



# Dynamic Network Routing Protocol

## Computer Networks Project

A Project Report Submitted by

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**November 20, 2024**

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# 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

```
1 import socket
2 import time
3
4 def client_request(server_id, target_node):
5     client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
6     client_socket.connect(('localhost', 8000 + server_id))
7     client_socket.send(str(target_node).encode('utf-8'))
8     start_time = time.time()
9
10    response = client_socket.recv(1024).decode('utf-8')
11
12    end_time = time.time()
13    round_trip_time = end_time - start_time
14
15    print(f"Client received: {response}")
16    print(f"Round-trip time for request: {round_trip_time:.6f} seconds"
17          )
18
19    client_socket.close()
20
21 # Simulate clients requesting shortest paths to different target nodes
22 def run_clients():
23     client_request(0, 4)
24     client_request(1, 4)
25     client_request(2, 4)
26
27 if __name__ == "__main__":
28     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

```
1 import socket
2 import threading
3 import heapq
4 import random
5 import time
6 import networkx as nx
```

```

7 import matplotlib.pyplot as plt
8
9
10 def generate_large_sparse_graph(nodes, edges):
11     graph = {i: {} for i in range(nodes)}
12     edge_count = 0
13     current_edge = 0
14
15
16     while edge_count < edges:
17         u = current_edge % nodes
18         v = (current_edge + 1) % nodes
19         weight = (current_edge + 1) % 10 + 1
20         if u != v and v not in graph[u]:
21             graph[u][v] = weight
22             graph[v][u] = weight
23             current_edge += 1
24
25
26         if current_edge > nodes * 2:
27             print("Unable to generate enough edges due to constraints.")
28             break
29
30     return graph
31
32
33 def plot_graph(graph, failed_nodes=None):
34     """Visualizes the graph with optional highlighting of failed nodes.
35     """
36     G = nx.Graph()
37     for node, neighbors in graph.items():
38         for neighbor, weight in neighbors.items():
39             G.add_edge(node, neighbor, weight=weight)
40
41     pos = nx.spring_layout(G)
42     plt.figure(figsize=(8, 6))
43     nx.draw(
44         G,
45         pos,
46         with_labels=True,
47         node_color="skyblue",
48         edge_color="gray",
49         node_size=700,
50         font_size=10,
51         font_weight="bold",
52     )
53     if failed_nodes:
54         nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes,
55                                node_color="red")
56
57     labels = nx.get_edge_attributes(G, "weight")
58     nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)
59
60     plt.title("Network Graph")
61     plt.show()

```

```

62 # Dijkstra's algorithm to find the shortest path
63 def dijkstra(graph, start_node, failed_node=None):
64
65     # Step 1: Initialize distances to all nodes as infinity, except the
        start node
66     queue = [(0, start_node)] # (cost, node)
67     distances = {node: float("inf") for node in graph}
68     distances[start_node] = 0
69     previous_nodes = {node: None for node in graph}
70
71     # Step 2: Modify graph to exclude failed node if specified
72     if failed_node is not None:
73         graph = {
74             node: {
75                 neighbor: weight
76                 for neighbor, weight in neighbors.items()
77                 if neighbor != failed_node
78             }
79             for node, neighbors in graph.items()
80             if node != failed_node
81         }
82
83     while queue:
84         current_distance, current_node = heapq.heappop(queue)
85
86         if current_distance > distances[current_node]:
87             continue
88
89         for neighbor, weight in graph[current_node].items():
90             distance = current_distance + weight
91             if distance < distances[neighbor]:
92                 distances[neighbor] = distance
93                 previous_nodes[neighbor] = current_node
94                 heapq.heappush(queue, (distance, neighbor))
95
96     return distances, previous_nodes
97
98
99 # Server code for each node
100 class Server:
101     def __init__(self, node_id, graph):
102         self.node_id = node_id
103         self.graph = graph # Network topology as graph
104         self.server_socket = socket.socket(socket.AF_INET, socket.
            SOCK_STREAM)
105         self.server_socket.bind(("localhost", 8000 + node_id))
106         self.server_socket.listen(5)
107         self.failed_nodes = set()
108         self.routing_table = {}
109         self.is_active = True
110         print(f"Server {node_id} started on port {8000 + node_id}")
111         self.recalculate_routing_table()
112
113     def recalculate_routing_table(self):
114         """Recalculate the routing table for all nodes."""
115         print(f"Recalculating routing table for Server {self.node_id}")
116         self.routing_table, _ = dijkstra(self.graph, self.node_id)
117         print(f"Updated Routing Table for Server {self.node_id}:")

```

```

118         for node, distance in self.routing_table.items():
119             print(f" To Node {node}: Distance {distance}")
120
121     def handle_client(self, client_socket):
122         try:
123             if not self.is_active:
124                 # Notify client that the server is down
125                 print(f"Server {self.node_id} is down. Rejecting
126                     request.")
127                 client_socket.send(
128                     f"Server {self.node_id} is currently down.".encode(
129                         "utf-8")
130                 )
131                 return
132
133             data = client_socket.recv(1024).decode("utf-8")
134             if data:
135                 target_node = int(data) # Target node ID
136                 print(
137                     f"Server {self.node_id} received request for
138                     shortest path to node {target_node}"
139                 )
140                 server_start_time = time.time()
141
142                 # Retrieve the shortest path from the precomputed
143                 # routing table
144                 distance = self.routing_table.get(target_node, float("
145                     inf"))
146                 response = f"Shortest path to node {target_node}: {
147                     distance}"
148                 server_end_time = time.time()
149                 server_computation_time = server_end_time -
150                     server_start_time # Time taken to process the
151                     request
152                 print(f"Server {self.node_id} computation time: {
153                     server_computation_time:.6f} seconds")
154
155                 client_socket.send(response.encode("utf-8"))
156             finally:
157                 client_socket.close()
158
159     def run(self):
160         while True:
161             client_socket, _ = self.server_socket.accept()
162             client_thread = threading.Thread(
163                 target=self.handle_client, args=(client_socket,)
164             )
165             client_thread.start()
166
167     def simulate_failure(self, failed_node):
168         print(f"Simulating failure of Node {failed_node} in Server {
169             self.node_id}")
170
171         if self.node_id == failed_node:
172             self.is_active = False
173             print(f"Server {self.node_id} is now marked as down.")
174             return

```

```

166
167
168     self.failed_nodes.add(failed_node)
169
170
171     for node in self.graph:
172         if failed_node in self.graph[node]:
173             del self.graph[node][failed_node]
174         if node == failed_node:
175             self.graph[node] = {}
176
177
178     print(f"Node {failed_node} failure simulated. Recalculating
          routing table.")
179     self.recalculate_routing_table()
180     # plot_graph(self.graph, failed_nodes=self.failed_nodes)
181
182
183 # Start server for each node in the network
184 def start_servers():
185     # graph = {
186     #     0: {1: 10},
187     #     1: {0: 10, 2: 10, 3: 50},
188     #     2: {1: 10, 3: 30},
189     #     3: {2: 30, 4: 40, 1: 50},
190     #     4: {3: 40},
191     # }
192     nodes = 100
193     edges = 200
194     graph=generate_large_sparse_graph(nodes,edges)
195     servers = []
196     # plot_graph(graph)
197     # Start servers
198     for node_id in range(len(graph)):
199         server = Server(node_id, graph)
200         threading.Thread(target=server.run).start()
201         servers.append(server)
202
203     # Simulate failure of a node
204     failed_node = 2
205     time.sleep(5)
206     for server in servers:
207         server.simulate_failure(failed_node)
208
209
210     print("\nSimulating client trying to access a failed server:")
211     client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
212     try:
213         client_socket.connect(("localhost", 16000 + failed_node))
214         client_socket.send("3".encode("utf-8"))
215         response = client_socket.recv(1024).decode("utf-8")
216         print(f"Response from Server {failed_node}: {response}")
217     except ConnectionRefusedError:
218         print(f"Server {failed_node} is unavailable.")
219     finally:
220         client_socket.close()
221
222

```



```

223 if __name__ == "__main__":
224     start_servers()

```

## 4.2.2 Bellman-Ford Algorithm

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

```

1  import socket
2  import threading
3  import time
4  import random
5  import networkx as nx
6  import matplotlib.pyplot as plt
7
8  def generate_large_sparse_graph(nodes, edges):
9      graph = {i: {} for i in range(nodes)}
10     edge_count = 0
11     current_edge = 0
12
13
14     while edge_count < edges:
15         u = current_edge % nodes
16         v = (current_edge + 1) % nodes
17         weight = (current_edge + 1) % 10 + 1
18
19         if u != v and v not in graph[u]:
20             graph[u][v] = weight
21             graph[v][u] = weight
22             edge_count += 1
23
24
25         current_edge += 1
26
27
28         if current_edge > nodes * 2:
29             print("Unable to generate enough edges due to constraints.")
30             break
31
32     return graph
33
34 def plot_graph(graph, failed_nodes=None):
35     """Visualizes the graph with optional highlighting of failed nodes.
36     """
37     G = nx.Graph()
38     for node, neighbors in graph.items():
39         for neighbor, weight in neighbors.items():
40             G.add_edge(node, neighbor, weight=weight)
41
42     pos = nx.spring_layout(G)
43     plt.figure(figsize=(8, 6))
44     nx.draw(
45         G,
46         pos,
47         with_labels=True,
48         node_color="skyblue",
49         edge_color="gray",

```

```

49         node_size=700,
50         font_size=10,
51         font_weight="bold",
52     )
53     if failed_nodes:
54         nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes,
55                                node_color="red")
56
57     labels = nx.get_edge_attributes(G, "weight")
58     nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)
59
60     plt.title("Network Graph")
61     plt.show()
62
63 # Bellman-Ford algorithm to find the shortest path
64 def bellman_ford(graph, start_node):
65
66     distances = {node: float('inf') for node in graph}
67     distances[start_node] = 0
68     previous_nodes = {node: None for node in graph}
69
70     for _ in range(len(graph) - 1):
71         for node in graph:
72             for neighbor, weight in graph[node].items():
73                 if distances[node] + weight < distances[neighbor]:
74                     distances[neighbor] = distances[node] + weight
75                     previous_nodes[neighbor] = node
76
77
78     for node in graph:
79         for neighbor, weight in graph[node].items():
80             if distances[node] + weight < distances[neighbor]:
81                 print("Graph contains a negative weight cycle")
82
83     return distances, previous_nodes
84
85 # Server code for each node
86 class Server:
87     def __init__(self, node_id, graph):
88         self.node_id = node_id
89         self.graph = graph # Network topology as graph
90         self.server_socket = socket.socket(socket.AF_INET, socket.
91                                             SOCK_STREAM)
92         self.server_socket.bind(("localhost", 8000 + node_id))
93         self.server_socket.listen(5)
94         self.failed_nodes = set()
95         self.routing_table = {}
96         self.is_active = True
97         print(f"Server {node_id} started on port {8000 + node_id}")
98         self.recalculate_routing_table()
99
100     def recalculate_routing_table(self):
101         """Recalculate the routing table for all nodes."""
102         print(f"Recalculating routing table for Server {self.node_id}")
103         self.routing_table, _ = bellman_ford(self.graph, self.node_id)
104         print(f"Updated Routing Table for Server {self.node_id}:")
105         for node, distance in self.routing_table.items():

```

```

105         print(f" To Node {node}: Distance {distance}")
106
107     def handle_client(self, client_socket):
108         try:
109             if not self.is_active:
110                 # Notify client that the server is down
111                 print(f"Server {self.node_id} is down. Rejecting
112                       request.")
113                 client_socket.send(
114                     f"Server {self.node_id} is currently down.".encode(
115                         "utf-8")
116                 )
117                 return
118
119             data = client_socket.recv(1024).decode("utf-8")
120             if data:
121                 target_node = int(data) # Target node ID
122                 print(
123                     f"Server {self.node_id} received request for
124                       shortest path to node {target_node}"
125                 )
126                 server_start_time = time.time()
127
128                 # Retrieve the shortest path from the precomputed
129                 # routing table
130                 distance = self.routing_table.get(target_node, float("
131                 inf"))
132                 response = f"Shortest path to node {target_node}: {
133                 distance}"
134                 server_end_time = time.time()
135                 server_computation_time = server_end_time -
136                     server_start_time # Time taken to process the
137                     request
138                 print(f"Server {self.node_id} computation time: {
139                 server_computation_time:.6f} seconds")
140
141                 client_socket.send(response.encode("utf-8"))
142             finally:
143                 client_socket.close()
144
145     def run(self):
146         while True:
147             client_socket, _ = self.server_socket.accept()
148             client_thread = threading.Thread(
149                 target=self.handle_client, args=(client_socket,)
150             )
151             client_thread.start()
152
153     def simulate_failure(self, failed_node):
154         print(f"Simulating failure of Node {failed_node} in Server {
155         self.node_id}")
156
157         if self.node_id == failed_node:
158             self.is_active = False
159             print(f"Server {self.node_id} is now marked as down.")
160             return

```

```

153
154     self.failed_nodes.add(failed_node)
155
156
157     for node in self.graph:
158         if failed_node in self.graph[node]:
159             del self.graph[node][failed_node]
160         if node == failed_node:
161             self.graph[node] = {}
162
163
164     print(f"Node {failed_node} failure simulated. Recalculating
165           routing table.")
166     self.recalculate_routing_table()
167     # plot_graph(self.graph, failed_nodes=self.failed_nodes)
168
169 # Start server for each node in the network
170 def start_servers():
171     # graph = {
172     #     0: {1: 10},
173     #     1: {0: 10, 2: 10, 3: 50},
174     #     2: {1: 10, 3: 30},
175     #     3: {2: 30, 4: 40, 1: 50},
176     #     4: {3: 40},
177     # }
178     nodes = 100
179     edges = 200
180     graph=generate_large_sparse_graph(nodes,edges)
181     servers = []
182     # plot_graph(graph)
183     # Start servers
184     for node_id in range(len(graph)):
185         server = Server(node_id, graph)
186         threading.Thread(target=server.run).start()
187         servers.append(server)
188
189     # Simulate failure of a node
190     failed_node = 2
191     time.sleep(5)
192     for server in servers:
193         server.simulate_failure(failed_node)
194
195
196     print("\nSimulating client trying to access a failed server:")
197     client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
198     try:
199         client_socket.connect(("localhost", 16000 + failed_node))
200         client_socket.send("3".encode("utf-8"))
201         response = client_socket.recv(1024).decode("utf-8")
202         print(f"Response from Server {failed_node}: {response}")
203     except ConnectionRefusedError:
204         print(f"Server {failed_node} is unavailable.")
205     finally:
206         client_socket.close()
207
208
209 if __name__ == "__main__":

```

```
210 start_servers()
```

### 4.2.3 Floyd-Warshall Algorithm

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

```
1 import socket
2 import threading
3 import heapq
4 import random
5 import time
6 import networkx as nx
7 import matplotlib.pyplot as plt
8
9
10 def generate_large_sparse_graph(nodes, edges):
11     graph = {i: {} for i in range(nodes)}
12     edge_count = 0
13     current_edge = 0
14
15
16     while edge_count < edges:
17         u = current_edge % nodes
18         v = (current_edge + 1) % nodes
19         weight = (current_edge + 1) % 10 + 1
20
21         if u != v and v not in graph[u]:
22             graph[u][v] = weight
23             graph[v][u] = weight
24             edge_count += 1
25
26
27         current_edge += 1
28
29
30         if current_edge > nodes * 2:
31             print("Unable to generate enough edges due to constraints.")
32             break
33
34     return graph
35 def floyd_warshall(graph, start_node, failed_node=None):
36     # Step 1: Initialize distances matrix
37     nodes = list(graph.keys())
38     num_nodes = len(nodes)
39     distances = {node: {neighbor: float("inf") for neighbor in nodes}
40                 for node in nodes}
41     previous_nodes = {node: None for node in nodes}
42
43     # Set initial distances based on the graph
44     for u in graph:
45         distances[u][u] = 0 # Distance to itself is 0
46         for v, weight in graph[u].items():
47             distances[u][v] = weight
48
49     # Step 2: Modify graph to exclude failed node if specified
50     if failed_node is not None:
```

```

50     distances = {
51         node: {
52             neighbor: distances[node][neighbor]
53             for neighbor in distances[node]
54             if neighbor != failed_node
55         }
56         for node in distances
57         if node != failed_node
58     }
59
60     # Step 3: Apply Floyd-Warshall algorithm
61     for k in distances:
62         for i in distances:
63             for j in distances:
64                 if distances[i][k] + distances[k][j] < distances[i][j]:
65                     distances[i][j] = distances[i][k] + distances[k][j]
66
67     # Extract the distances from the start_node
68     single_source_distances = distances[start_node]
69     return single_source_distances, previous_nodes
70
71
72 def plot_graph(graph, failed_nodes=None):
73     """Visualizes the graph with optional highlighting of failed nodes.
74     """
75
76     G = nx.Graph()
77     for node, neighbors in graph.items():
78         for neighbor, weight in neighbors.items():
79             G.add_edge(node, neighbor, weight=weight)
80
81     pos = nx.spring_layout(G)
82     plt.figure(figsize=(8, 6))
83     nx.draw(
84         G,
85         pos,
86         with_labels=True,
87         node_color="skyblue",
88         edge_color="gray",
89         node_size=700,
90         font_size=10,
91         font_weight="bold",
92     )
93     if failed_nodes:
94         nx.draw_networkx_nodes(G, pos, nodelist=failed_nodes,
95                                node_color="red")
96
97     labels = nx.get_edge_attributes(G, "weight")
98     nx.draw_networkx_edge_labels(G, pos, edge_labels=labels)
99
100     plt.title("Network Graph")
101     plt.show()
102
103 # Server code for each node
104 class Server:
105     def __init__(self, node_id, graph):
106         self.node_id = node_id
107         self.graph = graph # Network topology as graph

```

```

106     self.server_socket = socket.socket(socket.AF_INET, socket.
107         SOCK_STREAM)
108     self.server_socket.bind(("localhost", 8000 + node_id))
109     self.server_socket.listen(5)
110     self.failed_nodes = set()
111     self.routing_table = {} # Stores distances to all nodes
112     self.is_active = True # Indicates if the server is up or down
113     print(f"Server {node_id} started on port {8000 + node_id}")
114     self.recalculate_routing_table() # Calculate initial routing
115                                     table
116
117 def recalculate_routing_table(self):
118     """Recalculate the routing table for all nodes."""
119     print(f"Recalculating routing table for Server {self.node_id}")
120     self.routing_table, _ = floyd_warshall(self.graph, self.node_id
121 )
122     print(f"Updated Routing Table for Server {self.node_id}:")
123     for node, distance in self.routing_table.items():
124         print(f"    To Node {node}: Distance {distance}")
125
126 def handle_client(self, client_socket):
127     try:
128         if not self.is_active:
129             # Notify client that the server is down
130             print(f"Server {self.node_id} is down. Rejecting
131                 request.")
132             client_socket.send(
133                 f"Server {self.node_id} is currently down.".encode(
134                     "utf-8")
135             )
136             return
137
138         data = client_socket.recv(1024).decode("utf-8")
139         if data:
140             target_node = int(data) # Target node ID
141             print(
142                 f"Server {self.node_id} received request for
143                 shortest path to node {target_node}"
144             )
145             server_start_time = time.time()
146
147             # Retrieve the shortest path from the precomputed
148             # routing table
149             distance = self.routing_table.get(target_node, float("
150                 inf"))
151             response = f"Shortest path to node {target_node}: {
152                 distance}"
153             server_end_time = time.time()
154             server_computation_time = server_end_time -
155                 server_start_time # Time taken to process the
156                 request
157             print(f"Server {self.node_id} computation time: {
158                 server_computation_time:.6f} seconds")
159             # client_socket.send(response.encode("utf-8"))
160             client_socket.send(response.encode("utf-8"))
161         finally:
162             client_socket.close()

```

```

152     def run(self):
153         while True:
154             client_socket, _ = self.server_socket.accept()
155             client_thread = threading.Thread(
156                 target=self.handle_client, args=(client_socket,)
157             )
158             client_thread.start()
159
160     def simulate_failure(self, failed_node):
161         print(f"Simulating failure of Node {failed_node} in Server {
162             self.node_id}")
163
164         # If this server is the one that failed, mark it as inactive
165         if self.node_id == failed_node:
166             self.is_active = False
167             print(f"Server {self.node_id} is now marked as down.")
168             return
169
170         # Mark the failed node as unreachable and update the graph
171         self.failed_nodes.add(failed_node)
172
173         # Update the graph for the failure
174         for node in self.graph:
175             if failed_node in self.graph[node]:
176                 del self.graph[node][failed_node]
177             if node == failed_node:
178                 self.graph[node] = {}
179
180         # Recalculate the routing table for all servers after the
181         # failure
182         print(f"Node {failed_node} failure simulated. Recalculating
183             routing table.")
184         self.recalculate_routing_table()
185         # plot_graph(self.graph, failed_nodes=self.failed_nodes)
186
187 # Server code for each node
188 class Server:
189     def __init__(self, node_id, graph):
190         self.node_id = node_id
191         self.graph = graph # Network topology as graph
192         self.server_socket = socket.socket(socket.AF_INET, socket.
193             SOCK_STREAM)
194         self.server_socket.bind(("localhost", 8000 + node_id))
195         self.server_socket.listen(5)
196         self.failed_nodes = set()
197         self.routing_table = {}
198         self.is_active = True
199         print(f"Server {node_id} started on port {8000 + node_id}")
200         self.recalculate_routing_table()
201
202     def recalculate_routing_table(self):
203         """Recalculate the routing table for all nodes."""
204         print(f"Recalculating routing table for Server {self.node_id}")
205         self.routing_table, _ = floyd_warshall(self.graph, self.node_id
206             )
207         print(f"Updated Routing Table for Server {self.node_id}:")
208         for node, distance in self.routing_table.items():

```



```

205         print(f"    To Node {node}: Distance {distance}")
206
207     def handle_client(self, client_socket):
208         try:
209             if not self.is_active:
210                 # Notify client that the server is down
211                 print(f"Server {self.node_id} is down. Rejecting
212                       request.")
213                 client_socket.send(
214                     f"Server {self.node_id} is currently down.".encode(
215                         "utf-8")
216                 )
217                 return
218
219             data = client_socket.recv(1024).decode("utf-8")
220             if data:
221                 target_node = int(data) # Target node ID
222                 print(
223                     f"Server {self.node_id} received request for
224                       shortest path to node {target_node}"
225                 )
226                 server_start_time = time.time()
227
228                 # Retrieve the shortest path from the precomputed
229                 # routing table
230                 distance = self.routing_table.get(target_node, float("
231                     inf"))
232                 response = f"Shortest path to node {target_node}: {
233                     distance}"
234                 server_end_time = time.time()
235                 server_computation_time = server_end_time -
236                     server_start_time # Time taken to process the
237                     request
238                 print(f"Server {self.node_id} computation time: {
239                     server_computation_time:.6f} seconds")
240
241                 client_socket.send(response.encode("utf-8"))
242             finally:
243                 client_socket.close()
244
245     def run(self):
246         while True:
247             client_socket, _ = self.server_socket.accept()
248             client_thread = threading.Thread(
249                 target=self.handle_client, args=(client_socket,)
250             )
251             client_thread.start()
252
253     def simulate_failure(self, failed_node):
254         print(f"Simulating failure of Node {failed_node} in Server {
255             self.node_id}")
256
257         if self.node_id == failed_node:
258             self.is_active = False
259             print(f"Server {self.node_id} is now marked as down.")
260             return

```

```

253
254     self.failed_nodes.add(failed_node)
255
256
257     for node in self.graph:
258         if failed_node in self.graph[node]:
259             del self.graph[node][failed_node]
260         if node == failed_node:
261             self.graph[node] = {}
262
263
264     print(f"Node {failed_node} failure simulated. Recalculating
265           routing table.")
266     self.recalculate_routing_table()
267     # plot_graph(self.graph, failed_nodes=self.failed_nodes)
268
269 # Start server for each node in the network
270 def start_servers():
271     # graph = {
272     #     0: {1: 10},
273     #     1: {0: 10, 2: 10, 3: 50},
274     #     2: {1: 10, 3: 30},
275     #     3: {2: 30, 4: 40, 1: 50},
276     #     4: {3: 40},
277     # }
278     nodes = 100
279     edges = 200
280     graph=generate_large_sparse_graph(nodes,edges)
281     servers = []
282     # plot_graph(graph)
283     # Start servers
284     for node_id in range(len(graph)):
285         server = Server(node_id, graph)
286         threading.Thread(target=server.run).start()
287         servers.append(server)
288
289     # Simulate failure of a node
290     failed_node = 2
291     time.sleep(5)
292     for server in servers:
293         server.simulate_failure(failed_node)
294
295
296     print("\nSimulating client trying to access a failed server:")
297     client_socket = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
298     try:
299         client_socket.connect(("localhost", 16000 + failed_node))
300         client_socket.send("3".encode("utf-8"))
301         response = client_socket.recv(1024).decode("utf-8")
302         print(f"Response from Server {failed_node}: {response}")
303     except ConnectionRefusedError:
304         print(f"Server {failed_node} is unavailable.")
305     finally:
306         client_socket.close()
307
308
309 if __name__ == "__main__":

```

## 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.

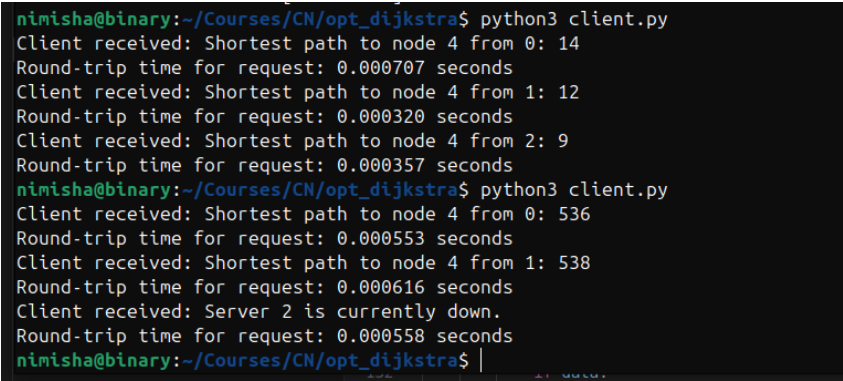
## 5.5 Time Complexities of Algorithms

The time complexities for each algorithm are as follows:

- **Dijkstra's Algorithm:**
  - $O(V^2)$  (for simple implementation)
  - $O(E + V \log V)$  (with priority queue)
- **Bellman-Ford Algorithm:**  $O(VE)$ , where  $V$  is the number of vertices and  $E$  is the number of edges.
- **Floyd-Warshall Algorithm:**  $O(V^3)$ , where  $V$  is the number of vertices. This is because it checks all pairs of nodes in the graph.

## 5.6 Screenshots

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



```
nimisha@binary:~/Courses/CN/opt_dijkstra$ python3 client.py
Client received: Shortest path to node 4 from 0: 14
Round-trip time for request: 0.000707 seconds
Client received: Shortest path to node 4 from 1: 12
Round-trip time for request: 0.000320 seconds
Client received: Shortest path to node 4 from 2: 9
Round-trip time for request: 0.000357 seconds
nimisha@binary:~/Courses/CN/opt_dijkstra$ python3 client.py
Client received: Shortest path to node 4 from 0: 536
Round-trip time for request: 0.000553 seconds
Client received: Shortest path to node 4 from 1: 538
Round-trip time for request: 0.000616 seconds
Client received: Server 2 is currently down.
Round-trip time for request: 0.000558 seconds
nimisha@binary:~/Courses/CN/opt_dijkstra$
```

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

```

nimisha@binary:~/Courses/CN/BellmanFord$ python3 client.py
Client received: Shortest path to node 4 from 0: 14
Round-trip time for request: 0.004469 seconds
Client received: Shortest path to node 4 from 1: 12
Round-trip time for request: 0.000442 seconds
Client received: Shortest path to node 4 from 2: 9
Round-trip time for request: 0.000594 seconds
nimisha@binary:~/Courses/CN/BellmanFord$ python3 client.py
Client received: Shortest path to node 4 from 0: 536
Round-trip time for request: 0.000633 seconds
Client received: Shortest path to node 4 from 1: 538
Round-trip time for request: 0.000347 seconds
Client received: Server 2 is currently down.
Round-trip time for request: 0.000293 seconds
nimisha@binary:~/Courses/CN/BellmanFord$ |

```

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

```

nimisha@binary:~/Courses/CN/Floyd-Warshall$ python3 client.py
Client received: Shortest path to node 4 from 0: 14
Round-trip time for request: 0.010982 seconds
Client received: Shortest path to node 4 from 1: 12
Round-trip time for request: 0.026344 seconds
Client received: Shortest path to node 4 from 2: 9
Round-trip time for request: 0.010396 seconds
nimisha@binary:~/Courses/CN/Floyd-Warshall$ python3 client.py
Client received: Shortest path to node 4 from 0: 536
Round-trip time for request: 0.011120 seconds
Client received: Shortest path to node 4 from 1: 538
Round-trip time for request: 0.005691 seconds
Client received: Server 2 is currently down.
Round-trip time for request: 0.005589 seconds
nimisha@binary:~/Courses/CN/Floyd-Warshall$ |

```

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](#)