

## Prototype Demonstration

The developed prototype demonstrates the essential functionality of a real-time multiplayer synchronization system based on a client–server architecture using Python and the UDP protocol. The objective of this prototype is to validate message exchange, state synchronization, and real-time communication reliability in a multi-client environment.

The server, implemented in the GameServer class, maintains the global game state and manages connected clients through a finite-state machine (FSM). Its operational stages include the following:

- Waiting for Join: Accepting client connections.
- Waiting for Initialization: Sending the initial full snapshot.
- Game Loop: Broadcasting full or delta snapshots at fixed intervals (every 50 ms) and processing client events.
- Game Over: Computing the leaderboard and resetting the session.

The server uses non-blocking sockets and the select module to handle multiple clients simultaneously with minimal latency. Each message contains structured headers with sequence numbers, timestamps, and snapshot identifiers, ensuring synchronized and traceable communication.

The client, represented by the ClientFSM class, follows a similar FSM structure. It joins the server, signals readiness, receives initial snapshots, and exchanges updates during gameplay. Clients acknowledge every received snapshot to maintain consistency and periodically send acquisition events that modify the shared grid. Upon receiving the final leaderboard message, each client transitions to the Game Over state and closes its session gracefully.

Communication between components follows a custom protocol defined in header.py. Each packet contains fields for protocol ID, version, message type, snapshot ID, sequence number, timestamp, and payload length. This ensures structured and consistent message handling throughout the system.

During execution, multiple clients successfully join, synchronize their local states, and interact with the shared grid in real time. The server continuously updates and distributes snapshots, while clients apply them without desynchronization or data loss. Once the grid is fully claimed, the server terminates the session and distributes the final scores.

## Client 1 Sample Log

```
1 Client started.
2 Initial state: WAIT_FOR_JOIN
3 client: starting...
4 client: state: WAIT_FOR_JOIN
5 Sent JOIN_REQ
6 ✓ JOIN_ACK received. Server assigned me ID: 1
7 Transition: WAIT_FOR_JOIN → WAIT_FOR_READY
8 → Sent READY_REQ
9 ✓ READY_ACK received. Waiting for start snapshot.
10 Transition: WAIT_FOR_READY → WAIT_FOR_STARTGAME
11 Waiting for full snapshot...
12 Waiting for full snapshot...
13 ✓ Received full snapshot #0
14 [FULL] Applied full snapshot #0
15 Transition: WAIT_FOR_STARTGAME → IN_GAME_LOOP
16 📦 Sent ACQUIRE event (3,7)
17 [DELTA] Applied 2 changes (snapshot #1)
18 ✓ Applied delta snapshot #1
19 SNAPSHOT recv_time=1762443039.5260103 server_ts=1762443039.5249758 snapshot_id=1 seq=18
20 [DELTA] Applied 0 changes (snapshot #2)
21 ✓ Applied delta snapshot #2
22 SNAPSHOT recv_time=1762443039.577288 server_ts=1762443039.5762565 snapshot_id=2 seq=19
23 [DELTA] Applied 2 changes (snapshot #3)
24 ✓ Applied delta snapshot #3
25 SNAPSHOT recv_time=1762443039.628363 server_ts=1762443039.6279445 snapshot_id=3 seq=20
26 📦 Sent ACQUIRE event (0,10)

2076 SNAPSHOT recv_time=1762443070.3622017 server_ts=1762443070.3613584 snapshot_id=605 seq=622
2077 📦 Sent ACQUIRE event (6,10)
2078 [DELTA] Applied 0 changes (snapshot #606)
2079 ✓ Applied delta snapshot #606
2080 SNAPSHOT recv_time=1762443070.4124737 server_ts=1762443070.4118493 snapshot_id=606 seq=623
2081 [DELTA] Applied 0 changes (snapshot #607)
2082 ✓ Applied delta snapshot #607
2083 SNAPSHOT recv_time=1762443070.4647346 server_ts=1762443070.463883 snapshot_id=607 seq=624
2084 📦 Sent ACQUIRE event (2,1)
2085 [DELTA] Applied 1 changes (snapshot #608)
2086 ✓ Applied delta snapshot #608
2087 SNAPSHOT recv_time=1762443070.5149202 server_ts=1762443070.5141044 snapshot_id=608 seq=625
2088 [DELTA] Applied 1 changes (snapshot #609)
2089 ✓ Applied delta snapshot #609
2090 SNAPSHOT recv_time=1762443070.5650814 server_ts=1762443070.5644906 snapshot_id=609 seq=626
2091 [DELTA] Applied 0 changes (snapshot #610)
2092 ✓ Applied delta snapshot #610
2093 SNAPSHOT recv_time=1762443070.6152933 server_ts=1762443070.6145415 snapshot_id=610 seq=627
2094 [DELTA] Applied 0 changes (snapshot #611)
2095 ✓ Applied delta snapshot #611
2096 SNAPSHOT recv_time=1762443070.6665566 server_ts=1762443070.6656275 snapshot_id=611 seq=628
2097 [DELTA] Applied 0 changes (snapshot #612)
2098 ✓ Applied delta snapshot #612

5187 🎊 Game Over message received (Leaderboard)
5188 🏆 Leaderboard:
5189 1. player 1 – score 107
5190 2. player 4 – score 107
5191 3. player 3 – score 96
5192 4. player 2 – score 90
5193 Transition: IN_GAME_LOOP → GAME_OVER
5194 🎊 Game Over! Finalizing session...
5195 ✓ Sent game over acknowledgment to server.
5196 🔒 Client session ended.
```

## Client 2 Sample Log

```
1 Client started.
2 Initial state: WAIT_FOR_JOIN
3 client: starting...
4 client: state: WAIT_FOR_JOIN
5 Sent JOIN_REQ
6 ✓ JOIN_ACK received. Server assigned me ID: 2
7 Transition: WAIT_FOR_JOIN → WAIT_FOR_READY
8 → Sent READY_REQ
9 ✓ READY_ACK received. Waiting for start snapshot.
10 Transition: WAIT_FOR_READY → WAIT_FOR_STARTGAME
11 Waiting for full snapshot...
12 ✓ Received full snapshot #0
13 [FULL] Applied full snapshot #0
14 Transition: WAIT_FOR_STARTGAME → IN_GAME_LOOP
15 [DELTA] Applied 2 changes (snapshot #1)
16 ✓ Applied delta snapshot #1
17 SNAPSHOT recv_time=1762443039.525873 server_ts=1762443039.5250297 snapshot_id=1 seq=18
18 [DELTA] Applied 0 changes (snapshot #2)
19 ✓ Applied delta snapshot #2
20 SNAPSHOT recv_time=1762443039.5771468 server_ts=1762443039.576288 snapshot_id=2 seq=19
21 📦 Sent ACQUIRE event (17,13)
22 [DELTA] Applied 2 changes (snapshot #3)
23 ✓ Applied delta snapshot #3
24 SNAPSHOT recv_time=1762443039.6282985 server_ts=1762443039.6279845 snapshot_id=3 seq=20
25 [DELTA] Applied 2 changes (snapshot #4)
26 ✓ Applied delta snapshot #4

3343 SNAPSHOT recv_time=1762443090.0868104 server_ts=1762443090.0862255 snapshot_id=991 seq=1008
3344 📦 Sent ACQUIRE event (6,11)
3345 [DELTA] Applied 0 changes (snapshot #992)
3346 ✓ Applied delta snapshot #992
3347 SNAPSHOT recv_time=1762443090.1369345 server_ts=1762443090.1363666 snapshot_id=992 seq=1009
3348 📦 Sent ACQUIRE event (14,2)
3349 [DELTA] Applied 0 changes (snapshot #993)
3350 ✓ Applied delta snapshot #993
3351 SNAPSHOT recv_time=1762443090.1890976 server_ts=1762443090.1883426 snapshot_id=993 seq=1010
3352 [DELTA] Applied 0 changes (snapshot #994)
3353 ✓ Applied delta snapshot #994
3354 SNAPSHOT recv_time=1762443090.2401235 server_ts=1762443090.239322 snapshot_id=994 seq=1011
3355 📦 Sent ACQUIRE event (16,6)
3356 [DELTA] Applied 0 changes (snapshot #995)
3357 ✓ Applied delta snapshot #995
3358 SNAPSHOT recv_time=1762443090.2902095 server_ts=1762443090.2894216 snapshot_id=995 seq=1012
3359 [DELTA] Applied 0 changes (snapshot #996)
3360 ✓ Applied delta snapshot #996
3361 SNAPSHOT recv_time=1762443090.3423052 server_ts=1762443090.34155 snapshot_id=996 seq=1013
3362 📦 Sent ACQUIRE event (18,13)
3363 [DELTA] Applied 0 changes (snapshot #997)
3364 ✓ Applied delta snapshot #997
3365 SNAPSHOT recv_time=1762443090.3934104 server_ts=1762443090.3926337 snapshot_id=997 seq=1014
3366 📦 Sent ACQUIRE event (14,13)

5137 🎊 Game Over message received (Leaderboard)
5138 🏆 Leaderboard:
5139     1. player 1 – score 107
5140     2. player 4 – score 107
5141     3. player 3 – score 96
5142     4. player 2 – score 90
5143     Transition: IN_GAME_LOOP → GAME_OVER
5144     🎊 Game Over! Finalizing session...
5145     ✓ Sent game over acknowledgment to server.
5146     🔒 Client session ended.
```

## Client 3 Sample Log

```
1 Client started.
2 Initial state: WAIT_FOR_JOIN
3 client: starting...
4 client: state: WAIT_FOR_JOIN
5 Sent JOIN_REQ
6 ✓ JOIN_ACK received. Server assigned me ID: 3
7 Transition: WAIT_FOR_JOIN → WAIT_FOR_READY
8 → Sent READY_REQ
9 ✓ READY_ACK received. Waiting for start snapshot.
10 Transition: WAIT_FOR_READY → WAIT_FOR_STARTGAME
11 Waiting for full snapshot...
12 ✓ Received full snapshot #0
13 [FULL] Applied full snapshot #0
14 Transition: WAIT_FOR_STARTGAME → IN_GAME_LOOP
15 [DELTA] Applied 2 changes (snapshot #1)
16 ✓ Applied delta snapshot #1
17 SNAPSHOT recv_time=1762443039.5257993 server_ts=1762443039.5250466 snapshot_id=1 seq=18
18 [DELTA] Applied 0 changes (snapshot #2)
19 ✓ Applied delta snapshot #2
20 SNAPSHOT recv_time=1762443039.577019 server_ts=1762443039.5763016 snapshot_id=2 seq=19
21 ♦ Sent ACQUIRE event (9,4)
22 [DELTA] Applied 2 changes (snapshot #3)
23 ✓ Applied delta snapshot #3
24 SNAPSHOT recv_time=1762443039.6281528 server_ts=1762443039.628003 snapshot_id=3 seq=20
25 [DELTA] Applied 2 changes (snapshot #4)
26 ✓ Applied delta snapshot #4

1703 SNAPSHOT recv_time=1762443065.1994743 server_ts=1762443065.1988847 snapshot_id=504 seq=521
1704 ♦ Sent ACQUIRE event (10,3)
1705 [DELTA] Applied 0 changes (snapshot #505)
1706 ✓ Applied delta snapshot #505
1707 SNAPSHOT recv_time=1762443065.2506669 server_ts=1762443065.249893 snapshot_id=505 seq=522
1708 [DELTA] Applied 0 changes (snapshot #506)
1709 ✓ Applied delta snapshot #506
1710 SNAPSHOT recv_time=1762443065.3017526 server_ts=1762443065.3007455 snapshot_id=506 seq=523
1711 [DELTA] Applied 0 changes (snapshot #507)
1712 ✓ Applied delta snapshot #507
1713 SNAPSHOT recv_time=1762443065.352803 server_ts=1762443065.352721 snapshot_id=507 seq=524
1714 [DELTA] Applied 0 changes (snapshot #508)
1715 ✓ Applied delta snapshot #508
1716 SNAPSHOT recv_time=1762443065.4038095 server_ts=1762443065.40358 snapshot_id=508 seq=525
1717 [DELTA] Applied 0 changes (snapshot #509)
1718 ✓ Applied delta snapshot #509
1719 SNAPSHOT recv_time=1762443065.4558058 server_ts=1762443065.455513 snapshot_id=509 seq=526
1720 ♦ Sent ACQUIRE event (15,3)
1721 [DELTA] Applied 0 changes (snapshot #510)
1722 ✓ Applied delta snapshot #510
1723 SNAPSHOT recv_time=1762443065.5079827 server_ts=1762443065.5075426 snapshot_id=510 seq=527
1724 ♦ Sent ACQUIRE event (7,6)

5144 🎊 Game Over message received (Leaderboard)
5145 🏆 Leaderboard:
5146 1. player 1 - score 107
5147 2. player 4 - score 107
5148 3. player 3 - score 96
5149 4. player 2 - score 90
5150 Transition: IN_GAME_LOOP → GAME_OVER
5151 🎊 Game Over! Finalizing session...
5152 ✓ Sent game over acknowledgment to server.
5153 🔒 Client session ended.
```

## Client 4 Sample Log

```
1 Client started.
2 Initial state: WAIT_FOR_JOIN
3 client: starting...
4 client: state: WAIT_FOR_JOIN
5 Sent JOIN_REQ
6 ✓ JOIN_ACK received. Server assigned me ID: 4
7 Transition: WAIT_FOR_JOIN → WAIT_FOR_READY
8 → Sent READY_REQ
9 ✓ READY_ACK received. Waiting for start snapshot.
10 Transition: WAIT_FOR_READY → WAIT_FOR_STARTGAME
11 Waiting for full snapshot...
12 ✓ Received full snapshot #0
13 [FULL] Applied full snapshot #0
14 Transition: WAIT_FOR_STARTGAME → IN_GAME_LOOP
15 📦 Sent ACQUIRE event (5,6)
16 [DELT A] Applied 2 changes (snapshot #1)
17 ✓ Applied delta snapshot #1
18 SNAPSHOT recv_time=1762443039.5252838 server_ts=1762443039.5250585 snapshot_id=1 seq=18
19 [DELT A] Applied 0 changes (snapshot #2)
20 ✓ Applied delta snapshot #2
21 SNAPSHOT recv_time=1762443039.5765352 server_ts=1762443039.5763113 snapshot_id=2 seq=19
22 [DELT A] Applied 2 changes (snapshot #3)
23 ✓ Applied delta snapshot #3
24 SNAPSHOT recv_time=1762443039.6287138 server_ts=1762443039.6280162 snapshot_id=3 seq=20
25 📦 Sent ACQUIRE event (19,5)
26 [DELT A] Applied 2 changes (snapshot #4)

3274 SNAPSHOT recv_time=1762443088.9094057 server_ts=1762443088.9087744 snapshot_id=968 seq=985
3275 [DELT A] Applied 0 changes (snapshot #969)
3276 ✓ Applied delta snapshot #969
3277 SNAPSHOT recv_time=1762443088.9615557 server_ts=1762443088.9607542 snapshot_id=969 seq=986
3278 [DELT A] Applied 0 changes (snapshot #970)
3279 ✓ Applied delta snapshot #970
3280 SNAPSHOT recv_time=1762443089.012633 server_ts=1762443089.012176 snapshot_id=970 seq=987
3281 [DELT A] Applied 0 changes (snapshot #971)
3282 ✓ Applied delta snapshot #971
3283 SNAPSHOT recv_time=1762443089.0647335 server_ts=1762443089.0643036 snapshot_id=971 seq=988
3284 [DELT A] Applied 0 changes (snapshot #972)
3285 ✓ Applied delta snapshot #972
3286 SNAPSHOT recv_time=1762443089.1148114 server_ts=1762443089.1146169 snapshot_id=972 seq=989
3287 📦 Sent ACQUIRE event (7,12)
3288 [DELT A] Applied 0 changes (snapshot #973)
3289 ✓ Applied delta snapshot #973
3290 SNAPSHOT recv_time=1762443089.1670215 server_ts=1762443089.16678 snapshot_id=973 seq=990
3291 📦 Sent ACQUIRE event (16,4)
3292 [DELT A] Applied 0 changes (snapshot #974)
3293 ✓ Applied delta snapshot #974

5144 🎊 Game Over message received (Leaderboard)
5145 🏆 Leaderboard:
5146     1. player 1 - score 107
5147     2. player 4 - score 107
5148     3. player 3 - score 96
5149     4. player 2 - score 90
5150 Transition: IN_GAME_LOOP → GAME_OVER
5151 🎊 Game Over! Finalizing session...
5152 ✓ Sent game over acknowledgment to server.
5153 🔒 Client session ended.
```

## Server Sample Log

```
1 Server started. Waiting for players...
2 Player 1 joined from ('127.0.0.1', 47850)
3 Player 1 is ready (1/1)
4 Player 2 joined from ('127.0.0.1', 56793)
5 Player 2 is ready (2/2)
6 Player 3 joined from ('127.0.0.1', 44167)
7 Player 3 is ready (3/3)
8 Player 4 joined from ('127.0.0.1', 52876)
9 Player 4 is ready (4/4)
10 Conditions met, moving to INIT state.
11 Sending initial snapshot...
12 Sent initial snapshot to Player 1
13 Sent initial snapshot to Player 2
14 Sent initial snapshot to Player 3
15 Sent initial snapshot to Player 4
16 Entering GAME_LOOP...
17 Player 1 acquired cell (3, 7)
18 Player 4 acquired cell (5, 6)
19 SNAPSHOT_SEND server_ts=1762443039.5250142 snapshot_id=1 seq=18
20 SNAPSHOT_SEND server_ts=1762443039.5250401 snapshot_id=1 seq=18
21 SNAPSHOT_SEND server_ts=1762443039.525053 snapshot_id=1 seq=18
22 SNAPSHOT_SEND server_ts=1762443039.5250642 snapshot_id=1 seq=18
23 SNAPSHOT_SEND server_ts=1762443039.5762784 snapshot_id=2 seq=19
24 SNAPSHOT_SEND server_ts=1762443039.5762963 snapshot_id=2 seq=19
25 SNAPSHOT_SEND server_ts=1762443039.5763073 snapshot_id=2 seq=19
26 SNAPSHOT_SEND server_ts=1762443039.5763168 snapshot_id=2 seq=19
27 Player 3 acquired cell (9, 4)
28 Player 2 acquired cell (17, 13)

1639 SNAPSHOT_SEND server_ts=1762443056.4742138 snapshot_id=333 seq=350
1640 SNAPSHOT_SEND server_ts=1762443056.4742258 snapshot_id=333 seq=350
1641 Player 1 acquired cell (4, 7)
1642 SNAPSHOT_SEND server_ts=1762443056.524262 snapshot_id=334 seq=351
1643 SNAPSHOT_SEND server_ts=1762443056.524288 snapshot_id=334 seq=351
1644 SNAPSHOT_SEND server_ts=1762443056.524304 snapshot_id=334 seq=351
1645 SNAPSHOT_SEND server_ts=1762443056.524318 snapshot_id=334 seq=351
1646 Player 1 acquired cell (9, 8)
1647 SNAPSHOT_SEND server_ts=1762443056.5749385 snapshot_id=335 seq=352
1648 SNAPSHOT_SEND server_ts=1762443056.5749612 snapshot_id=335 seq=352
1649 SNAPSHOT_SEND server_ts=1762443056.5749767 snapshot_id=335 seq=352
1650 SNAPSHOT_SEND server_ts=1762443056.5749898 snapshot_id=335 seq=352
1651 Player 2 acquired cell (12, 7)
1652 SNAPSHOT_SEND server_ts=1762443056.6267881 snapshot_id=336 seq=353
1653 SNAPSHOT_SEND server_ts=1762443056.6268108 snapshot_id=336 seq=353
1654 SNAPSHOT_SEND server_ts=1762443056.6268256 snapshot_id=336 seq=353
1655 SNAPSHOT_SEND server_ts=1762443056.6268404 snapshot_id=336 seq=353
1656 Player 1 acquired cell (15, 6)
1657 Player 3 acquired cell (14, 15)
1658 SNAPSHOT_SEND server_ts=1762443056.6785557 snapshot_id=337 seq=354
1659 SNAPSHOT_SEND server_ts=1762443056.6785743 snapshot_id=337 seq=354
1660 SNAPSHOT_SEND server_ts=1762443056.678639 snapshot_id=337 seq=354
1661 SNAPSHOT_SEND server_ts=1762443056.6786516 snapshot_id=337 seq=354
1662 Player 4 acquired cell (9, 6)
1663 SNAPSHOT_SEND server_ts=1762443056.7305968 snapshot_id=338 seq=355
1664 SNAPSHOT_SEND server_ts=1762443056.730617 snapshot_id=338 seq=355

16508 SNAPSHOT_SEND server_ts=1762443117.2946584 snapshot_id=1524 seq=1541
16509 SNAPSHOT_SEND server_ts=1762443117.2946813 snapshot_id=1524 seq=1541
16510 SNAPSHOT_SEND server_ts=1762443117.2946947 snapshot_id=1524 seq=1541
16511 SNAPSHOT_SEND server_ts=1762443117.2947073 snapshot_id=1524 seq=1541
16512 SNAPSHOT_SEND server_ts=1762443117.3451464 snapshot_id=1525 seq=1542
16513 SNAPSHOT_SEND server_ts=1762443117.3451676 snapshot_id=1525 seq=1542
16514 SNAPSHOT_SEND server_ts=1762443117.3451807 snapshot_id=1525 seq=1542
16515 SNAPSHOT_SEND server_ts=1762443117.3451922 snapshot_id=1525 seq=1542
16516 Player 1 acquired cell (11, 10)
16517 All cells claimed - ending game.
```