover directly mirror those from using DHCPv6 itself: information leakage through monitoring, and disruption of address assignment and configuration. Monitoring the failover TCP connection provides no additional data beyond that available from monitoring the interactions between DHCPv6 clients and the DHCPv6 server. Likewise, manipulating the data flow between failover servers provides no additional opportunities to disrupt address assignment and configuration beyond that provided by acting as a counterfeit DHCP server. Protection from both threats is easier than with basic DHCPv6, as only a single TCP connection needs to be protected. Either use secure mode to protect that TCP connection or ensure that it can only exist with a set of protected systems.

When operating in secure mode, TLS is used to secure the connection. The recommendations in [RFC7525] SHOULD be followed when negotiating a TLS connection.

Servers SHOULD offer configuration parameters to limit the sources of incoming connections through validation and use of the digital certificates presented to create a TLS connection. They SHOULD also limit the number of accepted connections and limit the period of time during which an idle connection will be left open.

Authentication for DHCPv6 messages [RFC3315] MUST NOT be used to attempt to secure transmission of the messages described in this document. If authentication is desired, secure mode using TLS SHOULD be employed as described in Sections 8.2 and 9.1 of [RFC7653].

11. IANA Considerations

IANA has assigned values for the following new DHCPv6 message types in the registry maintained at <http://www.iana.org/assignments/dhcpv6-parameters>:

- BNDUPD (24)
- BNDREPLY (25)
- POOLREQ (26)
- POOLRESP (27)
- UPDREQ (28)
- UPDREQALL (29)
- UPDDONE (30)
- CONNECT (31)
- CONNECTREPLY (32)
- DISCONNECT (33)
- STATE (34)
- CONTACT (35)

IANA has assigned values for the following new DHCPv6 option codes in the registry maintained at <http://www.iana.org/assignments/dhcpv6-parameters>:

- OPTION_F_BINDING_STATUS (114)
- OPTION_F_CONNECT_FLAGS (115)
- OPTION_F_DNS_REMOVAL_INFO (116)
- OPTION_F_DNS_HOST_NAME (117)
- OPTION_F_DNS_ZONE_NAME (118)
- OPTION_F_DNS_FLAGS (119)
- OPTION_F_EXPIRATION_TIME (120)
- OPTION_F_MAX_UNACKED_BNDUPD (121)
- OPTION_F_MCLT (122)
- OPTION_F_PARTNER_LIFETIME (123)
- OPTION_F_PARTNER_LIFETIME_SENT (124)
- OPTION_F_PARTNER_DOWN_TIME (125)
- OPTION_F_PARTNER_RAW_CLT_TIME (126)
- OPTION_F_PROTOCOL_VERSION (127)
- OPTION_F_KEEPALIVE_TIME (128)
- OPTION_F_RECONFIGURE_DATA (129)
- OPTION_F_RELATIONSHIP_NAME (130)
- OPTION_F_SERVER_FLAGS (131)
- OPTION_F_SERVER_STATE (132)
- OPTION_F_START_TIME_OF_STATE (133)
- OPTION_F_STATE_EXPIRATION_TIME (134)

IANA has assigned values for the following new DHCPv6 status codes in the registry maintained at <http://www.iana.org/assignments/dhcpv6-parameters>:

- AddressInUse (16)
- ConfigurationConflict (17)
- MissingBindingInformation (18)
- OutdatedBindingInformation (19)
- ServerShuttingDown (20)
- DNSUpdateNotSupported (21)
- ExcessiveTimeSkew (22)

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