Project Report

CSE351

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PHASE(1)

1. Introduction

1.1 Project Overview

The Dynamic Host Configuration Protocol (DHCP), as defined by RFC 2131 and RFC 2132, is an essential networking protocol designed to automate the assignment of IP addresses and other critical network parameters. This project focuses on the analysis and implementation of a DHCP server that complies with these RFCs, enabling it to interact seamlessly with standard client systems.
The project is divided into four sequential phases to ensure systematic development and compliance with DHCP standards. Phase 1 focuses on project planning and design, establishing the scope, goals, and architecture of the DHCP server while detailing communication protocols and key functionalities. Phase 2 involves building a foundational client-server setup using Python and sockets, enabling basic communication and showcasing server status via a command-line interface. In Phase 3, the server is extended with full DHCP features as outlined in RFCs 2131 and 2132, including lease management, error handling, and configuration options. Finally, Phase 4 emphasizes optimizing the server's performance by refining communication protocols, enhancing scalability, and improving the user interface for seamless usability and robust functionality

1.2 Scope of the Project

The scope of this project is to implement a Dynamic Host Configuration Protocol (DHCP) server based on the specifications outlined in RFC 2131 and RFC 2132. DHCP automates the configuration of network parameters, such as IP addresses, subnet masks, gateways, and domain name servers, for devices on a network. This server will dynamically allocate these parameters, allowing devices to request and receive configuration data seamlessly. The project also incorporates extended functionalities described in RFC 2132, which introduces DHCP options. These options enable the customization of network configurations. This implementation ensures compliance with the RFCs, making the server

interoperable with standard DHCP clients and capable of managing network configurations dynamically and efficiently

2. System Architecture

The DHCP architecture consists of key components and a well-defined interaction between them to manage IP address allocation and configuration in a network. The architecture is built on a **client-server model** and incorporates relay agents to enable communication across different network segments

2.1 Components of DHCP

- **DHCP Server**

a) Function:

The DHCP server is the central entity responsible for managing IP address assignments and delivering configuration parameters to clients

b) Key Responsibilities:

i. Maintain a pool of available IP addresses.
ii. Allocate IP addresses and other configuration data (e.g., DNS servers, gateway) to clients
iii. Track lease information, including timeouts and renewals
iv. Respond to DHCP messages (e.g., DISCOVER, REQUEST, RELEASE, etc.)

c) Sub-components:

i. **Lease Database:** Stores active leases and associated client information
ii. **Configuration Store:** Maintains server configuration, including IP ranges, subnet masks, DNS settings, etc

- **DHCP Client**

  a) **Function:**

  A device or host that requests an IP address and configuration parameters from the DHCP server

  b) **Key Responsibilities:**

  i. Broadcast a DHCPDISCOVER message to locate a DHCP server
  ii. Process responses (e.g., DHCPOFFER, DHCPACK).
  iii. Request lease renewals or release addresses when no longer needed

- **Configuration Parameters**

  a) **Function:**

  The server provides various parameters to configure the client's network interface

3. Functional Requirements

3.1 Client-Server Architecture

DHCP operates on a client-server model. A DHCP server is responsible for allocating network addresses and providing configuration parameters to client hosts requesting initialization data

3.2 Server Configuration

A host must be explicitly configured by a system administrator to act as a DHCP server. This ensures reliable operation and avoids conflicts from random hosts responding to DHCP requests

3.3 Configuration Parameters Repository

- **Persistent Storage:** DHCP provides a key-value store for client network parameters, where:
    a) **Key:** Typically a combination of IP subnet number and client's hardware address (or optionally, the client's hostname)
    b) **Value:** Configuration parameters for the client, such as IP address, lease time, and other network-related settings
    c) **Client Identifier:** The client can specify a unique identifier, typically through the 'client identifier' option, if needed. This overrides the default key of IP subnet and hardware address

- **Client Queries:** Clients can request their configuration parameters from the DHCP server via protocol messages, which contain:
    a) **Request:** Client asks for specific network settings.
    b) **Response:** Server sends back the required parameters

3.4 Dynamic Allocation of Network Addresses

a) **Lease Concept:** A client requests a network address for a specified period, called a "lease." The DHCP server allocates and guarantees that the same address is returned during the lease duration.
b) **Address Release:** Clients can release the assigned address back to the server when no longer needed, allowing for better address management.
c) **Permanent Assignment:** Clients may request an "infinite lease" for a permanent address. However, servers might use long but finite leases to monitor client activity and detect inactive clients.

3.5 IP Address Allocation Mechanisms

a) **Automatic Allocation:** The server permanently assigns an IP address to the client
b) **Dynamic Allocation:** The server assigns an IP address to the client for a limited period or until explicitly released, with the possibility of reusing the address once it is no longer needed
c) **Manual Allocation:** The server conveys an IP address assigned by the network administrator to the client

3.6 Option fields

Here are some examples of the options that can be used in DHCP

- **Requested IP Address**

  Functionality: Allows a DHCP client to request a specific IP address. This is used in DHCPDISCOVER or DHCPREQUEST messages

- **IP Address Lease Time**

  Functionality: Allows the client to request a lease duration for the assigned IP. The server specifies the lease duration in its response

- **DHCP Message Type**

  Functionality: Specifies the type of DHCP message (e.g., DHCPDISCOVER, DHCPOFFER, DHCPREQUEST, etc.)

- **Server Identifier**

  Functionality: Identifies the server in DHCPOFFER or DHCPREQUEST messages. It ensures clients can distinguish between multiple servers

- **Maximum DHCP Message Size**

  Functionality: Specifies the maximum message size a client can accept

4. Communication protocol

4.1 Client-Server Protocol

Dynamic Host Configuration Protocol (DHCP) uses a client-server model to dynamically allocate IP addresses and configuration information to devices on a network. This process involves message exchanges between the DHCP client and server

4.1.1 Client-Server Interaction for Allocating a Network Address

a) **DHCPDISCOVER:**
   i Purpose: Sent by the client to locate available DHCP servers on the network
   ii Mode: Broadcast message

b) **DHCPOFFER:**
   i Purpose: Sent by the server in response to a DHCPDISCOVER message, offering configuration parameters (such as IP address and subnet mask)
   ii Mode: Unicast or broadcast message

c) **DHCPREQUEST:**
   i Purpose: Sent by the client to (a) request the offered configuration from one specific server, (b) confirm previously allocated IP after a reboot, or (c) extend a lease on the assigned IP
   ii Implication: Declines all other offers implicitly

d) **DHCPACK:**
   i Purpose: Sent by the server to confirm the lease and provide the final configuration parameters
   ii Effect: Indicates that the network configuration is complete

e) **DHCPNAK:**
   i Purpose: Sent by the server to indicate the client's request is invalid. Reasons include expired leases or incorrect subnet

f) **DHCPDECLINE:**
   i. Purpose: Sent by the client to indicate the proposed IP address is already in use (e.g., detected via an Address Resolution Protocol (ARP) check)

g) **DHCPRELEASE:**

i. Purpose: Sent by the client to release its network address and terminate its lease.

h) DHCPINFORM

i. Purpose: Sent by the client when it only needs local configuration parameters and already has an externally configured IP address

4.1.2 Reusing a Previously Allocated Network Address

When reusing a previously assigned address, the process involves fewer steps:

a) The client sends a DHCPREQUEST to the server, asking to reuse its previously assigned address

b) The server responds with DHCPACK to confirm the reuse or DHCPNAK if the address is no longer valid.

c) If the server acknowledges, the client completes initialization and uses the address

This simplified handshake ensures faster reconfiguration after events like system reboots

4.1.3 Interpretation and Representation of Time Values

a) Lease Duration:

DHCP assigns IP leases for a specified time, measured in seconds. Leases can also be infinite (represented as 0xffffffff)

b) Relative Time:

Since client and server clocks may not be synchronized, lease durations are expressed as relative times instead of absolute timestamps. This avoids dependency on synchronized time settings

c) Clock Stability:

If client-server clocks drift, the server might expire a lease earlier than expected by the client. To mitigate this, servers

can issue shorter leases than internally committed durations

4.1.4 Obtaining Parameters with Externally Configured Network Address

If a client has already obtained a network address via manual configuration or other means, it can use the DHCPINFORM message to request additional configuration parameters from a DHCP server. The server responds with a DHCPACK message containing the requested parameters, but it does not allocate a new address, assign lease time, or check for an existing binding. Instead, the server verifies the consistency of the provided network address, but does not perform a lease check. The response is sent directly to the address specified in the ciaddr field of the DHCPINFORM message

4.1.5 DHCP Server Behavior

A DHCP server processes incoming messages from clients based on the current binding state of that client. The server may receive the following messages:

- DHCPDISCOVER
- DHCPREQUEST
- DHCPDECLINE
- DHCPRELEASE
- DHCPINFORM

4.1.5.1 DHCPDISCOVER Message

When a DHCP server receives a DHCPDISCOVER message, it selects a network address for the client. The address is chosen from the following options:

a) The client's current address from its binding record

b) The client's previous address if it's available in the server's pool of addresses

c) The requested IP address (if valid and not in use)

d) A new address from the server's available pool, chosen based on the subnet from which the message was received

4.1.5.2 DHCPREQUEST Message

The DHCPREQUEST message can be sent by a client to respond to a DHCPOFFER message, to verify a previously allocated address, or to extend the lease on an existing address. If the message includes a 'server identifier', it is responding to a DHCPOFFER; otherwise, it is a lease verification or extension request. If the client used a client identifier in a previous message, it must include the same identifier in all subsequent messages

4.1.5.3 DHCPDECLINE Message

When a server receives a DHCPDECLINE message, it indicates that the client has discovered the proposed network address is already in use. The server marks the address as unavailable and may notify the system administrator of a potential configuration issue

4.1.5.4 DHCPRELEASE Message

Upon receiving a DHCPRELEASE message, the server releases the network address, marking it as unallocated. The server may retain the client's configuration data for potential future use

4.1.5.5 DHCPINFORM Message

When a client sends a DHCPINFORM message, the server responds with a DHCPACK message containing the requested configuration parameters. However, the server will not send lease expiration times or fill in the yiaddr field, as no new address is being allocated. The response is sent directly to the address specified in the ciaddr field of the DHCPINFORM message

5. Design Details

5.1 Server Design

The DHCP server is responsible for processing client requests based on the current binding status. It handles various messages including DHCPDISCOVER, DHCPREQUEST, DHCPDECLINE, DHCPRELEASE, and DHCPINFORM. Upon receiving a DHCPDISCOVER, the server allocates a network address, either from the client's current or previous binding, the requested IP address, or from the available pool. The server sends a DHCPOFFER with the allocated address

When the client sends a DHCPREQUEST, the server checks if the request is for renewing a lease or requesting a new address. The server responds with a DHCPACK to confirm the request. If the client sends a DHCPDECLINE, the server marks the address as unavailable. If a DHCPRELEASE message is received, the server releases the address for reuse. For DHCPINFORM requests, the server responds with configuration parameters but does not assign a new IP address

5.2 Client Behavior

The client begins in the INIT state, broadcasting a DHCPDISCOVER message to locate a DHCP server. It may also request specific configuration options. Upon receiving a DHCPOFFER message, the client selects an offer and sends a DHCPREQUEST to confirm the allocation. If the address is in use, the client sends a DHCPDECLINE message. After receiving the DHCPACK from the server, the client moves to the BOUND state and starts network processing.
For clients that already have a network address, they enter the INIT-REBOOT state and send a DHCPREQUEST to revalidate their address. If a client is externally configured, it sends a DHCPINFORM message to

obtain additional configuration parameters without requesting a new address

5.3 Lease Database Design

The lease database tracks allocated IP addresses, including client hardware addresses, lease durations, and expiration times. When a client requests an address, the server checks the lease database for availability. The database is updated when a DHCPRELEASE or DHCPDECLINE message is received, marking the address as available. For DHCPINFORM messages, the database stores configuration parameters but does not allocate an IP address

5.4 Broadcast and Unicast Communication

The DHCP client uses both broadcast and unicast communication. It broadcasts DHCPDISCOVER, DHCPREQUEST, and DHCPINFORM messages when the server's address is unknown. If the client knows the server's address, it may use unicast for these messages. DHCPDECLINE messages are always broadcast, while DHCPRELEASE messages are unicasted to the server. When a client receives no response to unicast messages, it reverts to broadcasting. In the RENEWING and REBINDING states, the client tries to renew the lease using unicast (for RENEWING) and broadcasts for REBINDING if no response is received

5.5 Lease Reacquisition and Expiration

The client maintains two timers, T1 and T2, for lease reacquisition. T1 is the time the client attempts to renew the lease with the original server, while T2 is when it starts to contact any available server. If the

client does not receive a DHCPACK before T2, it enters the REBINDING state and attempts to renew the lease with any available server. If the lease expires, the client returns to the INIT state and starts the process again.The server can adjust T1 and T2 values and send them to the client in the DHCPACK message, allowing for some flexibility. If the client fails to renew the lease, it waits a randomized time before retrying, to avoid synchronized failures across clients

5.6 DHCPRELEASE

The client sends a DHCPRELEASE message when it no longer needs the allocated IP address, such as during a graceful shutdown. The DHCPRELEASE message is optional for correct DHCP operation but helps ensure address availability for other clients

6. Conclusion

The Dynamic Host Configuration Protocol (DHCP) is a cornerstone of efficient network management, providing a streamlined solution for IP address allocation and configuration. By automating these critical tasks, DHCP minimizes administrative complexity and ensures optimal utilization of available IP address resources.

Its three allocation methods—automatic, dynamic, and manual—cater to a range of networking needs, from assigning permanent addresses to temporary leasing and externally managed configurations. This flexibility allows network administrators to implement policies suited to

their specific requirements, whether for enterprise environments, temporary setups, or resource-constrained networks.

A well-implemented DHCP system comprises key components such as the DHCP server, clients, and a centralized lease database, ensuring efficient communication and configuration distribution. Its ability to dynamically allocate and manage IP addresses simplifies the setup and maintenance of networks while supporting scalability and reliability.

In conclusion, DHCP is an indispensable protocol in modern networking, empowering administrators with the tools to automate, optimize, and manage IP address configurations effectively across various network topologies and scales.

7. References

- Droms, R. (1997). *RFC 2131: Dynamic Host Configuration Protocol*