

Dynamic Host Configuration Protocol

Status of this memo

This document specifies an Internet standards track protocol for the Internet community, and requests discussion and suggestions for improvements. Please refer to the current edition of the "Internet Official Protocol Standards" (STD 1) for the standardization state and status of this protocol. Distribution of this memo is unlimited.

Abstract

The Dynamic Host Configuration Protocol (DHCP) provides a framework for passing configuration information to hosts on a TCPIP network. DHCP is based on the Bootstrap Protocol (BOOTP) [7], adding the capability of automatic allocation of reusable network addresses and additional configuration options [19]. DHCP captures the behavior of BOOTP relay agents [7, 21], and DHCP participants can interoperate with BOOTP participants [9].

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1. Introduction

The Dynamic Host Configuration Protocol (DHCP) provides configuration parameters to Internet hosts. DHCP consists of two components: a protocol for delivering host-specific configuration parameters from a DHCP server to a host and a mechanism for allocation of network addresses to hosts.

DHCP is built on a client-server model, where designated DHCP server hosts allocate network addresses and deliver configuration parameters to dynamically configured hosts. Throughout the remainder of this document, the term "server" refers to a host providing initialization parameters through DHCP, and the term "client" refers to a host requesting initialization parameters from a DHCP server.

A host should not act as a DHCP server unless explicitly configured to do so by a system administrator. The diversity of hardware and protocol implementations in the Internet would preclude reliable operation if random hosts were allowed to respond to DHCP requests. For example, IP requires the setting of many parameters within the protocol implementation software. Because IP can be used on many dissimilar kinds of network hardware, values for those parameters cannot be guessed or assumed to have correct defaults. Also, distributed address allocation schemes depend on a polling/defense

mechanism for discovery of addresses that are already in use. IP hosts may not always be able to defend their network addresses, so that such a distributed address allocation scheme cannot be guaranteed to avoid allocation of duplicate network addresses.

DHCP supports three mechanisms for IP address allocation. In "automatic allocation", DHCP assigns a permanent IP address to a client. In "dynamic allocation", DHCP assigns an IP address to a client for a limited period of time (or until the client explicitly relinquishes the address). In "manual allocation", a client's IP address is assigned by the network administrator, and DHCP is used simply to convey the assigned address to the client. A particular network will use one or more of these mechanisms, depending on the policies of the network administrator.

Dynamic allocation is the only one of the three mechanisms that allows automatic reuse of an address that is no longer needed by the client to which it was assigned. Thus, dynamic allocation is particularly useful for assigning an address to a client that will be connected to the network only temporarily or for sharing a limited pool of IP addresses among a group of clients that do not need permanent IP addresses. Dynamic allocation may also be a good choice for assigning an IP address to a new client being permanently connected to a network where IP addresses are sufficiently scarce that it is important to reclaim them when old clients are retired. Manual allocation allows DHCP to be used to eliminate the error-prone process of manually configuring hosts with IP addresses in environments where (for whatever reasons) it is desirable to manage IP address assignment outside of the DHCP mechanisms.

The format of DHCP messages is based on the format of BOOTP messages, to capture the BOOTP relay agent behavior described as part of the BOOTP specification [7, 21] and to allow interoperability of existing BOOTP clients with DHCP servers. Using BOOTP relay agents eliminates the necessity of having a DHCP server on each physical network segment.

1.1 Changes to RFC 1541

This document updates the DHCP protocol specification that appears in RFC1541. A new DHCP message type, DHCPINFORM, has been added; see section 3.4, 4.3 and 4.4 for details. The classing mechanism for identifying DHCP clients to DHCP servers has been extended to include "vendor" classes as defined in sections 4.2 and 4.3. The minimum lease time restriction has been removed. Finally, many editorial changes have been made to clarify the text as a result of experience gained in DHCP interoperability tests.

1.2 Related Work

There are several Internet protocols and related mechanisms that address some parts of the dynamic host configuration problem. The Reverse Address Resolution Protocol (RARP) [10] (through the extensions defined in the Dynamic RARP (DRARP) [5]) explicitly addresses the problem of network address discovery, and includes an automatic IP address assignment mechanism. The Trivial File Transfer Protocol (TFTP) [20] provides for transport of a boot image from a boot server. The Internet Control Message Protocol (ICMP) [16] provides for informing hosts of additional routers via "ICMP redirect" messages. ICMP also can provide subnet mask information through the "ICMP mask request" message and other information through the (obsolete) "ICMP information request" message. Hosts can locate routers through the ICMP router discovery mechanism [8].

BOOTP is a transport mechanism for a collection of configuration information. BOOTP is also extensible, and official extensions [17] have been defined for several configuration parameters. Morgan has proposed extensions to BOOTP for dynamic IP address assignment [15]. The Network Information Protocol (NIP), used by the Athena project at MIT, is a distributed mechanism for dynamic IP address assignment [19]. The Resource Location Protocol RLP [1] provides for location of higher level services. Sun Microsystems diskless workstations use a boot procedure that employs RARP, TFTP and an RPC mechanism called "bootparams" to deliver configuration information and operating system code to diskless hosts. (Sun Microsystems, Sun Workstation and SunOS are trademarks of Sun Microsystems, Inc.) Some Sun networks also use DRARP and an auto-installation mechanism to automate the configuration of new hosts in an existing network.

In other related work, the path minimum transmission unit (MTU) discovery algorithm can determine the MTU of an arbitrary internet path [14]. The Address Resolution Protocol (ARP) has been proposed as a transport protocol for resource location and selection [6]. Finally, the Host Requirements RFCs [3, 4] mention specific requirements for host reconfiguration and suggest a scenario for initial configuration of diskless hosts.

1.3 Problem definition and issues

DHCP is designed to supply DHCP clients with the configuration parameters defined in the Host Requirements RFCs. After obtaining parameters via DHCP, a DHCP client should be able to exchange packets with any other host in the Internet. The TCP/IP stack parameters supplied by DHCP are listed in Appendix A.

Not all of these parameters are required for a newly initialized client. A client and server may negotiate for the transmission of only those parameters required by the client or specific to a particular subnet.

DHCP allows but does not require the configuration of client parameters not directly related to the IP protocol. DHCP also does not address registration of newly configured clients with the Domain Name System (DNS) [12, 13].

DHCP is not intended for use in configuring routers.

1.4 Requirements

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

- o "MUST"

This word or the adjective "REQUIRED" means that the item is an absolute requirement of this specification.

- o "MUST NOT"

This phrase means that the item is an absolute prohibition of this specification.

- o "SHOULD"

This word or the adjective "RECOMMENDED" means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.

- o "SHOULD NOT"

This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

- o "MAY"

This word or the adjective "OPTIONAL" means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

1.5 Terminology

This document uses the following terms:

- o "DHCP client"

A DHCP client is an Internet host using DHCP to obtain configuration parameters such as a network address.

- o "DHCP server"

A DHCP server is an Internet host that returns configuration parameters to DHCP clients.

- o "BOOTP relay agent"

A BOOTP relay agent or relay agent is an Internet host or router that passes DHCP messages between DHCP clients and DHCP servers. DHCP is designed to use the same relay agent behavior as specified in the BOOTP protocol specification.

- o "binding"

A binding is a collection of configuration parameters, including at least an IP address, associated with or "bound to" a DHCP client. Bindings are managed by DHCP servers.

1.6 Design goals

The following list gives general design goals for DHCP.

- o DHCP should be a mechanism rather than a policy. DHCP must allow local system administrators control over configuration parameters where desired; e.g., local system administrators should be able to enforce local policies concerning allocation and access to local resources where desired.

- o Clients should require no manual configuration. Each client should be able to discover appropriate local configuration parameters without user intervention and incorporate those parameters into its own configuration.
- o Networks should require no manual configuration for individual clients. Under normal circumstances, the network manager should not have to enter any per-client configuration parameters.
- o DHCP should not require a server on each subnet. To allow for scale and economy, DHCP must work across routers or through the intervention of BOOTP relay agents.
- o A DHCP client must be prepared to receive multiple responses to a request for configuration parameters. Some installations may include multiple, overlapping DHCP servers to enhance reliability and increase performance.
- o DHCP must coexist with statically configured, non-participating hosts and with existing network protocol implementations.
- o DHCP must interoperate with the BOOTP relay agent behavior as described by RFC 951 and by RFC 1542 [21].
- o DHCP must provide service to existing BOOTP clients.

The following list gives design goals specific to the transmission of the network layer parameters. DHCP must:

- o Guarantee that any specific network address will not be in use by more than one DHCP client at a time,
- o Retain DHCP client configuration across DHCP client reboot. A DHCP client should, whenever possible, be assigned the same configuration parameters (e.g., network address) in response to each request,
- o Retain DHCP client configuration across server reboots, and, whenever possible, a DHCP client should be assigned the same configuration parameters despite restarts of the DHCP mechanism,
- o Allow automated assignment of configuration parameters to new clients to avoid hand configuration for new clients,
- o Support fixed or permanent allocation of configuration parameters to specific clients.

2. Protocol Summary

From the client's point of view, DHCP is an extension of the BOOTP mechanism. This behavior allows existing BOOTP clients to interoperate with DHCP servers without requiring any change to the clients' initialization software. RFC 1542 [2] details the interactions between BOOTP and DHCP clients and servers [9]. There are some new, optional transactions that optimize the interaction between DHCP clients and servers that are described in sections 3 and 4.

Figure 1 gives the format of a DHCP message and table 1 describes each of the fields in the DHCP message. The numbers in parentheses indicate the size of each field in octets. The names for the fields given in the figure will be used throughout this document to refer to the fields in DHCP messages.

There are two primary differences between DHCP and BOOTP. First, DHCP defines mechanisms through which clients can be assigned a network address for a finite lease, allowing for serial reassignment of network addresses to different clients. Second, DHCP provides the mechanism for a client to acquire all of the IP configuration parameters that it needs in order to operate.

DHCP introduces a small change in terminology intended to clarify the meaning of one of the fields. What was the "vendor extensions" field in BOOTP has been re-named the "options" field in DHCP. Similarly, the tagged data items that were used inside the BOOTP "vendor extensions" field, which were formerly referred to as "vendor extensions," are now termed simply "options."

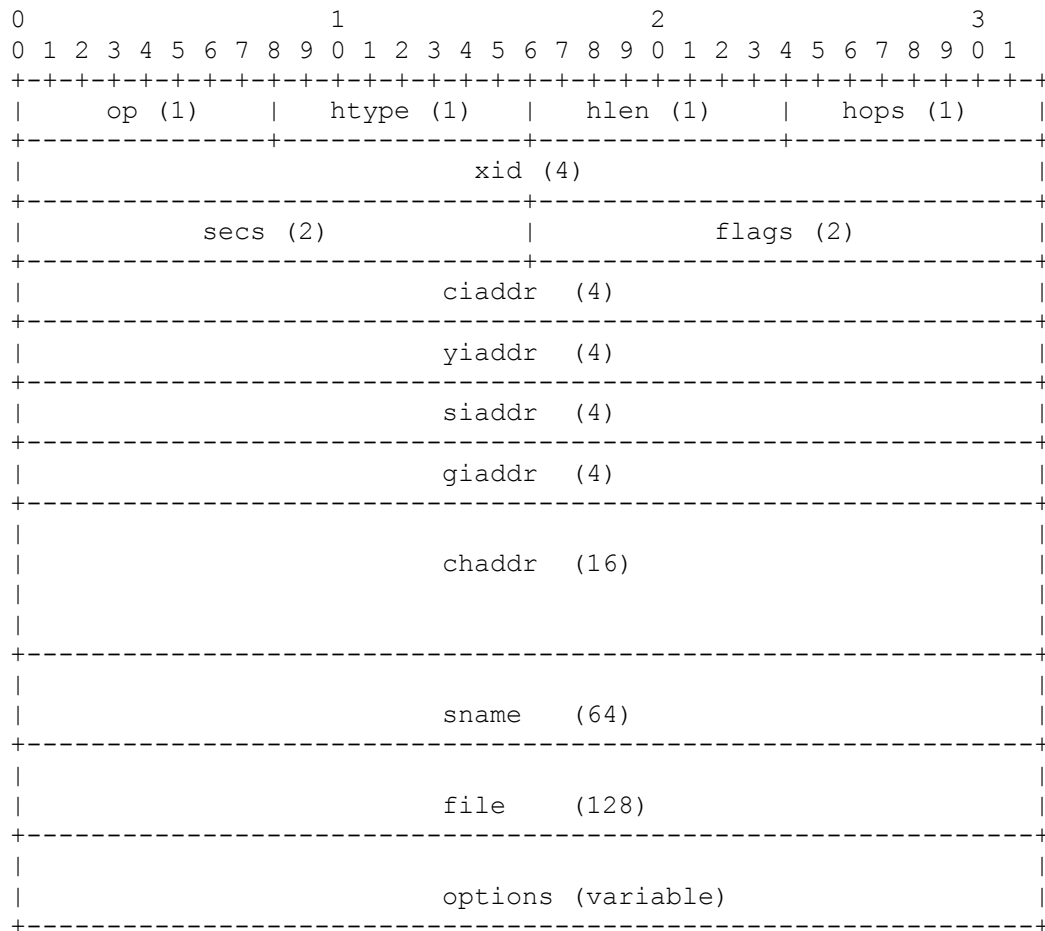


Figure 1: Format of a DHCP message

DHCP defines a new 'client identifier' option that is used to pass an explicit client identifier to a DHCP server. This change eliminates the overloading of the 'chaddr' field in BOOTP messages, where 'chaddr' is used both as a hardware address for transmission of BOOTP reply messages and as a client identifier. The 'client identifier' is an opaque key, not to be interpreted by the server; for example, the 'client identifier' may contain a hardware address, identical to the contents of the 'chaddr' field, or it may contain another type of identifier, such as a DNS name. The 'client identifier' chosen by a DHCP client MUST be unique to that client within the subnet to which the client is attached. If the client uses a 'client identifier' in one message, it MUST use that same identifier in all subsequent messages, to ensure that all servers correctly identify the client.

DHCP clarifies the interpretation of the 'siaddr' field as the address of the server to use in the next step of the client's bootstrap process. A DHCP server may return its own address in the 'siaddr' field, if the server is prepared to supply the next bootstrap service (e.g., delivery of an operating system executable image). A DHCP server always returns its own address in the 'server identifier' option.

FIELD	OCTETS	DESCRIPTION
-----	-----	-----
op	1	Message op code / message type. 1 = BOOTREQUEST, 2 = BOOTREPLY
htype	1	Hardware address type, see ARP section in "Assigned Numbers" RFC; e.g., '1' = 10mb ethernet.
hlen	1	Hardware address length (e.g. '6' for 10mb ethernet).
hops	1	Client sets to zero, optionally used by relay agents when booting via a relay agent.
xid	4	Transaction ID, a random number chosen by the client, used by the client and server to associate messages and responses between a client and a server.
secs	2	Filled in by client, seconds elapsed since client began address acquisition or renewal process.
flags	2	Flags (see figure 2).
ciaddr	4	Client IP address; only filled in if client is in BOUND, RENEW or REBINDING state and can respond to ARP requests.
yiaddr	4	'your' (client) IP address.
siaddr	4	IP address of next server to use in bootstrap; returned in DHCPOFFER, DHCPACK by server.
giaddr	4	Relay agent IP address, used in booting via a relay agent.
chaddr	16	Client hardware address.
sname	64	Optional server host name, null terminated string.
file	128	Boot file name, null terminated string; "generic" name or null in DHCPDISCOVER, fully qualified directory-path name in DHCPOFFER.
options	var	Optional parameters field. See the options documents for a list of defined options.

Table 1: Description of fields in a DHCP message

The 'options' field is now variable length. A DHCP client must be prepared to receive DHCP messages with an 'options' field of at least length 312 octets. This requirement implies that a DHCP client must be prepared to receive a message of up to 576 octets, the minimum IP

datagram size an IP host must be prepared to accept [3]. DHCP clients may negotiate the use of larger DHCP messages through the 'maximum DHCP message size' option. The options field may be further extended into the 'file' and 'sname' fields.

In the case of a client using DHCP for initial configuration (before the client's TCP/IP software has been completely configured), DHCP requires creative use of the client's TCP/IP software and liberal interpretation of RFC 1122. The TCP/IP software SHOULD accept and forward to the IP layer any IP packets delivered to the client's hardware address before the IP address is configured; DHCP servers and BOOTP relay agents may not be able to deliver DHCP messages to clients that cannot accept hardware unicast datagrams before the TCP/IP software is configured.

To work around some clients that cannot accept IP unicast datagrams before the TCP/IP software is configured as discussed in the previous paragraph, DHCP uses the 'flags' field [21]. The leftmost bit is defined as the BROADCAST (B) flag. The semantics of this flag are discussed in section 4.1 of this document. The remaining bits of the flags field are reserved for future use. They MUST be set to zero by clients and ignored by servers and relay agents. Figure 2 gives the format of the 'flags' field.

```

                1 1 1 1 1 1
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|B|          MBZ          |
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+

```

B: BROADCAST flag

MBZ: MUST BE ZERO (reserved for future use)

Figure 2: Format of the 'flags' field

2.1 Configuration parameters repository

The first service provided by DHCP is to provide persistent storage of network parameters for network clients. The model of DHCP persistent storage is that the DHCP service stores a key-value entry for each client, where the key is some unique identifier (for example, an IP subnet number and a unique identifier within the subnet) and the value contains the configuration parameters for the client.

For example, the key might be the pair (IP-subnet-number, hardware-address) (note that the "hardware-address" should be typed by the

type of hardware to accommodate possible duplication of hardware addresses resulting from bit-ordering problems in a mixed-media, bridged network) allowing for serial or concurrent reuse of a hardware address on different subnets, and for hardware addresses that may not be globally unique. Alternately, the key might be the pair (IP-subnet-number, hostname), allowing the server to assign parameters intelligently to a DHCP client that has been moved to a different subnet or has changed hardware addresses (perhaps because the network interface failed and was replaced). The protocol defines that the key will be (IP-subnet-number, hardware-address) unless the client explicitly supplies an identifier using the 'client identifier' option. A client can query the DHCP service to retrieve its configuration parameters. The client interface to the configuration parameters repository consists of protocol messages to request configuration parameters and responses from the server carrying the configuration parameters.

2.2 Dynamic allocation of network addresses

The second service provided by DHCP is the allocation of temporary or permanent network (IP) addresses to clients. The basic mechanism for the dynamic allocation of network addresses is simple: a client requests the use of an address for some period of time. The allocation mechanism (the collection of DHCP servers) guarantees not to reallocate that address within the requested time and attempts to return the same network address each time the client requests an address. In this document, the period over which a network address is allocated to a client is referred to as a "lease" [11]. The client may extend its lease with subsequent requests. The client may issue a message to release the address back to the server when the client no longer needs the address. The client may ask for a permanent assignment by asking for an infinite lease. Even when assigning "permanent" addresses, a server may choose to give out lengthy but non-infinite leases to allow detection of the fact that the client has been retired.

In some environments it will be necessary to reassign network addresses due to exhaustion of available addresses. In such environments, the allocation mechanism will reuse addresses whose lease has expired. The server should use whatever information is available in the configuration information repository to choose an address to reuse. For example, the server may choose the least recently assigned address. As a consistency check, the allocating server SHOULD probe the reused address before allocating the address, e.g., with an ICMP echo request, and the client SHOULD probe the newly received address, e.g., with ARP.

3. The Client-Server Protocol

DHCP uses the BOOTP message format defined in RFC 951 and given in table 1 and figure 1. The 'op' field of each DHCP message sent from a client to a server contains BOOTREQUEST. BOOTREPLY is used in the 'op' field of each DHCP message sent from a server to a client.

The first four octets of the 'options' field of the DHCP message contain the (decimal) values 99, 130, 83 and 99, respectively (this is the same magic cookie as is defined in RFC 1497 [17]). The remainder of the 'options' field consists of a list of tagged parameters that are called "options". All of the "vendor extensions" listed in RFC 1497 are also DHCP options. RFC 1533 gives the complete set of options defined for use with DHCP.

Several options have been defined so far. One particular option - the "DHCP message type" option - must be included in every DHCP message. This option defines the "type" of the DHCP message. Additional options may be allowed, required, or not allowed, depending on the DHCP message type.

Throughout this document, DHCP messages that include a 'DHCP message type' option will be referred to by the type of the message; e.g., a DHCP message with 'DHCP message type' option type 1 will be referred to as a "DHCPDISCOVER" message.

3.1 Client-server interaction - allocating a network address

The following summary of the protocol exchanges between clients and servers refers to the DHCP messages described in table 2. The timeline diagram in figure 3 shows the timing relationships in a typical client-server interaction. If the client already knows its address, some steps may be omitted; this abbreviated interaction is described in section 3.2.

1. The client broadcasts a DHCPDISCOVER message on its local physical subnet. The DHCPDISCOVER message MAY include options that suggest values for the network address and lease duration. BOOTP relay agents may pass the message on to DHCP servers not on the same physical subnet.
2. Each server may respond with a DHCPOFFER message that includes an available network address in the 'yiaddr' field (and other configuration parameters in DHCP options). Servers need not reserve the offered network address, although the protocol will work more efficiently if the server avoids allocating the offered network address to another client. When allocating a new address, servers SHOULD check that the offered network address is not

already in use; e.g., the server may probe the offered address with an ICMP Echo Request. Servers SHOULD be implemented so that network administrators MAY choose to disable probes of newly allocated addresses. The server transmits the DHCPOFFER message to the client, using the BOOTP relay agent if necessary.

Message -----	Use ---
DHCPDISCOVER	- Client broadcast to locate available servers.
DHCPOFFER	- Server to client in response to DHCPDISCOVER with offer of configuration parameters.
DHCPREQUEST	- Client message to servers either (a) requesting offered parameters from one server and implicitly declining offers from all others, (b) confirming correctness of previously allocated address after, e.g., system reboot, or (c) extending the lease on a particular network address.
DHCPACK	- Server to client with configuration parameters, including committed network address.
DHCNNAK	- Server to client indicating client's notion of network address is incorrect (e.g., client has moved to new subnet) or client's lease as expired
DHCPDECLINE	- Client to server indicating network address is already in use.
DHCPRELEASE	- Client to server relinquishing network address and cancelling remaining lease.
DHCPINFORM	- Client to server, asking only for local configuration parameters; client already has externally configured network address.

Table 2: DHCP messages

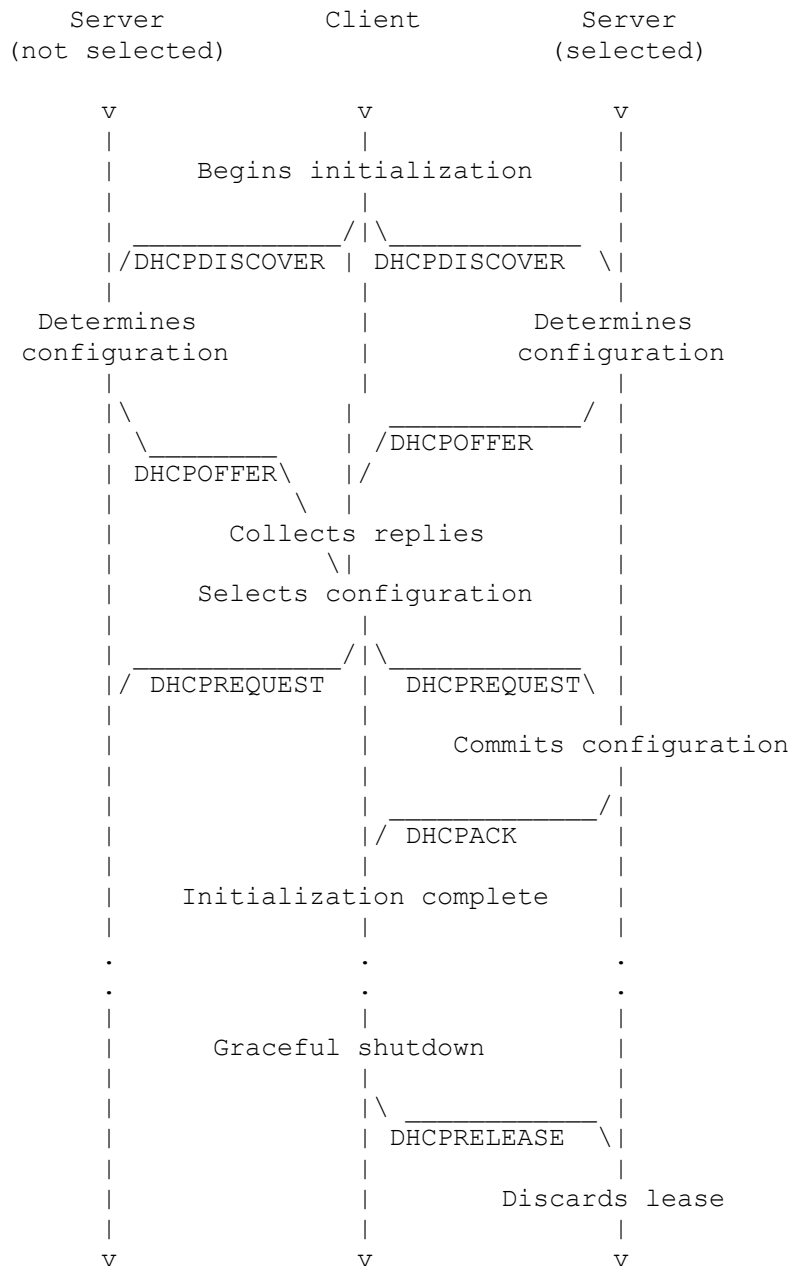


Figure 3: Timeline diagram of messages exchanged between DHCP client and servers when allocating a new network address

3. The client receives one or more DHCPOFFER messages from one or more servers. The client may choose to wait for multiple responses. The client chooses one server from which to request configuration parameters, based on the configuration parameters offered in the DHCPOFFER messages. The client broadcasts a DHCPREQUEST message that MUST include the 'server identifier' option to indicate which server it has selected, and that MAY include other options specifying desired configuration values. The 'requested IP address' option MUST be set to the value of 'yiaddr' in the DHCPOFFER message from the server. This DHCPREQUEST message is broadcast and relayed through DHCP/BOOTP relay agents. To help ensure that any BOOTP relay agents forward the DHCPREQUEST message to the same set of DHCP servers that received the original DHCPDISCOVER message, the DHCPREQUEST message MUST use the same value in the DHCP message header's 'secs' field and be sent to the same IP broadcast address as the original DHCPDISCOVER message. The client times out and retransmits the DHCPDISCOVER message if the client receives no DHCPOFFER messages.
4. The servers receive the DHCPREQUEST broadcast from the client. Those servers not selected by the DHCPREQUEST message use the message as notification that the client has declined that server's offer. The server selected in the DHCPREQUEST message commits the binding for the client to persistent storage and responds with a DHCPACK message containing the configuration parameters for the requesting client. The combination of 'client identifier' or 'chaddr' and assigned network address constitute a unique identifier for the client's lease and are used by both the client and server to identify a lease referred to in any DHCP messages. Any configuration parameters in the DHCPACK message SHOULD NOT conflict with those in the earlier DHCPOFFER message to which the client is responding. The server SHOULD NOT check the offered network address at this point. The 'yiaddr' field in the DHCPACK messages is filled in with the selected network address.

If the selected server is unable to satisfy the DHCPREQUEST message (e.g., the requested network address has been allocated), the server SHOULD respond with a DHCPNAK message.

A server MAY choose to mark addresses offered to clients in DHCPOFFER messages as unavailable. The server SHOULD mark an address offered to a client in a DHCPOFFER message as available if the server receives no DHCPREQUEST message from that client.

5. The client receives the DHCPACK message with configuration parameters. The client SHOULD perform a final check on the parameters (e.g., ARP for allocated network address), and notes the duration of the lease specified in the DHCPACK message. At this

point, the client is configured. If the client detects that the address is already in use (e.g., through the use of ARP), the client MUST send a DHCPDECLINE message to the server and restarts the configuration process. The client SHOULD wait a minimum of ten seconds before restarting the configuration process to avoid excessive network traffic in case of looping.

If the client receives a DHCPNAK message, the client restarts the configuration process.

The client times out and retransmits the DHCPREQUEST message if the client receives neither a DHCPACK or a DHCPNAK message. The client retransmits the DHCPREQUEST according to the retransmission algorithm in section 4.1. The client should choose to retransmit the DHCPREQUEST enough times to give adequate probability of contacting the server without causing the client (and the user of that client) to wait overly long before giving up; e.g., a client retransmitting as described in section 4.1 might retransmit the DHCPREQUEST message four times, for a total delay of 60 seconds, before restarting the initialization procedure. If the client receives neither a DHCPACK or a DHCPNAK message after employing the retransmission algorithm, the client reverts to INIT state and restarts the initialization process. The client SHOULD notify the user that the initialization process has failed and is restarting.

6. The client may choose to relinquish its lease on a network address by sending a DHCPRELEASE message to the server. The client identifies the lease to be released with its 'client identifier', or 'chaddr' and network address in the DHCPRELEASE message. If the client used a 'client identifier' when it obtained the lease, it MUST use the same 'client identifier' in the DHCPRELEASE message.

3.2 Client-server interaction - reusing a previously allocated network address

If a client remembers and wishes to reuse a previously allocated network address, a client may choose to omit some of the steps described in the previous section. The timeline diagram in figure 4 shows the timing relationships in a typical client-server interaction for a client reusing a previously allocated network address.

1. The client broadcasts a DHCPREQUEST message on its local subnet. The message includes the client's network address in the 'requested IP address' option. As the client has not received its network address, it MUST NOT fill in the 'ciaddr' field. BOOTP relay agents pass the message on to DHCP servers not on the same subnet. If the client used a 'client identifier' to obtain its address, the client MUST use the same 'client identifier' in the DHCPREQUEST message.
2. Servers with knowledge of the client's configuration parameters respond with a DHCPACK message to the client. Servers SHOULD NOT check that the client's network address is already in use; the client may respond to ICMP Echo Request messages at this point.

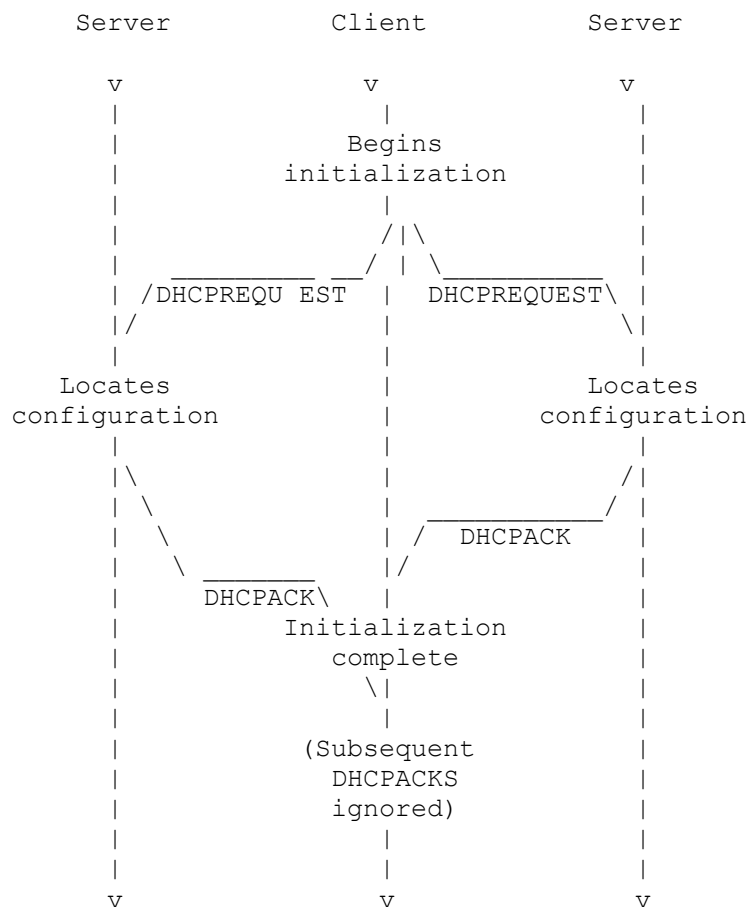


Figure 4: Timeline diagram of messages exchanged between DHCP client and servers when reusing a previously allocated network address

If the client's request is invalid (e.g., the client has moved to a new subnet), servers SHOULD respond with a DHCPNAK message to the client. Servers SHOULD NOT respond if their information is not guaranteed to be accurate. For example, a server that identifies a request for an expired binding that is owned by another server SHOULD NOT respond with a DHCPNAK unless the servers are using an explicit mechanism to maintain coherency among the servers.

If 'giaddr' is 0x0 in the DHCPREQUEST message, the client is on the same subnet as the server. The server MUST broadcast the DHCPNAK message to the 0xffffffff broadcast address because the client may not have a correct network address or subnet mask, and the client may not be answering ARP requests. Otherwise, the server MUST send the DHCPNAK message to the IP address of the BOOTP relay agent, as recorded in 'giaddr'. The relay agent will, in turn, forward the message directly to the client's hardware address, so that the DHCPNAK can be delivered even if the client has moved to a new network.

3. The client receives the DHCPACK message with configuration parameters. The client performs a final check on the parameters (as in section 3.1), and notes the duration of the lease specified in the DHCPACK message. The specific lease is implicitly identified by the 'client identifier' or 'chaddr' and the network address. At this point, the client is configured.

If the client detects that the IP address in the DHCPACK message is already in use, the client MUST send a DHCPDECLINE message to the server and restarts the configuration process by requesting a new network address. This action corresponds to the client moving to the INIT state in the DHCP state diagram, which is described in section 4.4.

If the client receives a DHCPNAK message, it cannot reuse its remembered network address. It must instead request a new address by restarting the configuration process, this time using the (non-abbreviated) procedure described in section 3.1. This action also corresponds to the client moving to the INIT state in the DHCP state diagram.

The client times out and retransmits the DHCPREQUEST message if the client receives neither a DHCPACK nor a DHCPNAK message. The client retransmits the DHCPREQUEST according to the retransmission algorithm in section 4.1. The client should choose to retransmit the DHCPREQUEST enough times to give adequate probability of contacting the server without causing the client (and the user of that client) to wait overly long before giving up; e.g., a client retransmitting as described in section 4.1 might retransmit the

DHCPREQUEST message four times, for a total delay of 60 seconds, before restarting the initialization procedure. If the client receives neither a DHCPACK or a DHCPNAK message after employing the retransmission algorithm, the client MAY choose to use the previously allocated network address and configuration parameters for the remainder of the unexpired lease. This corresponds to moving to BOUND state in the client state transition diagram shown in figure 5.

4. The client may choose to relinquish its lease on a network address by sending a DHCPRELEASE message to the server. The client identifies the lease to be released with its 'client identifier', or 'chaddr' and network address in the DHCPRELEASE message.

Note that in this case, where the client retains its network address locally, the client will not normally relinquish its lease during a graceful shutdown. Only in the case where the client explicitly needs to relinquish its lease, e.g., the client is about to be moved to a different subnet, will the client send a DHCPRELEASE message.

3.3 Interpretation and representation of time values

A client acquires a lease for a network address for a fixed period of time (which may be infinite). Throughout the protocol, times are to be represented in units of seconds. The time value of 0xffffffff is reserved to represent "infinity".

As clients and servers may not have synchronized clocks, times are represented in DHCP messages as relative times, to be interpreted with respect to the client's local clock. Representing relative times in units of seconds in an unsigned 32 bit word gives a range of relative times from 0 to approximately 100 years, which is sufficient for the relative times to be measured using DHCP.

The algorithm for lease duration interpretation given in the previous paragraph assumes that client and server clocks are stable relative to each other. If there is drift between the two clocks, the server may consider the lease expired before the client does. To compensate, the server may return a shorter lease duration to the client than the server commits to its local database of client information.

3.4 Obtaining parameters with externally configured network address

If a client has obtained a network address through some other means (e.g., manual configuration), it may use a DHCPINFORM request message

to obtain other local configuration parameters. Servers receiving a DHCPINFORM message construct a DHCPACK message with any local configuration parameters appropriate for the client without: allocating a new address, checking for an existing binding, filling in 'yiaddr' or including lease time parameters. The servers SHOULD unicast the DHCPACK reply to the address given in the 'ciaddr' field of the DHCPINFORM message.

The server SHOULD check the network address in a DHCPINFORM message for consistency, but MUST NOT check for an existing lease. The server forms a DHCPACK message containing the configuration parameters for the requesting client and sends the DHCPACK message directly to the client.

3.5 Client parameters in DHCP

Not all clients require initialization of all parameters listed in Appendix A. Two techniques are used to reduce the number of parameters transmitted from the server to the client. First, most of the parameters have defaults defined in the Host Requirements RFCs; if the client receives no parameters from the server that override the defaults, a client uses those default values. Second, in its initial DHCPDISCOVER or DHCPREQUEST message, a client may provide the server with a list of specific parameters the client is interested in. If the client includes a list of parameters in a DHCPDISCOVER message, it MUST include that list in any subsequent DHCPREQUEST messages.

The client SHOULD include the 'maximum DHCP message size' option to let the server know how large the server may make its DHCP messages. The parameters returned to a client may still exceed the space allocated to options in a DHCP message. In this case, two additional options flags (which must appear in the 'options' field of the message) indicate that the 'file' and 'sname' fields are to be used for options.

The client can inform the server which configuration parameters the client is interested in by including the 'parameter request list' option. The data portion of this option explicitly lists the options requested by tag number.

In addition, the client may suggest values for the network address and lease time in the DHCPDISCOVER message. The client may include the 'requested IP address' option to suggest that a particular IP address be assigned, and may include the 'IP address lease time' option to suggest the lease time it would like. Other options representing "hints" at configuration parameters are allowed in a DHCPDISCOVER or DHCPREQUEST message. However, additional options may

be ignored by servers, and multiple servers may, therefore, not return identical values for some options. The 'requested IP address' option is to be filled in only in a DHCPREQUEST message when the client is verifying network parameters obtained previously. The client fills in the 'ciaddr' field only when correctly configured with an IP address in BOUND, RENEWING or REBINDING state.

If a server receives a DHCPREQUEST message with an invalid 'requested IP address', the server SHOULD respond to the client with a DHCPNAK message and may choose to report the problem to the system administrator. The server may include an error message in the 'message' option.

3.6 Use of DHCP in clients with multiple interfaces

A client with multiple network interfaces must use DHCP through each interface independently to obtain configuration information parameters for those separate interfaces.

3.7 When clients should use DHCP

A client SHOULD use DHCP to reacquire or verify its IP address and network parameters whenever the local network parameters may have changed; e.g., at system boot time or after a disconnection from the local network, as the local network configuration may change without the client's or user's knowledge.

If a client has knowledge of a previous network address and is unable to contact a local DHCP server, the client may continue to use the previous network address until the lease for that address expires. If the lease expires before the client can contact a DHCP server, the client must immediately discontinue use of the previous network address and may inform local users of the problem.

4. Specification of the DHCP client-server protocol

In this section, we assume that a DHCP server has a block of network addresses from which it can satisfy requests for new addresses. Each server also maintains a database of allocated addresses and leases in local permanent storage.

4.1 Constructing and sending DHCP messages

DHCP clients and servers both construct DHCP messages by filling in fields in the fixed format section of the message and appending tagged data items in the variable length option area. The options area includes first a four-octet 'magic cookie' (which was described in section 3), followed by the options. The last option must always

be the 'end' option.

DHCP uses UDP as its transport protocol. DHCP messages from a client to a server are sent to the 'DHCP server' port (67), and DHCP messages from a server to a client are sent to the 'DHCP client' port (68). A server with multiple network address (e.g., a multi-homed host) MAY use any of its network addresses in outgoing DHCP messages.

The 'server identifier' field is used both to identify a DHCP server in a DHCP message and as a destination address from clients to servers. A server with multiple network addresses MUST be prepared to accept any of its network addresses as identifying that server in a DHCP message. To accommodate potentially incomplete network connectivity, a server MUST choose an address as a 'server identifier' that, to the best of the server's knowledge, is reachable from the client. For example, if the DHCP server and the DHCP client are connected to the same subnet (i.e., the 'giaddr' field in the message from the client is zero), the server SHOULD select the IP address the server is using for communication on that subnet as the 'server identifier'. If the server is using multiple IP addresses on that subnet, any such address may be used. If the server has received a message through a DHCP relay agent, the server SHOULD choose an address from the interface on which the message was received as the 'server identifier' (unless the server has other, better information on which to make its choice). DHCP clients MUST use the IP address provided in the 'server identifier' option for any unicast requests to the DHCP server.

DHCP messages broadcast by a client prior to that client obtaining its IP address must have the source address field in the IP header set to 0.

If the 'giaddr' field in a DHCP message from a client is non-zero, the server sends any return messages to the 'DHCP server' port on the BOOTP relay agent whose address appears in 'giaddr'. If the 'giaddr' field is zero and the 'ciaddr' field is nonzero, then the server unicasts DHCP OFFER and DHCP ACK messages to the address in 'ciaddr'. If 'giaddr' is zero and 'ciaddr' is zero, and the broadcast bit is set, then the server broadcasts DHCP OFFER and DHCP ACK messages to 0xffffffff. If the broadcast bit is not set and 'giaddr' is zero and 'ciaddr' is zero, then the server unicasts DHCP OFFER and DHCP ACK messages to the client's hardware address and 'yiaddr' address. In all cases, when 'giaddr' is zero, the server broadcasts any DHCP NAK messages to 0xffffffff.

If the options in a DHCP message extend into the 'sname' and 'file' fields, the 'option overload' option MUST appear in the 'options' field, with value 1, 2 or 3, as specified in RFC 1533. If the

'option overload' option is present in the 'options' field, the options in the 'options' field MUST be terminated by an 'end' option, and MAY contain one or more 'pad' options to fill the options field. The options in the 'sname' and 'file' fields (if in use as indicated by the 'option overload' option) MUST begin with the first octet of the field, MUST be terminated by an 'end' option, and MUST be followed by 'pad' options to fill the remainder of the field. Any individual option in the 'options', 'sname' and 'file' fields MUST be entirely contained in that field. The options in the 'options' field MUST be interpreted first, so that any 'option overload' options may be interpreted. The 'file' field MUST be interpreted next (if the 'option overload' option indicates that the 'file' field contains DHCP options), followed by the 'sname' field.

The values to be passed in an 'option' tag may be too long to fit in the 255 octets available to a single option (e.g., a list of routers in a 'router' option [21]). Options may appear only once, unless otherwise specified in the options document. The client concatenates the values of multiple instances of the same option into a single parameter list for configuration.

DHCP clients are responsible for all message retransmission. The client MUST adopt a retransmission strategy that incorporates a randomized exponential backoff algorithm to determine the delay between retransmissions. The delay between retransmissions SHOULD be chosen to allow sufficient time for replies from the server to be delivered based on the characteristics of the internetwork between the client and the server. For example, in a 10Mb/sec Ethernet internetwork, the delay before the first retransmission SHOULD be 4 seconds randomized by the value of a uniform random number chosen from the range -1 to +1. Clients with clocks that provide resolution granularity of less than one second may choose a non-integer randomization value. The delay before the next retransmission SHOULD be 8 seconds randomized by the value of a uniform number chosen from the range -1 to +1. The retransmission delay SHOULD be doubled with subsequent retransmissions up to a maximum of 64 seconds. The client MAY provide an indication of retransmission attempts to the user as an indication of the progress of the configuration process.

The 'xid' field is used by the client to match incoming DHCP messages with pending requests. A DHCP client MUST choose 'xid's in such a way as to minimize the chance of using an 'xid' identical to one used by another client. For example, a client may choose a different, random initial 'xid' each time the client is rebooted, and subsequently use sequential 'xid's until the next reboot. Selecting a new 'xid' for each retransmission is an implementation decision. A client may choose to reuse the same 'xid' or select a new 'xid' for each retransmitted message.

Normally, DHCP servers and BOOTP relay agents attempt to deliver DHCPDISCOVER, DHCPACK and DHCPNAK messages directly to the client using unicast delivery. The IP destination address (in the IP header) is set to the DHCP 'yiaddr' address and the link-layer destination address is set to the DHCP 'chaddr' address. Unfortunately, some client implementations are unable to receive such unicast IP datagrams until the implementation has been configured with a valid IP address (leading to a deadlock in which the client's IP address cannot be delivered until the client has been configured with an IP address).

A client that cannot receive unicast IP datagrams until its protocol software has been configured with an IP address SHOULD set the BROADCAST bit in the 'flags' field to 1 in any DHCPDISCOVER or DHCPREQUEST messages that client sends. The BROADCAST bit will provide a hint to the DHCP server and BOOTP relay agent to broadcast any messages to the client on the client's subnet. A client that can receive unicast IP datagrams before its protocol software has been configured SHOULD clear the BROADCAST bit to 0. The BOOTP clarifications document discusses the ramifications of the use of the BROADCAST bit [21].

A server or relay agent sending or relaying a DHCP message directly to a DHCP client (i.e., not to a relay agent specified in the 'giaddr' field) SHOULD examine the BROADCAST bit in the 'flags' field. If this bit is set to 1, the DHCP message SHOULD be sent as an IP broadcast using an IP broadcast address (preferably 0xffffffff) as the IP destination address and the link-layer broadcast address as the link-layer destination address. If the BROADCAST bit is cleared to 0, the message SHOULD be sent as an IP unicast to the IP address specified in the 'yiaddr' field and the link-layer address specified in the 'chaddr' field. If unicasting is not possible, the message MAY be sent as an IP broadcast using an IP broadcast address (preferably 0xffffffff) as the IP destination address and the link-layer broadcast address as the link-layer destination address.

4.2 DHCP server administrative controls

DHCP servers are not required to respond to every DHCPDISCOVER and DHCPREQUEST message they receive. For example, a network administrator, to retain stringent control over the clients attached to the network, may choose to configure DHCP servers to respond only to clients that have been previously registered through some external mechanism. The DHCP specification describes only the interactions between clients and servers when the clients and servers choose to interact; it is beyond the scope of the DHCP specification to describe all of the administrative controls that system administrators might want to use. Specific DHCP server

implementations may incorporate any controls or policies desired by a network administrator.

In some environments, a DHCP server will have to consider the values of the vendor class options included in DHCPDISCOVER or DHCPREQUEST messages when determining the correct parameters for a particular client.

A DHCP server needs to use some unique identifier to associate a client with its lease. The client MAY choose to explicitly provide the identifier through the 'client identifier' option. If the client supplies a 'client identifier', the client MUST use the same 'client identifier' in all subsequent messages, and the server MUST use that identifier to identify the client. If the client does not provide a 'client identifier' option, the server MUST use the contents of the 'chaddr' field to identify the client. It is crucial for a DHCP client to use an identifier unique within the subnet to which the client is attached in the 'client identifier' option. Use of 'chaddr' as the client's unique identifier may cause unexpected results, as that identifier may be associated with a hardware interface that could be moved to a new client. Some sites may choose to use a manufacturer's serial number as the 'client identifier', to avoid unexpected changes in a clients network address due to transfer of hardware interfaces among computers. Sites may also choose to use a DNS name as the 'client identifier', causing address leases to be associated with the DNS name rather than a specific hardware box.

DHCP clients are free to use any strategy in selecting a DHCP server among those from which the client receives a DHCP OFFER message. The client implementation of DHCP SHOULD provide a mechanism for the user to select directly the 'vendor class identifier' values.

4.3 DHCP server behavior

A DHCP server processes incoming DHCP messages from a client based on the current state of the binding for that client. A DHCP server can receive the following messages from a client:

- o DHCPDISCOVER
- o DHCPREQUEST
- o DHCPDECLINE
- o DHCPRELEASE
- o DHCPINFORM

Table 3 gives the use of the fields and options in a DHCP message by a server. The remainder of this section describes the action of the DHCP server for each possible incoming message.

4.3.1 DHCPDISCOVER message

When a server receives a DHCPDISCOVER message from a client, the server chooses a network address for the requesting client. If no address is available, the server may choose to report the problem to the system administrator. If an address is available, the new address SHOULD be chosen as follows:

- o The client's current address as recorded in the client's current binding, ELSE
- o The client's previous address as recorded in the client's (now expired or released) binding, if that address is in the server's pool of available addresses and not already allocated, ELSE
- o The address requested in the 'Requested IP Address' option, if that address is valid and not already allocated, ELSE
- o A new address allocated from the server's pool of available addresses; the address is selected based on the subnet from which the message was received (if 'giaddr' is 0) or on the address of the relay agent that forwarded the message ('giaddr' when not 0).

As described in section 4.2, a server MAY, for administrative reasons, assign an address other than the one requested, or may refuse to allocate an address to a particular client even though free addresses are available.

Note that, in some network architectures (e.g., internets with more than one IP subnet assigned to a physical network segment), it may be the case that the DHCP client should be assigned an address from a different subnet than the address recorded in 'giaddr'. Thus, DHCP does not require that the client be assigned an address from the subnet in 'giaddr'. A server is free to choose some other subnet, and it is beyond the scope of the DHCP specification to describe ways in which the assigned IP address might be chosen.

While not required for correct operation of DHCP, the server SHOULD NOT reuse the selected network address before the client responds to the server's DHCPOFFER message. The server may choose to record the address as offered to the client.

The server must also choose an expiration time for the lease, as follows:

- o IF the client has not requested a specific lease in the DHCPDISCOVER message and the client already has an assigned network address, the server returns the lease expiration time previously assigned to that address (note that the client must explicitly request a specific lease to extend the expiration time on a previously assigned address), ELSE
- o IF the client has not requested a specific lease in the DHCPDISCOVER message and the client does not have an assigned network address, the server assigns a locally configured default lease time, ELSE
- o IF the client has requested a specific lease in the DHCPDISCOVER message (regardless of whether the client has an assigned network address), the server may choose either to return the requested lease (if the lease is acceptable to local policy) or select another lease.

Field	DHCPOFFER	DHCPACK	DHCPNAK
----	-----	-----	-----
'op'	BOOTREPLY	BOOTREPLY	BOOTREPLY
'htype'	(From "Assigned Numbers" RFC)		
'hlen'	(Hardware address length in octets)		
'hops'	0	0	0
'xid'	'xid' from client	'xid' from client	'xid' from client
	DHCPDISCOVER message	DHCPREQUEST message	DHCPREQUEST message
'secs'	0	0	0
'ciaddr'	0	'ciaddr' from DHCPREQUEST or 0	0
'yiaddr'	IP address offered to client	IP address assigned to client	0
'siaddr'	IP address of next bootstrap server	IP address of next bootstrap server	0
'flags'	'flags' from client DHCPDISCOVER message	'flags' from client DHCPREQUEST message	'flags' from client DHCPREQUEST message
'giaddr'	'giaddr' from client DHCPDISCOVER message	'giaddr' from client DHCPREQUEST message	'giaddr' from client DHCPREQUEST message
'chaddr'	'chaddr' from client DHCPDISCOVER message	'chaddr' from client DHCPREQUEST message	'chaddr' from client DHCPREQUEST message
'sname'	Server host name or options	Server host name or options	(unused)
'file'	Client boot file name or options	Client boot file name or options	(unused)
'options'	options	options	

Option -----	DHCPOFFER -----	DHCPACK -----	DHCPNAK -----
Requested IP address	MUST NOT	MUST NOT	MUST NOT
IP address lease time	MUST	MUST (DHCPREQUEST) MUST NOT (DHCPINFORM)	MUST NOT
Use 'file'/'sname' fields	MAY	MAY	MUST NOT
DHCP message type	DHCPOFFER	DHCPACK	DHCPNAK
Parameter request list	MUST NOT	MUST NOT	MUST NOT
Message	SHOULD	SHOULD	SHOULD
Client identifier	MUST NOT	MUST NOT	MAY
Vendor class identifier	MAY	MAY	MAY
Server identifier	MUST	MUST	MUST
Maximum message size	MUST NOT	MUST NOT	MUST NOT
All others	MAY	MAY	MUST NOT

Table 3: Fields and options used by DHCP servers

Once the network address and lease have been determined, the server constructs a DHCPOFFER message with the offered configuration parameters. It is important for all DHCP servers to return the same parameters (with the possible exception of a newly allocated network address) to ensure predictable client behavior regardless of which server the client selects. The configuration parameters MUST be selected by applying the following rules in the order given below. The network administrator is responsible for configuring multiple DHCP servers to ensure uniform responses from those servers. The server MUST return to the client:

- o The client's network address, as determined by the rules given earlier in this section,
- o The expiration time for the client's lease, as determined by the rules given earlier in this section,
- o Parameters requested by the client, according to the following rules:
 - IF the server has been explicitly configured with a default value for the parameter, the server MUST include that value in an appropriate option in the 'option' field, ELSE
 - IF the server recognizes the parameter as a parameter defined in the Host Requirements Document, the server MUST include the default value for that parameter as given in the Host Requirements Document in an appropriate option in the 'option' field, ELSE
 - The server MUST NOT return a value for that parameter,

The server MUST supply as many of the requested parameters as possible and MUST omit any parameters it cannot provide. The server MUST include each requested parameter only once unless explicitly allowed in the DHCP Options and BOOTP Vendor Extensions document.

- o Any parameters from the existing binding that differ from the Host Requirements Document defaults,
- o Any parameters specific to this client (as identified by the contents of 'chaddr' or 'client identifier' in the DHCPDISCOVER or DHCPREQUEST message), e.g., as configured by the network administrator,
- o Any parameters specific to this client's class (as identified by the contents of the 'vendor class identifier' option in the DHCPDISCOVER or DHCPREQUEST message), e.g., as configured by the network administrator; the parameters MUST be identified by an exact match between the client's vendor class identifiers and the client's classes identified in the server,
- o Parameters with non-default values on the client's subnet.

The server MAY choose to return the 'vendor class identifier' used to determine the parameters in the DHCP OFFER message to assist the client in selecting which DHCP OFFER to accept. The server inserts the 'xid' field from the DHCPDISCOVER message into the 'xid' field of the DHCP OFFER message and sends the DHCP OFFER message to the requesting client.

4.3.2 DHCPREQUEST message

A DHCPREQUEST message may come from a client responding to a DHCP OFFER message from a server, from a client verifying a previously allocated IP address or from a client extending the lease on a network address. If the DHCPREQUEST message contains a 'server identifier' option, the message is in response to a DHCP OFFER message. Otherwise, the message is a request to verify or extend an existing lease. If the client uses a 'client identifier' in a DHCPREQUEST message, it MUST use that same 'client identifier' in all subsequent messages. If the client included a list of requested parameters in a DHCPDISCOVER message, it MUST include that list in all subsequent messages.

Any configuration parameters in the DHCPACK message SHOULD NOT conflict with those in the earlier DHCPOFFER message to which the client is responding. The client SHOULD use the parameters in the DHCPACK message for configuration.

Clients send DHCPREQUEST messages as follows:

- o DHCPREQUEST generated during SELECTING state:

Client inserts the address of the selected server in 'server identifier', 'ciaddr' MUST be zero, 'requested IP address' MUST be filled in with the yiaddr value from the chosen DHCPOFFER.

Note that the client may choose to collect several DHCPOFFER messages and select the "best" offer. The client indicates its selection by identifying the offering server in the DHCPREQUEST message. If the client receives no acceptable offers, the client may choose to try another DHCPDISCOVER message. Therefore, the servers may not receive a specific DHCPREQUEST from which they can decide whether or not the client has accepted the offer. Because the servers have not committed any network address assignments on the basis of a DHCPOFFER, servers are free to reuse offered network addresses in response to subsequent requests. As an implementation detail, servers SHOULD NOT reuse offered addresses and may use an implementation-specific timeout mechanism to decide when to reuse an offered address.

- o DHCPREQUEST generated during INIT-REBOOT state:

'server identifier' MUST NOT be filled in, 'requested IP address' option MUST be filled in with client's notion of its previously assigned address. 'ciaddr' MUST be zero. The client is seeking to verify a previously allocated, cached configuration. Server SHOULD send a DHCPNAK message to the client if the 'requested IP address' is incorrect, or is on the wrong network.

Determining whether a client in the INIT-REBOOT state is on the correct network is done by examining the contents of 'giaddr', the 'requested IP address' option, and a database lookup. If the DHCP server detects that the client is on the wrong net (i.e., the result of applying the local subnet mask or remote subnet mask (if 'giaddr' is not zero) to 'requested IP address' option value doesn't match reality), then the server SHOULD send a DHCPNAK message to the client.

If the network is correct, then the DHCP server should check if the client's notion of its IP address is correct. If not, then the server SHOULD send a DHCPNAK message to the client. If the DHCP server has no record of this client, then it MUST remain silent, and MAY output a warning to the network administrator. This behavior is necessary for peaceful coexistence of non-communicating DHCP servers on the same wire.

If 'giaddr' is 0x0 in the DHCPREQUEST message, the client is on the same subnet as the server. The server MUST broadcast the DHCPNAK message to the 0xffffffff broadcast address because the client may not have a correct network address or subnet mask, and the client may not be answering ARP requests.

If 'giaddr' is set in the DHCPREQUEST message, the client is on a different subnet. The server MUST set the broadcast bit in the DHCPNAK, so that the relay agent will broadcast the DHCPNAK to the client, because the client may not have a correct network address or subnet mask, and the client may not be answering ARP requests.

o DHCPREQUEST generated during RENEWING state:

'server identifier' MUST NOT be filled in, 'requested IP address' option MUST NOT be filled in, 'ciaddr' MUST be filled in with client's IP address. In this situation, the client is completely configured, and is trying to extend its lease. This message will be unicast, so no relay agents will be involved in its transmission. Because 'giaddr' is therefore not filled in, the DHCP server will trust the value in 'ciaddr', and use it when replying to the client.

A client MAY choose to renew or extend its lease prior to T1. The server may choose not to extend the lease (as a policy decision by the network administrator), but should return a DHCPACK message regardless.

o DHCPREQUEST generated during REBINDING state:

'server identifier' MUST NOT be filled in, 'requested IP address' option MUST NOT be filled in, 'ciaddr' MUST be filled in with client's IP address. In this situation, the client is completely configured, and is trying to extend its lease. This message MUST be broadcast to the 0xffffffff IP broadcast address. The DHCP server SHOULD check 'ciaddr' for correctness before replying to the DHCPREQUEST.

The DHCPREQUEST from a REBINDING client is intended to accommodate sites that have multiple DHCP servers and a mechanism for maintaining consistency among leases managed by multiple servers. A DHCP server MAY extend a client's lease only if it has local administrative authority to do so.

4.3.3 DHCPDECLINE message

If the server receives a DHCPDECLINE message, the client has discovered through some other means that the suggested network address is already in use. The server MUST mark the network address as not available and SHOULD notify the local system administrator of a possible configuration problem.

4.3.4 DHCPRELEASE message

Upon receipt of a DHCPRELEASE message, the server marks the network address as not allocated. The server SHOULD retain a record of the client's initialization parameters for possible reuse in response to subsequent requests from the client.

4.3.5 DHCPINFORM message

The server responds to a DHCPINFORM message by sending a DHCPACK message directly to the address given in the 'ciaddr' field of the DHCPINFORM message. The server MUST NOT send a lease expiration time to the client and SHOULD NOT fill in 'yiaddr'. The server includes other parameters in the DHCPACK message as defined in section 4.3.1.

4.3.6 Client messages

Table 4 details the differences between messages from clients in various states.

	INIT-REBOOT	SELECTING	RENEWING	REBINDING
broad/unicast	broadcast	broadcast	unicast	broadcast
server-ip	MUST NOT	MUST	MUST NOT	MUST NOT
requested-ip	MUST	MUST	MUST NOT	MUST NOT
ciaddr	zero	zero	IP address	IP address

Table 4: Client messages from different states

4.4 DHCP client behavior

Figure 5 gives a state-transition diagram for a DHCP client. A client can receive the following messages from a server:

- o DHCPPOFFER
- o DHCPACK
- o DHCPNAK

The DHCPINFORM message is not shown in figure 5. A client simply sends the DHCPINFORM and waits for DHCPACK messages. Once the client has selected its parameters, it has completed the configuration process.

Table 5 gives the use of the fields and options in a DHCP message by a client. The remainder of this section describes the action of the DHCP client for each possible incoming message. The description in the following section corresponds to the full configuration procedure previously described in section 3.1, and the text in the subsequent section corresponds to the abbreviated configuration procedure described in section 3.2.

4.4.1 Initialization and allocation of network address

The client begins in INIT state and forms a DHCPDISCOVER message. The client SHOULD wait a random time between one and ten seconds to desynchronize the use of DHCP at startup. The client sets 'ciaddr' to 0x00000000. The client MAY request specific parameters by including the 'parameter request list' option. The client MAY suggest a network address and/or lease time by including the 'requested IP address' and 'IP address lease time' options. The client MUST include its hardware address in the 'chaddr' field, if necessary for delivery of DHCP reply messages. The client MAY include a different unique identifier in the 'client identifier' option, as discussed in section 4.2. If the client included a list of requested parameters in a DHCPDISCOVER message, it MUST include that list in all subsequent messages.

The client generates and records a random transaction identifier and inserts that identifier into the 'xid' field. The client records its own local time for later use in computing the lease expiration. The client then broadcasts the DHCPDISCOVER on the local hardware broadcast address to the 0xffffffff IP broadcast address and 'DHCP server' UDP port.

If the 'xid' of an arriving DHCPOFFER message does not match the 'xid' of the most recent DHCPDISCOVER message, the DHCPOFFER message must be silently discarded. Any arriving DHCPACK messages must be silently discarded.

The client collects DHCPOFFER messages over a period of time, selects one DHCPOFFER message from the (possibly many) incoming DHCPOFFER messages (e.g., the first DHCPOFFER message or the DHCPOFFER message from the previously used server) and extracts the server address from the 'server identifier' option in the DHCPOFFER message. The time over which the client collects messages and the mechanism used to select one DHCPOFFER are implementation dependent.

Field	DHCPDISCOVER DHCPIFORM	DHCPREQUEST -----	DHCPDECLINE, DHCPRELEASE -----
'op'	BOOTREQUEST	BOOTREQUEST	BOOTREQUEST
'htype'	(From "Assigned Numbers" RFC)		
'hlen'	(Hardware address length in octets)		
'hops'	0	0	0
'xid'	selected by client	'xid' from server DHCP OFFER message	selected by client
'secs'	0 or seconds since DHCP process started	0 or seconds since DHCP process started	0
'flags'	Set 'BROADCAST' flag if client requires broadcast reply	Set 'BROADCAST' flag if client requires broadcast reply	0
'ciaddr'	0 (DHCPDISCOVER) client's network address (DHCPIFORM)	0 or client's network address (BOUND/RENEW/REBIND)	0 (DHCPDECLINE) client's network address (DHCPRELEASE)
'yiaddr'	0	0	0
'siaddr'	0	0	0
'giaddr'	0	0	0
'chaddr'	client's hardware address	client's hardware address	client's hardware address
'sname'	options, if indicated in 'sname/file' option; otherwise unused	options, if indicated in 'sname/file' option; otherwise unused	(unused)
'file'	options, if indicated in 'sname/file' option; otherwise unused	options, if indicated in 'sname/file' option; otherwise unused	(unused)
'options'	options	options	(unused)

Option	DHCPDISCOVER DHCPIFORM	DHCPREQUEST	DHCPDECLINE, DHCPRELEASE
-----	-----	-----	-----
Requested IP address	MAY (DISCOVER) MUST NOT (INFORM)	MUST (in SELECTING or INIT-REBOOT) MUST NOT (in BOUND or RENEWING)	MUST (DHCPDECLINE), MUST NOT (DHCPRELEASE)
IP address lease time	MAY (DISCOVER) MUST NOT (INFORM)	MAY	MUST NOT
Use 'file'/'sname' fields	MAY	MAY	MAY
DHCP message type	DHCPDISCOVER/ DHCPIFORM	DHCPREQUEST	DHCPDECLINE/ DHCPRELEASE
Client identifier	MAY	MAY	MAY
Vendor class identifier	MAY	MAY	MUST NOT
Server identifier	MUST NOT	MUST (after SELECTING) MUST NOT (after INIT-REBOOT, BOUND, RENEWING or REBINDING)	MUST
Parameter request list	MAY	MAY	MUST NOT
Maximum message size	MAY	MAY	MUST NOT
Message	SHOULD NOT	SHOULD NOT	SHOULD
Site-specific	MAY	MAY	MUST NOT
All others	MAY	MAY	MUST NOT

Table 5: Fields and options used by DHCP clients

If the parameters are acceptable, the client records the address of the server that supplied the parameters from the 'server identifier' field and sends that address in the 'server identifier' field of a DHCPREQUEST broadcast message. Once the DHCPACK message from the server arrives, the client is initialized and moves to BOUND state. The DHCPREQUEST message contains the same 'xid' as the DHCPDISCOVER message. The client records the lease expiration time as the sum of the time at which the original request was sent and the duration of the lease from the DHCPACK message. The client SHOULD perform a check on the suggested address to ensure that the address is not already in use. For example, if the client is on a network that supports ARP, the client may issue an ARP request for the suggested request. When broadcasting an ARP request for the suggested address, the client must fill in its own hardware address as the sender's hardware address, and 0 as the sender's IP address, to avoid confusing ARP caches in other hosts on the same subnet. If the

network address appears to be in use, the client MUST send a DHCPDECLINE message to the server. The client SHOULD broadcast an ARP reply to announce the client's new IP address and clear any outdated ARP cache entries in hosts on the client's subnet.

4.4.2 Initialization with known network address

The client begins in INIT-REBOOT state and sends a DHCPREQUEST message. The client MUST insert its known network address as a 'requested IP address' option in the DHCPREQUEST message. The client may request specific configuration parameters by including the 'parameter request list' option. The client generates and records a random transaction identifier and inserts that identifier into the 'xid' field. The client records its own local time for later use in computing the lease expiration. The client MUST NOT include a 'server identifier' in the DHCPREQUEST message. The client then broadcasts the DHCPREQUEST on the local hardware broadcast address to the 'DHCP server' UDP port.

Once a DHCPACK message with an 'xid' field matching that in the client's DHCPREQUEST message arrives from any server, the client is initialized and moves to BOUND state. The client records the lease expiration time as the sum of the time at which the DHCPREQUEST message was sent and the duration of the lease from the DHCPACK message.

4.4.3 Initialization with an externally assigned network address

The client sends a DHCPINFORM message. The client may request specific configuration parameters by including the 'parameter request list' option. The client generates and records a random transaction identifier and inserts that identifier into the 'xid' field. The client places its own network address in the 'ciaddr' field. The client SHOULD NOT request lease time parameters.

The client then unicasts the DHCPINFORM to the DHCP server if it knows the server's address, otherwise it broadcasts the message to the limited (all 1s) broadcast address. DHCPINFORM messages MUST be directed to the 'DHCP server' UDP port.

Once a DHCPACK message with an 'xid' field matching that in the client's DHCPINFORM message arrives from any server, the client is initialized.

If the client does not receive a DHCPACK within a reasonable period of time (60 seconds or 4 tries if using timeout suggested in section 4.1), then it SHOULD display a message informing the user of the problem, and then SHOULD begin network processing using suitable

defaults as per Appendix A.

4.4.4 Use of broadcast and unicast

The DHCP client broadcasts DHCPDISCOVER, DHCPREQUEST and DHCPINFORM messages, unless the client knows the address of a DHCP server. The client unicasts DHCPRELEASE messages to the server. Because the client is declining the use of the IP address supplied by the server, the client broadcasts DHCPDECLINE messages.

When the DHCP client knows the address of a DHCP server, in either INIT or REBOOTING state, the client may use that address in the DHCPDISCOVER or DHCPREQUEST rather than the IP broadcast address. The client may also use unicast to send DHCPINFORM messages to a known DHCP server. If the client receives no response to DHCP messages sent to the IP address of a known DHCP server, the DHCP client reverts to using the IP broadcast address.

4.4.5 Reacquisition and expiration

The client maintains two times, T1 and T2, that specify the times at which the client tries to extend its lease on its network address. T1 is the time at which the client enters the RENEWING state and attempts to contact the server that originally issued the client's network address. T2 is the time at which the client enters the REBINDING state and attempts to contact any server. T1 MUST be earlier than T2, which, in turn, MUST be earlier than the time at which the client's lease will expire.

To avoid the need for synchronized clocks, T1 and T2 are expressed in options as relative times [2].

At time T1 the client moves to RENEWING state and sends (via unicast) a DHCPREQUEST message to the server to extend its lease. The client sets the 'ciaddr' field in the DHCPREQUEST to its current network address. The client records the local time at which the DHCPREQUEST message is sent for computation of the lease expiration time. The client MUST NOT include a 'server identifier' in the DHCPREQUEST message.

Any DHCPACK messages that arrive with an 'xid' that does not match the 'xid' of the client's DHCPREQUEST message are silently discarded. When the client receives a DHCPACK from the server, the client computes the lease expiration time as the sum of the time at which the client sent the DHCPREQUEST message and the duration of the lease in the DHCPACK message. The client has successfully reacquired its network address, returns to BOUND state and may continue network processing.

If no DHCPACK arrives before time T2, the client moves to REBINDING state and sends (via broadcast) a DHCPREQUEST message to extend its lease. The client sets the 'ciaddr' field in the DHCPREQUEST to its current network address. The client MUST NOT include a 'server identifier' in the DHCPREQUEST message.

Times T1 and T2 are configurable by the server through options. T1 defaults to $(0.5 * \text{duration_of_lease})$. T2 defaults to $(0.875 * \text{duration_of_lease})$. Times T1 and T2 SHOULD be chosen with some random "fuzz" around a fixed value, to avoid synchronization of client reacquisition.

A client MAY choose to renew or extend its lease prior to T1. The server MAY choose to extend the client's lease according to policy set by the network administrator. The server SHOULD return T1 and T2, and their values SHOULD be adjusted from their original values to take account of the time remaining on the lease.

In both RENEWING and REBINDING states, if the client receives no response to its DHCPREQUEST message, the client SHOULD wait one-half of the remaining time until T2 (in RENEWING state) and one-half of the remaining lease time (in REBINDING state), down to a minimum of 60 seconds, before retransmitting the DHCPREQUEST message.

If the lease expires before the client receives a DHCPACK, the client moves to INIT state, MUST immediately stop any other network processing and requests network initialization parameters as if the client were uninitialized. If the client then receives a DHCPACK allocating that client its previous network address, the client SHOULD continue network processing. If the client is given a new network address, it MUST NOT continue using the previous network address and SHOULD notify the local users of the problem.

4.4.6 DHCPRELEASE

If the client no longer requires use of its assigned network address (e.g., the client is gracefully shut down), the client sends a DHCPRELEASE message to the server. Note that the correct operation of DHCP does not depend on the transmission of DHCPRELEASE messages.

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6. References

- [1] Acetta, M., "Resource Location Protocol", RFC 887, CMU, December 1983.
- [2] Alexander, S., and R. Droms, "DHCP Options and BOOTP Vendor Extensions", RFC 1533, Lachman Technology, Inc., Bucknell University, October 1993.
- [3] Braden, R., Editor, "Requirements for Internet Hosts -- Communication Layers", STD 3, RFC 1122, USC/Information Sciences Institute, October 1989.
- [4] Braden, R., Editor, "Requirements for Internet Hosts -- Application and Support", STD 3, RFC 1123, USC/Information Sciences Institute, October 1989.
- [5] Brownell, D, "Dynamic Reverse Address Resolution Protocol (DRARP)", Work in Progress.
- [6] Comer, D., and R. Droms, "Uniform Access to Internet Directory Services", Proc. of ACM SIGCOMM '90 (Special issue of Computer Communications Review), 20(4):50--59, 1990.
- [7] Croft, B., and J. Gilmore, "Bootstrap Protocol (BOOTP)", RFC 951, Stanford and SUN Microsystems, September 1985.
- [8] Deering, S., "ICMP Router Discovery Messages", RFC 1256, Xerox PARC, September 1991.
- [9] Droms, D., "Interoperation between DHCP and BOOTP", RFC 1534, Bucknell University, October 1993.

- [10] Finlayson, R., Mann, T., Mogul, J., and M. Theimer, "A Reverse Address Resolution Protocol", RFC 903, Stanford, June 1984.
- [11] Gray C., and D. Cheriton, "Leases: An Efficient Fault-Tolerant Mechanism for Distributed File Cache Consistency", In Proc. of the Twelfth ACM Symposium on Operating Systems Design, 1989.
- [12] Mockapetris, P., "Domain Names -- Concepts and Facilities", STD 13, RFC 1034, USC/Information Sciences Institute, November 1987.
- [13] Mockapetris, P., "Domain Names -- Implementation and Specification", STD 13, RFC 1035, USC/Information Sciences Institute, November 1987.
- [14] Mogul J., and S. Deering, "Path MTU Discovery", RFC 1191, November 1990.
- [15] Morgan, R., "Dynamic IP Address Assignment for Ethernet Attached Hosts", Work in Progress.
- [16] Postel, J., "Internet Control Message Protocol", STD 5, RFC 792, USC/Information Sciences Institute, September 1981.
- [17] Reynolds, J., "BOOTP Vendor Information Extensions", RFC 1497, USC/Information Sciences Institute, August 1993.
- [18] Reynolds, J., and J. Postel, "Assigned Numbers", STD 2, RFC 1700, USC/Information Sciences Institute, October 1994.
- [19] Jeffrey Schiller and Mark Rosenstein. A Protocol for the Dynamic Assignment of IP Addresses for use on an Ethernet. (Available from the Athena Project, MIT), 1989.
- [20] Sollins, K., "The TFTP Protocol (Revision 2)", RFC 783, NIC, June 1981.
- [21] Wimer, W., "Clarifications and Extensions for the Bootstrap Protocol", RFC 1542, Carnegie Mellon University, October 1993.

7. Security Considerations

DHCP is built directly on UDP and IP which are as yet inherently insecure. Furthermore, DHCP is generally intended to make maintenance of remote and/or diskless hosts easier. While perhaps not impossible, configuring such hosts with passwords or keys may be difficult and inconvenient. Therefore, DHCP in its current form is quite insecure.

Unauthorized DHCP servers may be easily set up. Such servers can then send false and potentially disruptive information to clients such as incorrect or duplicate IP addresses, incorrect routing information (including spoof routers, etc.), incorrect domain nameserver addresses (such as spoof nameservers), and so on. Clearly, once this seed information is in place, an attacker can further compromise affected systems.

Malicious DHCP clients could masquerade as legitimate clients and retrieve information intended for those legitimate clients. Where dynamic allocation of resources is used, a malicious client could claim all resources for itself, thereby denying resources to legitimate clients.

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A. Host Configuration Parameters

IP-layer_parameters,_per_host:_

Be a router	on/off	HRC 3.1
Non-local source routing	on/off	HRC 3.3.5
Policy filters for non-local source routing	(list)	HRC 3.3.5
Maximum reassembly size	integer	HRC 3.3.2
Default TTL	integer	HRC 3.2.1.7
PMTU aging timeout	integer	MTU 6.6
MTU plateau table	(list)	MTU 7
IP-layer_parameters,_per_interface:_		
IP address	(address)	HRC 3.3.1.6
Subnet mask	(address mask)	HRC 3.3.1.6
MTU	integer	HRC 3.3.3
All-subnets-MTU	on/off	HRC 3.3.3
Broadcast address flavor	0x00000000/0xffffffff	HRC 3.3.6
Perform mask discovery	on/off	HRC 3.2.2.9
Be a mask supplier	on/off	HRC 3.2.2.9
Perform router discovery	on/off	RD 5.1
Router solicitation address	(address)	RD 5.1
Default routers, list of:		
router address	(address)	HRC 3.3.1.6
preference level	integer	HRC 3.3.1.6
Static routes, list of:		
destination	(host/subnet/net)	HRC 3.3.1.2
destination mask	(address mask)	HRC 3.3.1.2
type-of-service	integer	HRC 3.3.1.2
first-hop router	(address)	HRC 3.3.1.2
ignore redirects	on/off	HRC 3.3.1.2
PMTU	integer	MTU 6.6
perform PMTU discovery	on/off	MTU 6.6
Link-layer_parameters,_per_interface:_		
Trailers	on/off	HRC 2.3.1
ARP cache timeout	integer	HRC 2.3.2.1
Ethernet encapsulation	(RFC 894/RFC 1042)	HRC 2.3.3
TCP_parameters,_per_host:_		
TTL	integer	HRC 4.2.2.19
Keep-alive interval	integer	HRC 4.2.3.6
Keep-alive data size	0/1	HRC 4.2.3.6

Key:

MTU = Path MTU Discovery (RFC 1191, Proposed Standard)

RD = Router Discovery (RFC 1256, Proposed Standard)