Dynamic Network Routing Protocol

Computer Networks Project

A Project Report Submitted by

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November 20, 2024

Contents

1 Aim

The aim of this project is to implement and compare the performance of three popular shortest path algorithms—Dijkstra's Algorithm, Bellman-Ford Algorithm, and Floyd-Warshall Algorithm—using Python. The project also explores the effects of node failures on the routing process and measures round-trip time for client-server communication during pathfinding requests.

2 Introduction

Shortest path algorithms are crucial in computer networks for determining the most efficient paths between nodes in a graph, which can represent networks, transportation systems, and various other systems. This project focuses on implementing and analyzing three key algorithms—Dijkstra's, Bellman-Ford, and Floyd-Warshall. These algorithms are essential for routing and network optimization tasks.

The project will compare their computational efficiencies and ability to handle dynamic changes in the network, such as node failures.

3 System Design

3.1 Architecture

The system is designed with a client-server model where:

- The server implements the shortest path algorithms.
- Clients send requests for shortest paths between two nodes.
- A node failure simulation is included to test the resilience of the algorithms.

Each client communicates with a server on a specific port number. The system uses Python's socket programming for client-server communication.

3.2 Protocol/Concept Details

- **Dijkstra's Algorithm**: Efficient for graphs with non-negative edge weights, providing the shortest path from a source node to all other nodes.
- **Bellman-Ford Algorithm**: Capable of handling negative edge weights and detecting negative weight cycles.
- **Floyd-Warshall Algorithm**: Computes the shortest paths between all pairs of nodes in a graph.

3.3 Tools and Technologies

- Programming Language: Python
- Communication Protocol: TCP (Socket Programming)
- Libraries: socket, time

4 Implementation Details

4.1 Client-Side Code

The client code sends a request for the shortest path to a target node from a given server and calculates the round-trip time. Below is the implementation of the common client-side code:

Listing 1: Client-Side Code for Requesting Shortest Paths

```python
import socket
import time

def client_request(server_id, target_node):
    client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    client_socket.connect(('localhost', 8000 + server_id))
    client_socket.send(str(target_node).encode('utf-8'))
    start_time = time.time()

    response = client_socket.recv(1024).decode('utf-8')

    end_time = time.time()
    round_trip_time = end_time - start_time

    print(f"Client received: {response}")
    print(f"Round-trip time for request: {round_trip_time:.6f} seconds"
        )

    client_socket.close()

# Simulate clients requesting shortest paths to different target nodes
def run_clients():
    client_request(0, 4)
    client_request(1, 4)
    client_request(2, 4)

if __name__ == "__main__":
    run_clients()
```

4.2 Server-Side Code

Here is the placeholder for the server-side code for each algorithm. Replace the corresponding sections with the actual code for Dijkstra, Bellman-Ford, and Floyd-Warshall algorithms.

4.2.1 Dijkstra's Algorithm

Listing 2: Server-Side Code for Dijkstra's Algorithm

```python
import socket
import threading
import heapq
import random
import time
import networkx as nx
```

```python
import matplotlib.pyplot as plt


def generate_large_sparse_graph(nodes, edges):
    graph = {i: {} for i in range(nodes)}
    edge_count = 0
    current_edge = 0


    while edge_count < edges:
        u = current_edge % nodes
        v = (current_edge + 1) % nodes
        weight = (current_edge + 1) % 10 + 1
        if u != v and v not in graph[u]:
            graph[u][v] = weight
            graph[v][u] = weight
        current_edge += 1


        if current_edge > nodes * 2:
            print("Unable to generate enough edges due to constraints.")
            break

    return graph


def plot_graph(graph, failed_nodes=None):
    """Visualizes the graph with optional highlighting of failed nodes."""
    G = nx.Graph()
    for node, neighbors in graph.items():
        for neighbor, weight in neighbors.items():
            G.add_edge(node, neighbor, weight=weight)

    pos = nx.spring_layout(G)
    plt.figure(figsize=(8, 6))
    nx.draw(
        G,
        pos,
        with_labels=True,
        node_color="skyblue",
        edge_color="gray",
        node_size=700,
        font_size=10,
        font_weight="bold",
    )
    if failed_nodes:
        nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes, node_color="red")

    labels = nx.get_edge_attributes(G, "weight")
    nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)

    plt.title("Network Graph")
    plt.show()
```

```python
# Dijkstra's algorithm to find the shortest path
def dijkstra(graph, start_node, failed_node=None):

    # Step 1: Initialize distances to all nodes as infinity, except the start node
    queue = [(0, start_node)]  # (cost, node)
    distances = {node: float("inf") for node in graph}
    distances[start_node] = 0
    previous_nodes = {node: None for node in graph}

    # Step 2: Modify graph to exclude failed node if specified
    if failed_node is not None:
        graph = {
            node: {
                neighbor: weight
                for neighbor, weight in neighbors.items()
                if neighbor != failed_node
            }
            for node, neighbors in graph.items()
            if node != failed_node
        }

    while queue:
        current_distance, current_node = heapq.heappop(queue)

        if current_distance > distances[current_node]:
            continue

        for neighbor, weight in graph[current_node].items():
            distance = current_distance + weight
            if distance < distances[neighbor]:
                distances[neighbor] = distance
                previous_nodes[neighbor] = current_node
                heapq.heappush(queue, (distance, neighbor))

    return distances, previous_nodes


# Server code for each node
class Server:
    def __init__(self, node_id, graph):
        self.node_id = node_id
        self.graph = graph  # Network topology as graph
        self.server_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        self.server_socket.bind(("localhost", 8000 + node_id))
        self.server_socket.listen(5)
        self.failed_nodes = set()
        self.routing_table = {}
        self.is_active = True
        print(f"Server {node_id} started on port {8000 + node_id}")
        self.recalculate_routing_table()

    def recalculate_routing_table(self):
        """Recalculate the routing table for all nodes."""
        print(f"Recalculating routing table for Server {self.node_id}")
        self.routing_table, _ = dijkstra(self.graph, self.node_id)
        print(f"Updated Routing Table for Server {self.node_id}:")
```

```python
        for node, distance in self.routing_table.items():
            print(f"  To Node {node}: Distance {distance}")

    def handle_client(self, client_socket):
        try:
            if not self.is_active:
                # Notify client that the server is down
                print(f"Server {self.node_id} is down. Rejecting request.")
                client_socket.send(
                    f"Server {self.node_id} is currently down.".encode("utf-8")
                )
                return

            data = client_socket.recv(1024).decode("utf-8")
            if data:
                target_node = int(data)  # Target node ID
                print(
                    f"Server {self.node_id} received request for shortest path to node {target_node}"
                )
                server_start_time = time.time()

                # Retrieve the shortest path from the precomputed routing table
                distance = self.routing_table.get(target_node, float("inf"))
                response = f"Shortest path to node {target_node}: {distance}"
                server_end_time = time.time()
                server_computation_time = server_end_time - server_start_time  # Time taken to process the request
                print(f"Server {self.node_id} computation time: {server_computation_time:.6f} seconds")

                client_socket.send(response.encode("utf-8"))
        finally:
            client_socket.close()

    def run(self):
        while True:
            client_socket, _ = self.server_socket.accept()
            client_thread = threading.Thread(
                target=self.handle_client, args=(client_socket,)
            )
            client_thread.start()

    def simulate_failure(self, failed_node):
        print(f"Simulating failure of Node {failed_node} in Server {self.node_id}")


        if self.node_id == failed_node:
            self.is_active = False
            print(f"Server {self.node_id} is now marked as down.")
            return
```

```python
        self.failed_nodes.add(failed_node)


        for node in self.graph:
            if failed_node in self.graph[node]:
                del self.graph[node][failed_node]
            if node == failed_node:
                self.graph[node] = {}


        print(f"Node {failed_node} failure simulated. Recalculating routing table.")
        self.recalculate_routing_table()
        # plot_graph(self.graph, failed_nodes=self.failed_nodes)


# Start server for each node in the network
def start_servers():
    # graph = {
    #     0: {1: 10},
    #     1: {0: 10, 2: 10, 3: 50},
    #     2: {1: 10, 3: 30},
    #     3: {2: 30, 4: 40, 1: 50},
    #     4: {3: 40},
    # }
    nodes = 100
    edges = 200
    graph=generate_large_sparse_graph(nodes,edges)
    servers = []
    # plot_graph(graph)
    # Start servers
    for node_id in range(len(graph)):
        server = Server(node_id, graph)
        threading.Thread(target=server.run).start()
        servers.append(server)

    # Simulate failure of a node
    failed_node = 2
    time.sleep(5)
    for server in servers:
        server.simulate_failure(failed_node)


    print("\nSimulating client trying to access a failed server:")
    client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    try:
        client_socket.connect(("localhost", 16000 + failed_node))
        client_socket.send("3".encode("utf-8"))
        response = client_socket.recv(1024).decode("utf-8")
        print(f"Response from Server {failed_node}: {response}")
    except ConnectionRefusedError:
        print(f"Server {failed_node} is unavailable.")
    finally:
        client_socket.close()
```

```python
if __name__ == "__main__":
    start_servers()
```

4.2.2 Bellman-Ford Algorithm

Listing 3: Server-Side Code for Bellman-Ford Algorithm

```python
import socket
import threading
import time
import random
import networkx as nx
import matplotlib.pyplot as plt

def generate_large_sparse_graph(nodes, edges):
    graph = {i: {} for i in range(nodes)}
    edge_count = 0
    current_edge = 0


    while edge_count < edges:
        u = current_edge % nodes
        v = (current_edge + 1) % nodes
        weight = (current_edge + 1) % 10 + 1

        if u != v and v not in graph[u]:
            graph[u][v] = weight
            graph[v][u] = weight
            edge_count += 1


        current_edge += 1


        if current_edge > nodes * 2:
            print("Unable to generate enough edges due to constraints."
                )
            break

    return graph

def plot_graph(graph, failed_nodes=None):
    """Visualizes the graph with optional highlighting of failed nodes.
        """
    G = nx.Graph()
    for node, neighbors in graph.items():
        for neighbor, weight in neighbors.items():
            G.add_edge(node, neighbor, weight=weight)

    pos = nx.spring_layout(G)
    plt.figure(figsize=(8, 6))
    nx.draw(
        G,
        pos,
        with_labels=True,
        node_color="skyblue",
        edge_color="gray",
```

```python
        node_size=700,
        font_size=10,
        font_weight="bold",
    )
    if failed_nodes:
        nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes,
            node_color="red")

    labels = nx.get_edge_attributes(G, "weight")
    nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)

    plt.title("Network Graph")
    plt.show()

# Bellman-Ford algorithm to find the shortest path
def bellman_ford(graph, start_node):

    distances = {node: float('inf') for node in graph}
    distances[start_node] = 0
    previous_nodes = {node: None for node in graph}


    for _ in range(len(graph) - 1):
        for node in graph:
            for neighbor, weight in graph[node].items():
                if distances[node] + weight < distances[neighbor]:
                    distances[neighbor] = distances[node] + weight
                    previous_nodes[neighbor] = node


    for node in graph:
        for neighbor, weight in graph[node].items():
            if distances[node] + weight < distances[neighbor]:
                print("Graph contains a negative weight cycle")

    return distances, previous_nodes

# Server code for each node
class Server:
    def __init__(self, node_id, graph):
        self.node_id = node_id
        self.graph = graph  # Network topology as graph
        self.server_socket = socket.socket(socket.AF_INET, socket.
            SOCK_STREAM)
        self.server_socket.bind(("localhost", 8000 + node_id))
        self.server_socket.listen(5)
        self.failed_nodes = set()
        self.routing_table = {}
        self.is_active = True
        print(f"Server {node_id} started on port {8000 + node_id}")
        self.recalculate_routing_table()

    def recalculate_routing_table(self):
        """Recalculate the routing table for all nodes."""
        print(f"Recalculating routing table for Server {self.node_id}")
        self.routing_table, _ = bellman_ford(self.graph, self.node_id)
        print(f"Updated Routing Table for Server {self.node_id}:")
        for node, distance in self.routing_table.items():
```

```
            print(f"  To Node {node}: Distance {distance}")

    def handle_client(self, client_socket):
        try:
            if not self.is_active:
                # Notify client that the server is down
                print(f"Server {self.node_id} is down. Rejecting request.")
                client_socket.send(
                    f"Server {self.node_id} is currently down.".encode("utf-8")
                )
                return

            data = client_socket.recv(1024).decode("utf-8")
            if data:
                target_node = int(data)  # Target node ID
                print(
                    f"Server {self.node_id} received request for shortest path to node {target_node}"
                )
                server_start_time = time.time()

                # Retrieve the shortest path from the precomputed routing table
                distance = self.routing_table.get(target_node, float("inf"))
                response = f"Shortest path to node {target_node}: {distance}"
                server_end_time = time.time()
                server_computation_time = server_end_time - server_start_time  # Time taken to process the request
                print(f"Server {self.node_id} computation time: {server_computation_time:.6f} seconds")

                client_socket.send(response.encode("utf-8"))
        finally:
            client_socket.close()

    def run(self):
        while True:
            client_socket, _ = self.server_socket.accept()
            client_thread = threading.Thread(
                target=self.handle_client, args=(client_socket,)
            )
            client_thread.start()

    def simulate_failure(self, failed_node):
        print(f"Simulating failure of Node {failed_node} in Server {self.node_id}")


        if self.node_id == failed_node:
            self.is_active = False
            print(f"Server {self.node_id} is now marked as down.")
            return

```

```
        self.failed_nodes.add(failed_node)


        for node in self.graph:
            if failed_node in self.graph[node]:
                del self.graph[node][failed_node]
            if node == failed_node:
                self.graph[node] = {}


        print(f"Node {failed_node} failure simulated. Recalculating routing table.")
        self.recalculate_routing_table()
        # plot_graph(self.graph, failed_nodes=self.failed_nodes)


# Start server for each node in the network
def start_servers():
    # graph = {
    #     0: {1: 10},
    #     1: {0: 10, 2: 10, 3: 50},
    #     2: {1: 10, 3: 30},
    #     3: {2: 30, 4: 40, 1: 50},
    #     4: {3: 40},
    # }
    nodes = 100
    edges = 200
    graph=generate_large_sparse_graph(nodes,edges)
    servers = []
    # plot_graph(graph)
    # Start servers
    for node_id in range(len(graph)):
        server = Server(node_id, graph)
        threading.Thread(target=server.run).start()
        servers.append(server)

    # Simulate failure of a node
    failed_node = 2
    time.sleep(5)
    for server in servers:
        server.simulate_failure(failed_node)


    print("\nSimulating client trying to access a failed server:")
    client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    try:
        client_socket.connect(("localhost", 16000 + failed_node))
        client_socket.send("3".encode("utf-8"))
        response = client_socket.recv(1024).decode("utf-8")
        print(f"Response from Server {failed_node}: {response}")
    except ConnectionRefusedError:
        print(f"Server {failed_node} is unavailable.")
    finally:
        client_socket.close()


if __name__ == "__main__":
```

```
    start_servers()
```

4.2.3 Floyd-Warshall Algorithm

Listing 4: Server-Side Code for Floyd-Warshall Algorithm

```
import socket
import threading
import heapq
import random
import time
import networkx as nx
import matplotlib.pyplot as plt


def generate_large_sparse_graph(nodes, edges):
    graph = {i: {} for i in range(nodes)}
    edge_count = 0
    current_edge = 0


    while edge_count < edges:
        u = current_edge % nodes
        v = (current_edge + 1) % nodes
        weight = (current_edge + 1) % 10 + 1

        if u != v and v not in graph[u]:
            graph[u][v] = weight
            graph[v][u] = weight
            edge_count += 1


        current_edge += 1


        if current_edge > nodes * 2:
            print("Unable to generate enough edges due to constraints."
                )
            break

    return graph
def floyd_warshall(graph, start_node, failed_node=None):
    # Step 1: Initialize distances matrix
    nodes = list(graph.keys())
    num_nodes = len(nodes)
    distances = {node: {neighbor: float("inf") for neighbor in nodes}
        for node in nodes}
    previous_nodes = {node: None for node in nodes}

    # Set initial distances based on the graph
    for u in graph:
        distances[u][u] = 0  # Distance to itself is 0
        for v, weight in graph[u].items():
            distances[u][v] = weight

    # Step 2: Modify graph to exclude failed node if specified
    if failed_node is not None:
```

```
        distances = {
            node: {
                neighbor: distances[node][neighbor]
                for neighbor in distances[node]
                if neighbor != failed_node
            }
            for node in distances
            if node != failed_node
        }

    # Step 3: Apply Floyd-Warshall algorithm
    for k in distances:
        for i in distances:
            for j in distances:
                if distances[i][k] + distances[k][j] < distances[i][j]:
                    distances[i][j] = distances[i][k] + distances[k][j]

    # Extract the distances from the start_node
    single_source_distances = distances[start_node]
    return single_source_distances, previous_nodes


def plot_graph(graph, failed_nodes=None):
    """Visualizes the graph with optional highlighting of failed nodes.
    """
    G = nx.Graph()
    for node, neighbors in graph.items():
        for neighbor, weight in neighbors.items():
            G.add_edge(node, neighbor, weight=weight)

    pos = nx.spring_layout(G)
    plt.figure(figsize=(8, 6))
    nx.draw(
        G,
        pos,
        with_labels=True,
        node_color="skyblue",
        edge_color="gray",
        node_size=700,
        font_size=10,
        font_weight="bold",
    )
    if failed_nodes:
        nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes,
            node_color="red")

    labels = nx.get_edge_attributes(G, "weight")
    nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)

    plt.title("Network Graph")
    plt.show()


# Server code for each node
class Server:
    def __init__(self, node_id, graph):
        self.node_id = node_id
        self.graph = graph  # Network topology as graph
```

```python
        self.server_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        self.server_socket.bind(("localhost", 8000 + node_id))
        self.server_socket.listen(5)
        self.failed_nodes = set()
        self.routing_table = {}  # Stores distances to all nodes
        self.is_active = True  # Indicates if the server is up or down
        print(f"Server {node_id} started on port {8000 + node_id}")
        self.recalculate_routing_table()  # Calculate initial routing table

    def recalculate_routing_table(self):
        """Recalculate the routing table for all nodes."""
        print(f"Recalculating routing table for Server {self.node_id}")
        self.routing_table, _ = floyd_warshall(self.graph, self.node_id)
        print(f"Updated Routing Table for Server {self.node_id}:")
        for node, distance in self.routing_table.items():
            print(f"  To Node {node}: Distance {distance}")

    def handle_client(self, client_socket):
        try:
            if not self.is_active:
                # Notify client that the server is down
                print(f"Server {self.node_id} is down. Rejecting request.")
                client_socket.send(
                    f"Server {self.node_id} is currently down.".encode("utf-8")
                )
                return

            data = client_socket.recv(1024).decode("utf-8")
            if data:
                target_node = int(data)  # Target node ID
                print(
                    f"Server {self.node_id} received request for shortest path to node {target_node}"
                )
                server_start_time = time.time()

                # Retrieve the shortest path from the precomputed routing table
                distance = self.routing_table.get(target_node, float("inf"))
                response = f"Shortest path to node {target_node}: {distance}"
                server_end_time = time.time()
                server_computation_time = server_end_time - server_start_time  # Time taken to process the request
                print(f"Server {self.node_id} computation time: {server_computation_time:.6f} seconds")
                # client_socket.send(response.encode("utf-8"))
                client_socket.send(response.encode("utf-8"))
        finally:
            client_socket.close()

```

```python
    def run(self):
        while True:
            client_socket, _ = self.server_socket.accept()
            client_thread = threading.Thread(
                target=self.handle_client, args=(client_socket,)
            )
            client_thread.start()

    def simulate_failure(self, failed_node):
        print(f"Simulating failure of Node {failed_node} in Server {self.node_id}")

        # If this server is the one that failed, mark it as inactive
        if self.node_id == failed_node:
            self.is_active = False
            print(f"Server {self.node_id} is now marked as down.")
            return

        # Mark the failed node as unreachable and update the graph
        self.failed_nodes.add(failed_node)

        # Update the graph for the failure
        for node in self.graph:
            if failed_node in self.graph[node]:
                del self.graph[node][failed_node]
            if node == failed_node:
                self.graph[node] = {}

        # Recalculate the routing table for all servers after the failure
        print(f"Node {failed_node} failure simulated. Recalculating routing table.")
        self.recalculate_routing_table()
        # plot_graph(self.graph, failed_nodes=self.failed_nodes)


# Server code for each node
class Server:
    def __init__(self, node_id, graph):
        self.node_id = node_id
        self.graph = graph  # Network topology as graph
        self.server_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
        self.server_socket.bind(("localhost", 8000 + node_id))
        self.server_socket.listen(5)
        self.failed_nodes = set()
        self.routing_table = {}
        self.is_active = True
        print(f"Server {node_id} started on port {8000 + node_id}")
        self.recalculate_routing_table()

    def recalculate_routing_table(self):
        """Recalculate the routing table for all nodes."""
        print(f"Recalculating routing table for Server {self.node_id}")
        self.routing_table, _ = floyd_warshall(self.graph, self.node_id)
        print(f"Updated Routing Table for Server {self.node_id}:")
        for node, distance in self.routing_table.items():
```

```python
            print(f"  To Node {node}: Distance {distance}")

    def handle_client(self, client_socket):
        try:
            if not self.is_active:
                # Notify client that the server is down
                print(f"Server {self.node_id} is down. Rejecting request.")
                client_socket.send(
                    f"Server {self.node_id} is currently down.".encode("utf-8")
                )
                return

            data = client_socket.recv(1024).decode("utf-8")
            if data:
                target_node = int(data)  # Target node ID
                print(
                    f"Server {self.node_id} received request for shortest path to node {target_node}"
                )
                server_start_time = time.time()

                # Retrieve the shortest path from the precomputed routing table
                distance = self.routing_table.get(target_node, float("inf"))
                response = f"Shortest path to node {target_node}: {distance}"
                server_end_time = time.time()
                server_computation_time = server_end_time - server_start_time  # Time taken to process the request
                print(f"Server {self.node_id} computation time: {server_computation_time:.6f} seconds")

                client_socket.send(response.encode("utf-8"))
        finally:
            client_socket.close()

    def run(self):
        while True:
            client_socket, _ = self.server_socket.accept()
            client_thread = threading.Thread(
                target=self.handle_client, args=(client_socket,)
            )
            client_thread.start()

    def simulate_failure(self, failed_node):
        print(f"Simulating failure of Node {failed_node} in Server {self.node_id}")


        if self.node_id == failed_node:
            self.is_active = False
            print(f"Server {self.node_id} is now marked as down.")
            return

```

```python

        self.failed_nodes.add(failed_node)


        for node in self.graph:
            if failed_node in self.graph[node]:
                del self.graph[node][failed_node]
            if node == failed_node:
                self.graph[node] = {}


        print(f"Node {failed_node} failure simulated. Recalculating
            routing table.")
        self.recalculate_routing_table()
        # plot_graph(self.graph, failed_nodes=self.failed_nodes)


# Start server for each node in the network
def start_servers():
    # graph = {
    #     0: {1: 10},
    #     1: {0: 10, 2: 10, 3: 50},
    #     2: {1: 10, 3: 30},
    #     3: {2: 30, 4: 40, 1: 50},
    #     4: {3: 40},
    # }
    nodes = 100
    edges = 200
    graph=generate_large_sparse_graph(nodes,edges)
    servers = []
    # plot_graph(graph)
    # Start servers
    for node_id in range(len(graph)):
        server = Server(node_id, graph)
        threading.Thread(target=server.run).start()
        servers.append(server)

    # Simulate failure of a node
    failed_node = 2
    time.sleep(5)
    for server in servers:
        server.simulate_failure(failed_node)


    print("\nSimulating client trying to access a failed server:")
    client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
    try:
        client_socket.connect(("localhost", 16000 + failed_node))
        client_socket.send("3".encode("utf-8"))
        response = client_socket.recv(1024).decode("utf-8")
        print(f"Response from Server {failed_node}: {response}")
    except ConnectionRefusedError:
        print(f"Server {failed_node} is unavailable.")
    finally:
        client_socket.close()


if __name__ == "__main__":
```

```
    start_servers()
```

5 Testing and Results

5.1 Testing Strategy

To evaluate the project, the shortest path algorithms were implemented on separate servers. Each client sends requests for the shortest path between nodes in a weighted graph. The servers calculate the shortest paths using their respective algorithms. The round-trip time for each request was measured to assess performance.

5.2 Results

Algorithm	**Average Time**	**Node Failure Handling**	**Suitability for Networks**
Dijkstra's	Fast	Limited	Efficient for static networks with consistent routing needs
Bellman-Ford	Moderate	Effective	Ideal for dynamic networks prone to frequent topology changes
Floyd-Warshall	Slow	Limited	Suitable for fully connected networks requiring comprehensive path analysis

Table 1: Performance Comparison of Shortest Path Algorithms in Network Scenarios

5.3 Data Collected During Testing

During testing, the following metrics were recorded:

- Round-trip time for each client request.
- The shortest path returned by the server for a given source and target node.
- Server response times under different network conditions (e.g., increased load or simulated failures).

5.4 Analysis of Results

- **Performance Comparison:** Dijkstra's algorithm was the fastest among the three, followed by Bellman-Ford and Floyd-Warshall. The response times matched expectations based on the complexity of the algorithms.

- **Accuracy:** All algorithms produced accurate results for their respective scenarios, including handling negative weights and computing all-pairs shortest paths.
- **Network Delays:** The average round-trip time for client-server communication was consistent with minimal packet loss under normal conditions. However, under heavy load, delays increased, particularly for Floyd-Warshall.

5.5 Screenshots

Below are the screenshots demonstrating the client-server interaction and the output for each algorithm.

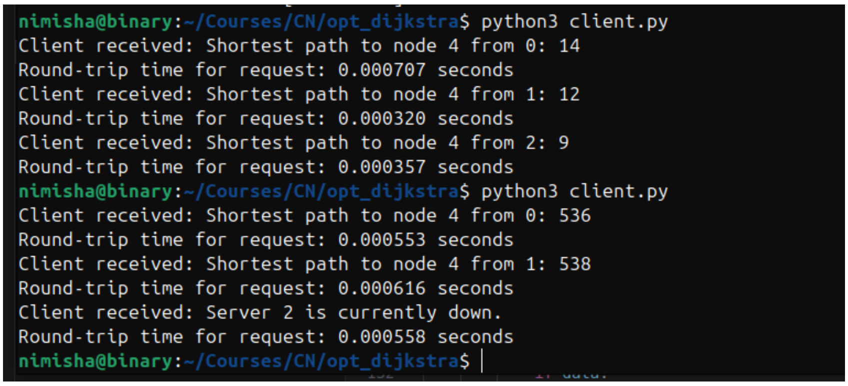

Figure 1: Output Screenshot 1: Client Request to Dijkstra Server

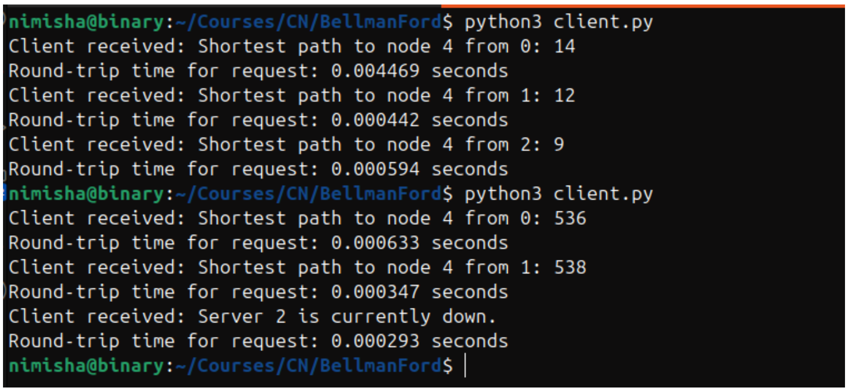

Figure 2: Output Screenshot 2: Client Request to Bellman-Ford Server

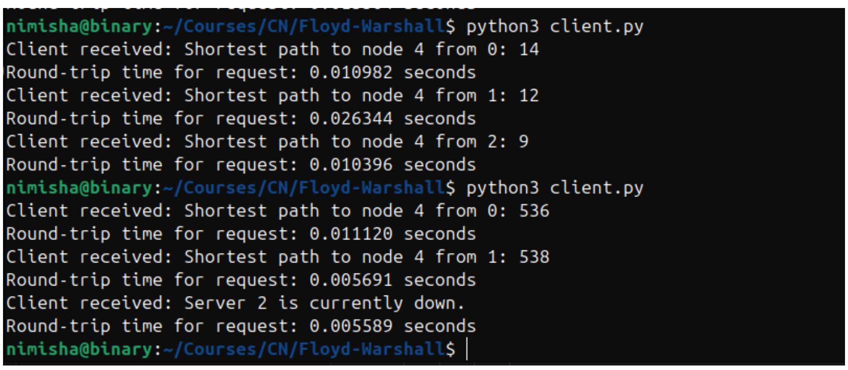

Figure 3: Output Screenshot 3: Client Request to Floyd-Warshall Server

6 Discussions

The implementation of each algorithm revealed specific strengths and weaknesses:

- **Dijkstra's Algorithm:** It performed efficiently in terms of computational time, making it suitable for scenarios requiring quick calculations of shortest paths. However, its performance depends on the data structure used for managing the priority queue.
- **Bellman-Ford Algorithm:** While slower than Dijkstra's algorithm, it demonstrated robustness in recomputing paths after network topology changes, such as node or link failures. This flexibility makes it well-suited for dynamic networks.
- **Floyd-Warshall Algorithm:** The algorithm provides a comprehensive solution for all-pairs shortest path problems. However, its high computational complexity limits its practicality for large-scale networks.

Other notable observations include:

- **Scalability:** As the size of the network increased, the computational overhead for Floyd-Warshall became significantly higher compared to the other algorithms. Dijkstra's algorithm scaled better for larger graphs when implemented with an efficient priority queue.
- **Real-Time Adaptability:** During node failure simulations, Bellman-Ford adapted to the changes more effectively than Dijkstra's algorithm, as it recalculated the paths without requiring a fresh initialization.
- **Algorithmic Trade-offs:** Each algorithm exhibited trade-offs between computational efficiency and comprehensiveness. The choice of the algorithm should be guided by the specific requirements of the use case, such as the need for real-time updates or comprehensive connectivity analysis.

Overall, the project highlighted the importance of understanding the context in which each algorithm is deployed, as their performance and utility vary significantly depending on the network's size and dynamic nature.

7 Future Enhancements

Future work can include the following:

- Implementing more efficient algorithms like A* for pathfinding in large graphs.
- Adding support for real-time dynamic updates to the network topology, such as node or link failures.
- Optimizing the performance of the Floyd-Warshall algorithm using parallel computing techniques.

8 References

1. Thomas H. Cormen, Charles E. Leiserson, Ronald L. Rivest, and Clifford Stein. *Introduction to Algorithms*, 3rd Edition.

2. Forouzan, B. A. (2007). Data Communications and Networking with TCP/IP Protocol Suite (6th ed.). McGraw-Hill.

3. Ming-Xin Yang Bing-Tong Wang Wen-Dong Guo , "Research on the performance of dynamic routing algorithm," *IEEE*. Available: link