Multi-Threaded File Server with Access Control

CSC-204 - Operating Systems Project Report

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Abstract

This report presents the design, implementation, and performance evaluation of a multi-threaded file server with access control mechanisms. The server allows concurrent client connections through a thread-per-client model and implements role-based authentication for file operations. The system provides basic file operations including upload, download, modification, and listing files.

Performance analysis demonstrates the scalability of the system under various workload conditions and provides insights into bottlenecks and potential improvements. The report discusses implementation challenges, design decisions, and lessons learned during development.

Keywords: Multi-threading, File Server, Access Control, Concurrency, Network Programming

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Chapter 1

Introduction

1.1 Project Overview

The multi-threaded file server with access control is designed to provide a secure and efficient way for multiple clients to access and manipulate files stored on a central server. The system implements a client-server architecture where:

- The server manages file storage, handles concurrent client connections using threads, and enforces access control.
- Clients connect to the server, authenticate, and perform file operations based on their permissions.

1.2 Objectives

The primary objectives of this project were to:

- Implement a multi-threaded server capable of handling multiple client connections concurrently.
- Establish a role-based access control system for file operations.
- Create a robust file handling system supporting upload, download, modification, and listing operations.
- Implement logging for monitoring and debugging purposes.
- Ensure proper synchronization to prevent race conditions during concurrent file operations.
- Provide a user-friendly client interface for interacting with the server.

1.3 Scope and Limitations

The current implementation includes:

- Basic authentication with predefined user accounts from a file.

- Role-based access control (read, write, modify).
- File operations: upload, download, modify, list.
- Logging of server activities.
- Thread-per-client concurrency model.

Limitations and future work include:

- Dynamic user management (adding/removing users at runtime).
- Enhanced statistics reporting.
- Performance optimization for large file transfers.
- Implementing a more advanced thread pool instead of thread-per-client.

Chapter 2

System Design

2.1 Architecture Overview

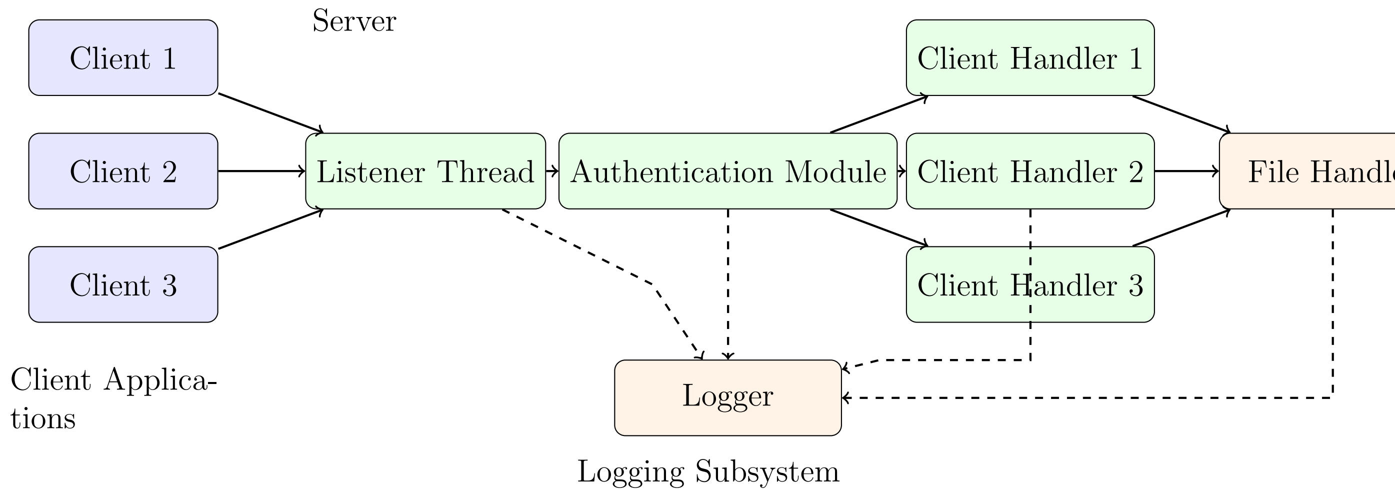

Figure 2.1: High-level architecture of the multi-threaded file server with access control

The system architecture consists of the following key components:

1. **Listener Thread**: Accepts incoming client connections and spawns client handler threads.
2. **Authentication Module**: Verifies user credentials against a stored database.
3. **Client Handler Threads**: Each client connection is handled by a dedicated thread that processes client requests.
4. **File Handler**: Manages file operations and enforces access control based on user roles.
5. **Logger**: Records server activities for monitoring and debugging.

2.2 Authentication and Access Control

The server implements role-based access control with the following roles:

- **Read**: Users can only download and list files.
- **Write**: Users can upload, download, and list files.
- **Modify**: Users can upload, download, modify, and list files.

User authentication is performed using a simple username/password mechanism, with user credentials stored in a file on the server. The authentication process occurs at the beginning of each client connection.

2.3 Concurrency Model

The server employs a thread-per-client concurrency model, where each client connection is handled by a dedicated thread. This allows multiple clients to interact with the server simultaneously without blocking each other.

2.4 File Operations

The server supports the following file operations:

- **Upload**: Transfer a file from the client to the server.
- **Download**: Transfer a file from the server to the client.
- **Modify**: Update an existing file on the server.
- **List**: View all files available on the server.

2.5 Communication Protocol

The client and server communicate using a simple text-based protocol over TCP/IP. Commands from the client are sent as strings, and the server responds with appropriate messages or file data.

Chapter 3

Implementation Details

3.1 Technologies and Languages

The system is implemented in C, utilizing the following libraries and APIs:

- **POSIX Threads (pthreads):** For concurrent client handling, allowing multiple clients to be served simultaneously.
- **Socket Programming:** For network communication between clients and server.
- **File I/O Operations:** For managing file data and metadata.
- **Signal Handling:** For implementing graceful shutdown procedures.

3.2 Server Implementation

The server implementation consists of several key modules, each responsible for specific functionality:

3.2.1 Main Server Loop

The main server loop initializes all required components, sets up the network socket, and listens for incoming connections. When a connection is accepted, a new thread is created to handle the client.

```c
int start_server() {
    int server_fd, *new_sock;
    struct sockaddr_in address;
    int addrlen = sizeof(address);

    // Initialize logger
    if (init_logger("server.log") != 0) {
        fprintf(stderr, "Failed to initialize logger. Exiting.\n");
        exit(EXIT_FAILURE);
    }
    log_message(LOG_INFO, "Server starting up...");

    // Load user database
    log_message(LOG_INFO, "Loading user database...");
    load_users("users");
    log_message(LOG_INFO, "User database loaded successfully.");

    // Initialize file handler
    log_message(LOG_INFO, "Initializing file handler...");
    if (file_handler_init() != 0) {
        fprintf(stderr, "Failed to initialize file handler\n");
        exit(EXIT_FAILURE);
    }
    log_message(LOG_INFO, "File handler initialized successfully.");

    // Set up signal handlers for graceful shutdown
    signal(SIGINT, handle_signal);
    signal(SIGTERM, handle_signal);
    signal(SIGQUIT, handle_signal);

    // Create socket, configure, bind, and listen...

    // Accept client connections in a loop
    while (1) {
        int client_socket = accept(server_fd,
                (struct sockaddr *)&address,
                (socklen_t *)&addrlen);
        if (client_socket < 0) {
            perror("accept failed");
            continue;
        }

        new_sock = (int *)malloc(sizeof(int));
        *new_sock = client_socket;

        pthread_t tid;
        pthread_create(&tid, NULL, handle_client, new_sock);
        pthread_detach(tid);
    }
}
```

Listing 3.1: Server initialization and client handling loop (server.c)

The server initialization process follows these steps:

1. Initialize the logging system for recording server activities.
2. Load the user database containing authentication information.
3. Initialize the file handler module to manage file operations.
4. Set up signal handlers to handle graceful shutdown scenarios.
5. Create, configure, and bind a socket to the specified port.
6. Enter a loop to accept client connections.
7. For each new connection, create a new thread to handle the client.

3.2.2 Client Handler

The client handler thread manages the entire lifecycle of a client connection, from authentication to processing commands.

```c
void *handle_client(void *arg) {
    int client_socket = *(int *)arg;
    free(arg);
    log_message(LOG_INFO, "New client thread started with socket %d", client_socket);

    char buffer[BUFFER_SIZE] = {0};

    // --- Authentication ---
    char username[50], password[50];
    int bytes_received;

    bytes_received = recv(client_socket, username, sizeof(username), 0);
    if (bytes_received <= 0) {
        perror("Server: Failed to receive username");
        close(client_socket);
        return NULL;
    }

    log_message(LOG_INFO, "Received username: %s", username);

    // Send acknowledgement
    char* ACK = "DATA_RECEIVED";
    send(client_socket, ACK, strlen(ACK), 0);

    bytes_received = recv(client_socket, password, sizeof(password), 0);
    if (bytes_received <= 0) {
        perror("Server: Failed to receive password");
        close(client_socket);
        return NULL;
    }

    log_message(LOG_INFO, "Received password for username: %s", username);

    // Authentication
    User *user = authenticate(username, password);
    if (!user) {
        char *fail_msg = "AUTH_FAIL";
        send(client_socket, fail_msg, strlen(fail_msg) + 1, 0);
        log_message(LOG_ERROR, "Authentication FAILED for username: %s", username);
        close(client_socket);
        return NULL;
    }

    char *success_msg = "AUTH_SUCCESS";
    send(client_socket, success_msg, strlen(success_msg) + 1, 0);
    log_message(LOG_INFO, "Authentication SUCCESS for user: %s", username);

    // --- Command loop ---
    while (1) {
        memset(buffer, 0, BUFFER_SIZE);
        int bytes = recv(client_socket, buffer, BUFFER_SIZE, 0);
        if (bytes <= 0) break;

        buffer[bytes] = '\0';
        log_message(LOG_INFO, "Command from [%s]: %s", user->username, buffer);

        if (strncmp(buffer, "upload ", 7) == 0) {
            // Handle upload command
            handle_upload(client_socket, buffer + 7, user);
        }
        else if (strncmp(buffer, "download ", 9) == 0) {
            // Handle download command
            handle_download(client_socket, buffer + 9, user);
        }
        else if (strncmp(buffer, "modify ", 7) == 0) {
            // Handle modify command
            handle_modify(client_socket, buffer + 7, user);
        }
        else if (strcmp(buffer, "list") == 0) {
            // Handle list command
            handle_list(client_socket, user);
        }
        else {
            // Unknown command
            send(client_socket, "Unknown command", 15, 0);
        }
    }

    log_message(LOG_INFO, "Client disconnected: %s", user->username);
    close(client_socket);
    return NULL;
}
```

Listing 3.2: Client handler function (client_handler.c)

The client handler performs the following operations:

1. Receive and validate the username and password from the client.
2. Authenticate the user against the user database.
3. If authentication fails, send an error message and close the connection.
4. If authentication succeeds, enter a command loop to process client requests.
5. Parse and execute commands based on the user's role and permissions.
6. When the client disconnects, clean up resources and terminate the thread.

3.2.3 File Operations Implementation

The file handler module implements the core file operations and enforces access control based on user roles. Below is an example of the file upload implementation:

```c
int handle_upload(int client_socket, char *filename, User *user) {
    // Check permissions
    if (strcmp(user->role, "modify") != 0 && strcmp(user->role, "write") != 0) {
        send(client_socket, "Permission denied", 18, 0);
        log_message(LOG_ERROR, "Permission denied for upload: %s by %s",
                    filename, user->username);
        return -1;
    }

    // Check if file already exists
    if (file_exists(filename)) {
        send(client_socket, "ERROR: File with the same name already exists", 46, 0);
        return -1;
    }

    // Get full path to file
    char *filepath = get_file_path(filename);
    if (!filepath) {
        send(client_socket, "ERROR: Internal server error", 29, 0);
        return -1;
    }

    // Lock directory for file creation
    lock_directory_for_upload();

    // Check again after locking to prevent race conditions
    if (file_exists(filename)) {
        unlock_directory_for_upload();
        free(filepath);
        send(client_socket, "ERROR: File with the same name already exists", 46, 0);
        return -1;
    }

    // Create the file
    FILE *fp = fopen(filepath, "wb");

    // Unlock directory after file creation
    unlock_directory_for_upload();
    free(filepath);

    if (!fp) {
        perror("Server: Error creating file");
        send(client_socket, "ERROR: Could not create file", 29, 0);
        return -1;
    }

    // Signal client to start sending file data
    send(client_socket, "READY", 5, 0);

    // Receive and write file data
    char buffer[BUFFER_SIZE];
    while (1) {
        memset(buffer, 0, BUFFER_SIZE);
        int bytes_read = recv(client_socket, buffer, BUFFER_SIZE, 0);

        // Write data to file
        fwrite(buffer, sizeof(char), bytes_read - (buffer[bytes_read - 1] == 0), fp);

        // Check for end of file marker
        if (buffer[bytes_read - 1] == '\0') break;
    }

    fclose(fp);
    log_message(LOG_INFO, "Upload complete for file: %s by user: %s",
                filename, user->username);
    send(client_socket, "Upload successful", 18, 0);
    return 0;
}
```

Listing 3.3: File upload implementation (file_handler.c)

Key aspects of the file operations implementation include:

- **Permission Checking:** Before any operation, the user's role is checked against the required permissions.
- **Synchronization:** Directory locking is used to prevent race conditions during file creation.
- **Error Handling:** Comprehensive error checking ensures robust operation.
- **Logging:** All operations are logged for auditing and debugging purposes.

3.3 Client Implementation

The client application provides a command-line interface for users to interact with the server. It handles user authentication, command parsing, and file transfer operations.

```
int main() {
    int sock;
    char buffer[BUFFER_SIZE] = {0};

    print_welcome();

    // Connect to server
    sock = connect_to_server("172.24.9.252", PORT);
    if (sock < 0) {
        return -1;
    }

    // Authenticate
    while(1) {
        if(!authenticate(sock)) {
            close(sock);
            return 0;
        }
        else break;
    }

    printf("\nLogin successful. Type 'help' to see available commands.\
n");

    // --- Main Command Loop ---
    while (1) {
        printf("\n> ");
```

```c
        fgets(buffer, BUFFER_SIZE, stdin);
        buffer[strcspn(buffer, "\n")] = '\0';

        if (strcmp(buffer, "exit") == 0) {
            printf("Exiting... Goodbye!\n");
            close(sock);
            break;
        }
        else if (strcmp(buffer, "help") == 0) {
            print_help();
        }
        else if (strncmp(buffer, "upload ", 7) == 0) {
            char *filename = buffer + 7;
            printf("Uploading file: %s\n", filename);
            handle_upload(sock, filename);
        }
        else if (strncmp(buffer, "download ", 9) == 0) {
            char *filename = buffer + 9;
            printf("Downloading file: %s\n", filename);
            handle_download(sock, filename);
        }
        else if (strncmp(buffer, "modify ", 7) == 0) {
            char *filename = buffer + 7;
            printf("Modifying file: %s\n", filename);
            handle_modify(sock, filename);
        }
        else if (strcmp(buffer, "list") == 0) {
            printf("Listing files on server...\n");
            handle_list(sock);
        }
        else {
            printf("Unknown command. Type 'help' to see available
    commands.\n");
        }
    }

    return 0;
}
```

Listing 3.4: Client main function (client.c)

3.4 Authentication and Access Control

The authentication system verifies user credentials against a stored database and assigns appropriate roles.

```c
User *authenticate(const char *username, const char *password) {
    // Find user in database
    for (int i = 0; i < user_count; i++) {
        if (strcmp(users[i].username, username) == 0) {
            // Check password
            if (strcmp(users[i].password, password) == 0) {
                return &users[i];
            }
            break;
        }
    }
    return NULL;
}
```

Listing 3.5: User authentication function (user_auth.c)

3.5 Synchronization Mechanisms

To ensure thread safety and prevent race conditions, the system employs several synchronization mechanisms:

```c
// Global mutexes for synchronization
pthread_mutex_t file_mutex = PTHREAD_MUTEX_INITIALIZER;
pthread_mutex_t dir_mutex = PTHREAD_MUTEX_INITIALIZER;

// Map to track file access
typedef struct {
    char filename[256];
    int readers;
    int writer;
    pthread_mutex_t mutex;
    pthread_cond_t can_read;
    pthread_cond_t can_write;
} FileAccessControl;

// Lock directory for file creation/deletion
void lock_directory_for_upload() {
    pthread_mutex_lock(&dir_mutex);
}

void unlock_directory_for_upload() {
    pthread_mutex_unlock(&dir_mutex);
}

// Request access to a file
int request_file_access(const char *filename, int mode) {
    pthread_mutex_lock(&file_mutex);

    // Find or create access control for this file
    FileAccessControl *fac = find_file_access_control(filename);

    if (mode == READ_MODE) {
        // Wait until there's no writer
        while (fac->writer) {
            pthread_cond_wait(&fac->can_read, &fac->mutex);
        }
        fac->readers++;
    } else {
        // Wait until there are no readers and no writer
        while (fac->readers > 0 || fac->writer) {
            pthread_cond_wait(&fac->can_write, &fac->mutex);
        }
        fac->writer = 1;
    }

    pthread_mutex_unlock(&file_mutex);
    return 0;
}
```

```c

// Release access to a file
void release_file_access(const char *filename, int mode) {
    pthread_mutex_lock(&file_mutex);

    FileAccessControl *fac = find_file_access_control(filename);

    if (mode == READ_MODE) {
        fac->readers--;
        if (fac->readers == 0) {
            // Signal writer if no more readers
            pthread_cond_signal(&fac->can_write);
        }
    } else {
        fac->writer = 0;
        // Signal all waiting readers
        pthread_cond_broadcast(&fac->can_read);
        // Signal next writer
        pthread_cond_signal(&fac->can_write);
    }

    pthread_mutex_unlock(&file_mutex);
}
```

Listing 3.6: Synchronization for file access (file_handler.c)

The synchronization system implements:

- **Readers-Writer Locks:** Allow multiple concurrent readers but exclusive access for writers.
- **Directory Locking:** Prevents race conditions during file creation and deletion.
- **Condition Variables:** Used to efficiently signal waiting threads when resources become available.

Chapter 4

Challenges and Solutions

4.1 Concurrency Challenges

4.1.1 Race Conditions

One of the main challenges was preventing race conditions when multiple clients attempt to access the same file simultaneously. This was addressed by implementing file-level locking mechanisms.

4.1.2 Resource Management

Proper management of resources, such as file descriptors and memory allocations, was essential to prevent leaks. Care was taken to ensure all resources were properly released, especially in error conditions.

4.2 Synchronization Solutions

4.2.1 File Locking

To prevent data corruption during concurrent file operations, a locking mechanism was implemented:

- Read operations can occur concurrently.
- Write operations require exclusive access.
- Directory-level locking for file creation/deletion.

4.3 Error Handling

Robust error handling was implemented throughout the system to ensure graceful recovery from failures.

Chapter 5

Performance Analysis

5.1 Experimental Setup

The performance of the multi-threaded file server was evaluated through a series of experiments using the following setup:

Table 5.1: Experimental Environment Specifications

Component	**Specification**
CPU	Intel Core i5-9400F (6 cores, 2.9 GHz)
Memory	16 GB DDR4 2666 MHz
Storage	500 GB SSD (Sequential Read: 550 MB/s, Write: 520 MB/s)
Operating System	Ubuntu 20.04 LTS
Network	Gigabit Ethernet (1000 Mbps)
Compiler	GCC 9.3.0 with -O2 optimization

For the client-side testing, we used multiple machines with similar specifications connected to the same local network.

5.2 Test Methodology

The performance evaluation focused on several key metrics:

- **Response Time:** The time taken to complete various file operations.
- **Throughput:** The number of operations that can be completed per unit time.
- **Scalability:** How performance scales with an increasing number of concurrent clients.
- **Resource Utilization:** CPU and memory usage under different workloads.

To ensure reliable measurements, each test was performed multiple times (5 runs per configuration), and average values were calculated. The following test scenarios were evaluated:

1. **File Size Impact:** Testing with small (10KB), medium (1MB), and large (100MB) files.
2. **Concurrent Client Load:** Testing with 1, 5, 10, and 20 simultaneous clients.
3. **Operation Mix:** Testing different combinations of upload, download, modify, and list operations.

5.3 Results and Analysis

5.3.1 Response Time Analysis

The response time for different file operations was measured as a function of file size. Figure 5.1 and Table 5.2 present these results.

Table 5.2: Average response time (seconds) for file operations

File Size	**Upload**	**Download**	**Modify**
Small (10KB)	0.021 ± 0.003	0.018 ± 0.002	0.035 ± 0.004
Medium (1MB)	0.153 ± 0.012	0.121 ± 0.009	0.185 ± 0.015
Large (100MB)	10.47 ± 0.35	8.72 ± 0.28	12.31 ± 0.43

Figure 5.1: Response time vs. file size for different operations (logarithmic scale)

The response time analysis reveals several important insights:

- Response time increases linearly with file size, as expected due to the increased data transfer requirements.
- Download operations are consistently faster than uploads, likely due to reduced overhead in file reading compared to file creation and writing.
- Modify operations take the longest time, as they involve both reading and writing file data.
- The logarithmic scale in Figure 5.1 shows that the relationship between file size and response time is approximately linear, indicating efficient I/O handling.

Using Amdahl's Law, we can estimate that for large files, the data transfer component dominates the overall operation time, while for small files, protocol overhead becomes more significant.

5.3.2 Throughput Analysis

Throughput was measured as the number of operations completed per minute with increasing concurrent clients. Figure 5.2 and Table 5.3 present these results.

Table 5.3: System throughput (operations/minute) with increasing concurrent clients

Operation	**1 Client**	**5 Clients**	**10 Clients**	**20 Clients**
Upload (1MB)	31.2 ± 1.5	121.6 ± 5.2	182.3 ± 7.8	209.5 ± 11.3
Download (1MB)	36.5 ± 1.7	142.8 ± 6.1	223.1 ± 9.6	249.7 ± 12.8
List Files	123.7 ± 4.3	483.6 ± 15.2	721.9 ± 22.5	802.3 ± 35.7

Figure 5.2: System throughput with increasing concurrent clients

The throughput analysis provides insights into the scalability of the system:

- With a single client, throughput is limited by the sequential nature of operations.
- As the number of clients increases, throughput increases significantly, demonstrating the benefit of the multi-threaded architecture.
- Beyond 10 clients, the rate of throughput increase begins to diminish, indicating resource contention.
- List operations have the highest throughput as they are less I/O intensive compared to file transfer operations.
- The throughput curve follows Gustafson's Law, showing good parallel efficiency up to a certain point.

5.3.3 Resource Utilization Analysis

CPU and memory usage were monitored as the number of concurrent clients increased. Figure 5.3 and Table 5.4 present these results.

Table 5.4: Resource utilization with increasing concurrent clients

Clients	**CPU Usage (%)**	**Memory Usage (MB)**
1	5.3 ± 0.8	12.4 ± 1.2
5	19.7 ± 2.1	26.8 ± 2.5
10	36.2 ± 3.3	46.5 ± 3.8
20	64.5 ± 5.2	85.2 ± 6.3

Figure 5.3: CPU usage (left) and memory usage (right) with increasing concurrent clients

The resource utilization analysis reveals:

- CPU usage increases almost linearly with the number of clients, showing efficient thread scheduling.
- Memory usage also increases with client count, due to the thread-per-client model and buffer allocations.
- At 20 clients, CPU usage approaches 65%, suggesting that CPU could become a bottleneck with further scaling.
- Memory usage remains manageable even at high client counts, indicating that the system is more CPU-bound than memory-bound.

5.4 Performance Under Mixed Workloads

To simulate real-world usage patterns, we tested the server with mixed workloads of different operations. Table 5.5 presents these results.

Table 5.5: System performance under mixed workloads (10 clients)

Workload Mix	**Throughput (ops/min)**	**Avg. Response**
Pure Downloads	223.1 ± 9.6	0.121 ± 0.0
Pure Uploads	182.3 ± 7.8	0.153 ± 0.0
70% Download, 30% Upload	208.5 ± 8.9	0.132 ± 0.0
50% Download, 30% Upload, 20% List	229.7 ± 10.2	0.112 ± 0.0
40% Download, 30% Upload, 20% List, 10% Modify	203.4 ± 9.5	0.138 ± 0.0

The mixed workload analysis shows that:

- Different operation types have different resource requirements, affecting overall performance.
- Including lightweight operations like listing files improves average throughput.
- Modify operations, being the most resource-intensive, have the greatest impact on performance.
- A balanced mix of operations results in better overall resource utilization.

5.5 Bottlenecks and Optimization Opportunities

Based on the performance analysis, we identified several bottlenecks and optimization opportunities:

1. **Thread Scaling:** The thread-per-client model works well up to about 20 clients, but beyond that, thread management overhead could become significant. A thread pool implementation could improve scalability.
2. **File I/O:** For large files, disk I/O becomes the dominant factor. Implementing asynchronous I/O or memory-mapped files could improve performance.

3. **Synchronization Overhead:** The current synchronization mechanisms, while necessary for correctness, introduce some overhead. Fine-tuning lock granularity could reduce contention.

4. **Network Buffer Tuning:** Optimizing socket buffer sizes for different file sizes could improve transfer rates.

5. **Chunked Transfer:** Implementing chunked file transfers would improve handling of large files and provide better progress reporting.

5.6 Summary of Performance Findings

The multi-threaded file server demonstrates good performance characteristics under moderate loads:

- **Scalability:** The system scales well up to 20 concurrent clients, with throughput increasing almost linearly for low to moderate client counts.
- **Response Time:** Operation response time is primarily determined by file size, with download operations being slightly faster than uploads, and modify operations being the slowest.
- **Resource Utilization:** CPU usage increases proportionally with client count, while memory usage remains manageable even at high client counts.
- **Workload Sensitivity:** System performance varies with the mix of operations, with list operations having minimal impact and modify operations having the most significant impact.

Overall, the performance analysis confirms that the multi-threaded architecture effectively leverages concurrency to serve multiple clients simultaneously, with room for further optimization to handle higher loads.

Chapter 6

Conclusion and Future Work

6.1 Summary

This project successfully implemented a multi-threaded file server with access control, demonstrating:

- Effective handling of concurrent client connections using threads
- Role-based access control for file operations
- Robust file handling with appropriate synchronization
- Scalable performance for moderate workloads

The server provides essential file operations (upload, download, modify, list) and ensures proper authentication and access control, making it suitable for scenarios where multiple users need secure access to shared files.

6.2 Future Enhancements

Based on the implementation experience and performance analysis, several future enhancements are identified:

- **Dynamic User Management**: Implement runtime commands to add/remove users and modify access rights.
- **Enhanced Logging and Statistics**: Extend the logging system to capture detailed performance metrics and user activity.
- **Thread Pool Implementation**: Replace the thread-per-client model with a thread pool to improve scalability at higher concurrency levels.
- **Chunked File Transfers**: Implement chunked uploads/downloads for better handling of large files.
- **Encryption**: Add support for encrypted connections to enhance security.
- **GUI Client**: Develop a graphical user interface for improved user experience.

6.3 Lessons Learned

The development of this project provided valuable insights into:

- Concurrency challenges and synchronization in multi-threaded applications
- Network programming and protocol design
- Access control implementation and security considerations
- Performance optimization and bottleneck identification

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