CS6650 Assignment 1 – Design Document

> *Git repository:* https://github.com/VivianDongChen/cs6650_assignment.git
> *Modules:* `/server` , `/client-part1` , `/client-part2` , `/results`

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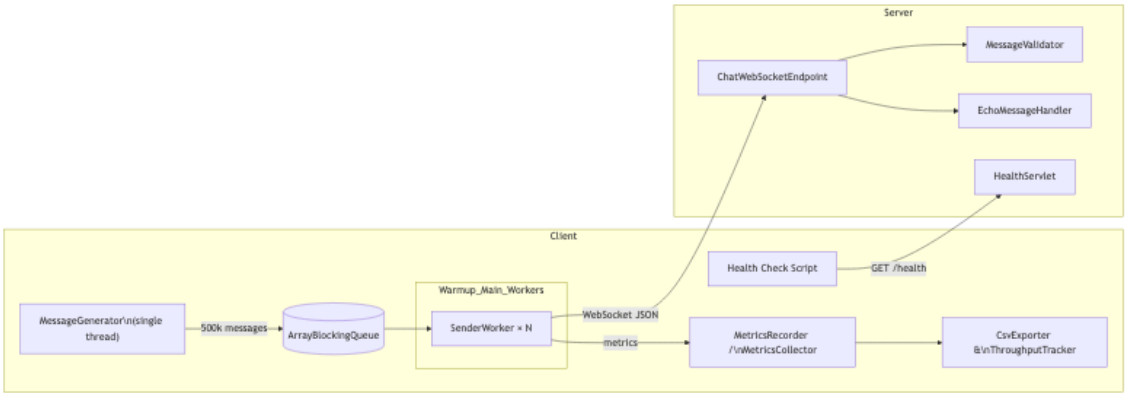
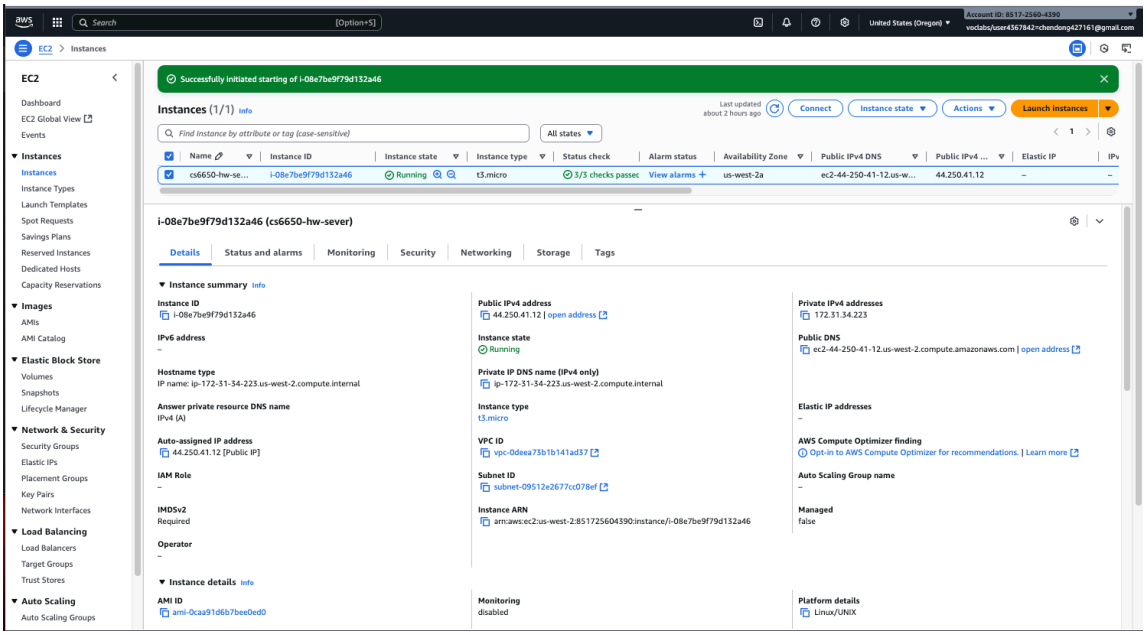
1. Architecture Overview



The client simulates load in two phases (warmup + main) using a shared message queue. Each sender maintains its own WebSocket connection to the Tomcat-hosted server. Metrics are captured locally and exported for analysis (Part 2/Part 3).

EC2 Deployment Evidence:



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2. Major Classes and Relationships

Server Module (`/server`)

Class	Responsibility	Key Collaborators
`ChatWebSocketEndpoint`	Entry point for `/chat/{roomId}` WebSocket sessions. Parses payloads, delegates validation, and echoes results.	`MessageValidator`, `EchoMessageHandler`
`MessageValidator`	Validates userId, username, message, timestamp, messageType against assignment rules.	`ChatMessage`
`EchoMessageHandler`	Builds success/error JSON responses with server timestamps.	`ChatMessage`
`ChatMessage`	Jackson-mapped POJO for inbound payloads.	Used by endpoint + validator
`HealthServlet`	`/health` REST endpoint returning `{status,timestamp}` JSON for monitoring.	`ObjectMapperProvider`
`ObjectMapperProvider`	Centralizes Jackson configuration (JavaTimeModule).	All JSON consumers

Client Part 1 (`/client-part1`)

Class	Responsibility	Key Collaborators
`App`	Bootstraps client, loads config, wires generator + orchestrator.	`ClientConfig`, `MessageGenerator`, `SenderOrchestrator`
`ClientConfig` / `ClientConfigLoader`	Immutable configuration + CLI parsing with defaults (500k messages, warmup 32×1000, etc.).	All client components
`MessageGenerator`	Single thread generating 500k messages with required distributions into a bounded queue.	`ChatMessage`, queue
`SenderOrchestrator`	Manages warmup/main phases, submits `SenderWorker` tasks to executor, records timing.	`SenderWorker`, `MetricsRecorder`
`SenderWorker`	Maintains a persistent WebSocket connection, sends messages with retries (max 5) and exponential backoff.	`ReliableWebSocketClient`, `MetricsRecorder`
`ReliableWebSocketClient`	Thin wrapper over `java.net.http.WebSocket` providing connect/reconnect/send-and-wait semantics.	`SenderWorker`

`MetricsRecorder`	Thread-safe counters for successes, failures, retries, connections, runtime, throughput.	`SenderOrchestrator`, `SenderWorker`

Client Part 2 (`/client-part2`)

Extends Part 1 with additional metrics & exports:

Class	Responsibility	Notes
`MessageMetric`, `MetricsCollector`	Per-message latency capture and thread-safe aggregation.	Stores 500k records in memory
`StatisticsAnalyzer`, `Statistics`	Compute mean/median/p95/p99/min/max, message type & room distribution.	Used after run completion
`ThroughputTracker`	Buckets acknowledgements into 10s windows for throughput CSV/chart.	
`CsvExporter`	Writes metrics and throughput CSV outputs to `results/part2-output`.	
`MetricsRecorder` (extended)	Includes per-phase timing hooks and integrates with collectors.	

All Part 2 classes reuse Part 1 networking/threading components to keep behavior consistent.

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3. Threading Model

Message Generation

- **Single producer thread** (`MessageGenerator`) pre-generates up to 500,000 messages.
- Uses `ArrayBlockingQueue` (capacity 10,000) to buffer messages; workers block if queue drains.
- Messages follow spec distributions: `userId` 1–100,000, `username = user<id>` , 50 message templates, `roomId` 1–20, messageType mix 90% TEXT / 5% JOIN / 5% LEAVE, `timestamp = Instant.now()` .

Warmup Phase

- Exactly 32 threads, each sending 1,000 messages (32,000 warmup messages).
- Workers establish new WebSocket connections; metrics captured separately.

Main Phase

- Configurable thread count (typically 128 locally, 224–320 in EC2 tests).
- `SenderOrchestrator` divides remaining messages evenly across workers.
- Executors use cached thread pool; each worker runs to completion (no reuse).

Metrics Threads (Part 2)

- Metrics collection is non-blocking: workers record metrics and return to sending.
- Post-run aggregation (single thread) generates statistics and CSV outputs.

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4. WebSocket Connection Management

1. **Connection Lifecycle**
   - Each `SenderWorker` owns a `ReliableWebSocketClient`.
   - On start, `connect()` is invoked (timeout configurable, default `PT5S`).
   - After sending all assigned messages, the worker closes the connection gracefully.
2. **Retry Semantics**
   - For each message: up to 5 attempts (`max-retries=5`).
   - Backoff starts at `initial-backoff` (default 50ms) and doubles until `max-backoff` (default 200ms Part 1, 1s Part 2).
   - On retry, `metrics.addRetries(1)` is recorded.
3. **Reconnection Strategy**
   - Any failure during send triggers `client.reconnect()` (closing + re-opening).
   - Successful reconnection increments `metrics.incrementConnectionReconnected()`.
   - Certain failures (e.g., invalid payload) mark message as failed after final attempt.
4. **Thread Safety**
   - `ReliableWebSocketClient` synchronizes critical sections to avoid concurrent writes on a single WebSocket.
   - Message queue + metrics classes use `BlockingQueue` and `AtomicLong` / `ConcurrentLinkedQueue` to avoid contention.
5. **Server Handling**
   - `ChatWebSocketEndpoint` validates messages and echoes them with server timestamps.
   - Invalid payloads return `{status:"error",errors:[...]}`; valid payloads include `serverReceiveTime` and `serverSendTime`.
   - Endpoint logs errors and performs best-effort close on IO exceptions.

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5. Little's Law Calculations & Observations

Little's Law: `λ = L / W` (throughput equals concurrency divided by service time).

Local Environment (Loopback)

- **Single-thread baseline**: 1,000 messages in **1,916 ms** → `W_local = 1.916 ms`.
- Predicted vs observed throughput:

Threads (L)	Predicted λ = L / W_local (msg/s)	Observed λ (msg/s)	Efficiency
48	≈ 25,052	16,061	64.1%
64	≈ 33,403	20,435	61.2%
96	≈ 50,104	27,382	54.7%
128	**≈ 66,805**	**30,255**	**45.3%**
160	≈ 83,507	28,249	33.8%

Takeaway: Optimal throughput occurs at 128 threads (≈30k msg/s). Efficiency drops as contention and retries grow, revealing diminishing returns beyond 128 threads.

EC2 Environment (Public Internet)

- **Single-thread baseline**: 1,000 messages in **17,371 ms** → `W_ec2 = 17.371 ms` (≈15.455 ms slower than local).
- Predicted vs observed throughput:

Threads (L)	Predicted λ = L / W_ec2 (msg/s)	Observed λ (msg/s)	Efficiency
224	≈ 12,900	6,747	52.3%
256	≈ 14,739	7,687	52.2%
288	**≈ 16,582**	**7,941**	**47.9%**
320	≈ 18,424	5,325	28.9%

Takeaway: Higher latency necessitates more concurrency (288 threads) to hide network delays. Efficiency remains ~50% until overload at 320 threads causes timeouts and failures.

Part 2 Enhancements

- Detailed metrics (latency percentiles, throughput buckets) confirm Little's Law insights:
  - Mean latency ≈ 21.4 ms, aligning with predicted 17.371 ms + retry overhead.
  - Peak throughput 10,972 msg/s in Part 2 indicates improved connection reuse and instrumentation overhead is negligible.

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6. Deployment & Testing Notes

- **Server Deployment**: Tomcat 9 on AWS EC2 (us-west-2). Health verified via `/health` and WebSocket echo tests (`wscat` , Postman).
- **Client Execution**: Maven builds shaded JARs for Part 1 & Part 2. CLI flags allow tuning thread counts, retries, and URIs.
- **Results Artifacts**: Screenshots, CSV exports, charts, and this design document reside in `/results/` for quick reference.
- **EC2 Evidence**: The included AWS console screenshot (see above) documents the running instance (region us-west-2, public IP 44.250.41.12) used for performance testing.