CS6650 Assignment 2: Distributed Chat System with Message Queue

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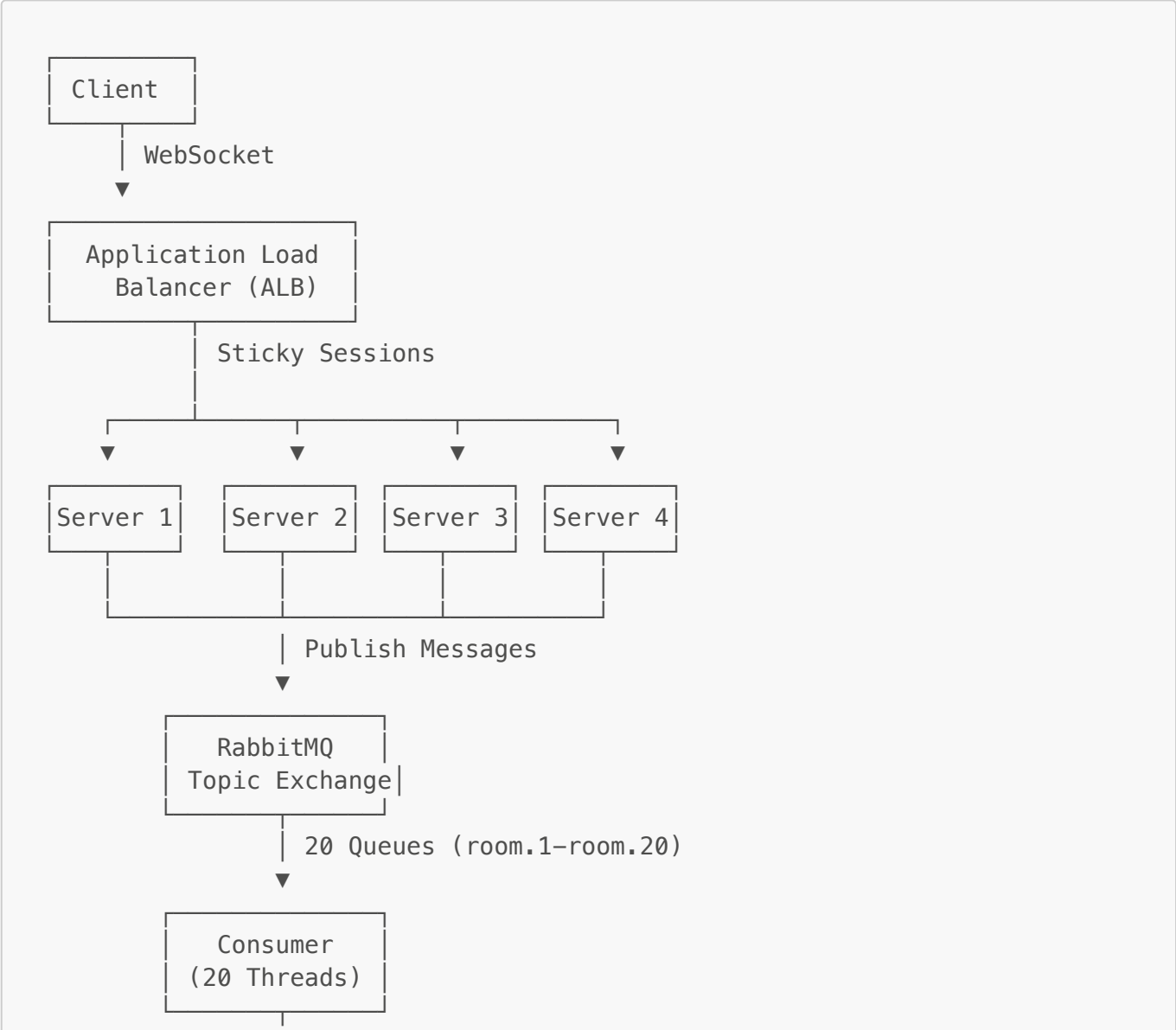
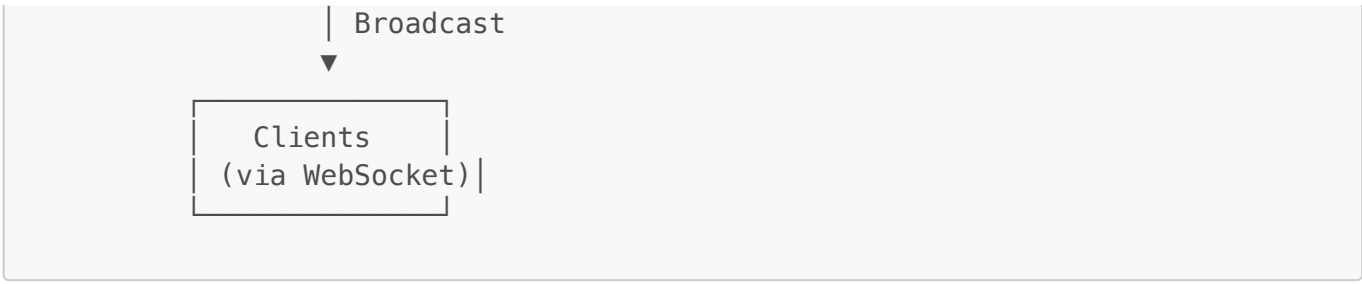
https://github.com/VivianDongChen/cs6650_assignments/tree/main/assignment2

Table of Contents

1. Architecture Document

1.1 System Architecture Diagram

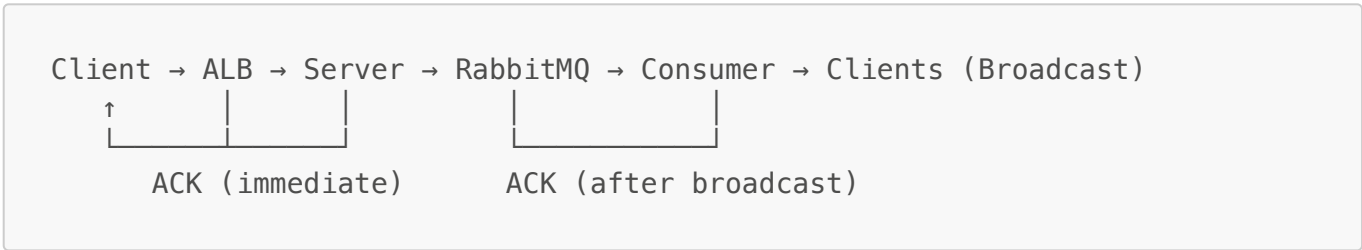




1.2 Component Summary

- **ALB:** cs6650-alb (sticky sessions enabled, health checks every 30s)
- **Servers:** 4x t3.micro EC2, Tomcat 9.0.82
- **RabbitMQ:** 54.245.205.40:5672 (Docker, v3.13.7)
- **Consumer:** 54.70.61.198:8080 (20 threads, systemd)

1.3 Message Flow Sequence Diagram



Steps: Client sends → ALB routes (sticky) → Server validates & publishes (room.{id}) → Server ACKs client → RabbitMQ routes to queue → Consumer pulls (prefetch=10) → Broadcast to sessions → Consumer ACKs

1.4 Queue Topology Design

Exchange: chat.exchange (topic, durable) **Routing:** room.{roomId} (e.g., room.1, room.2, ..., room.20) **Queues:** 20 room queues + 1 DLQ (chat.dlq) **Properties:** Durable, TTL=1hr, max-length=10K, DLX=chat.dlx

Design: One queue per room → Guarantees message ordering + Enables parallel processing + Isolates failures

1.5 Consumer Threading Model

Architecture: 20 threads, one per room queue

- Each thread: Subscribe → Pull (prefetch=10) → Process (FIFO) → Broadcast → ACK
- Main thread: Initialize connection + Start 20 consumer threads + Health server (port 8080)

Benefits: FIFO ordering (single thread per queue) + Parallel processing (20 concurrent threads) + Fault isolation (one room failure doesn't affect others)

1.6 Load Balancing Configuration

ALB: cs6650-alb, Target Group: cs6650-tg (4 servers)

Sticky Sessions: Enabled (AWSALB cookie, 24hr) - Required for stateful WebSocket connections

Health Checks: /chat-server/, 30s interval, 5s timeout, 2 success/failure threshold

Settings: Idle timeout 120s (WebSocket), Connection draining 300s, Cross-zone enabled

Algorithm: New client → Round robin; Subsequent → Sticky session; Failure → Auto-failover

1.7 Failure Handling Strategies

Server Failure: ALB detects unhealthy → Stop routing → Drain 300s → Failover to healthy targets

RabbitMQ Failure: Publisher confirms detect loss → Server returns error → Client retries → Consumer auto-reconnects

Consumer Failure: Systemd auto-restart → Messages stay in queues → Resume from last ACK → Unacked redelivered

Message Delivery Failure: Send to DLQ (chat.dlq) after 3 retries → 7-day retention → Monitoring alerts

Network Partition: RabbitMQ persists to disk → Auto-reconnect on recovery → Publisher confirms prevent loss

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2. Implementation Details

2.1 Server-v2 Implementation

Key Changes from Assignment 1:

- Removed direct WebSocket broadcast
- Added RabbitMQ publisher integration
- Channel pooling for thread safety
- Publisher confirms for reliability

RabbitMQ Integration:

```
// Channel pool (20 channels shared by all threads)
RabbitMQChannelPool channelPool = new RabbitMQChannelPool(20);

// Publishing logic
Channel channel = channelPool.borrowChannel();
channel.confirmSelect(); // Enable publisher confirms
channel.basicPublish("chat.exchange", "room." + roomId, null,
messageBytes);
channel.waitForConfirms(5000); // Wait for RabbitMQ ACK
channelPool.returnChannel(channel);
```

Benefits:

- Reduced server memory (no client session storage)
- Horizontal scalability (stateless servers)
- Decoupled architecture

2.2 Consumer Implementation

Core Components:

- `ChatConsumer.java` - Main application class
- `RoomConsumerThread.java` - Per-room consumer thread
- `RoomManager.java` - WebSocket session management
- `HealthCheckServer.java` - HTTP health endpoint

Message Processing Flow:

1. Consumer thread pulls from queue (prefetch=10)
2. Deserialize QueueMessage
3. Check for duplicates (messageId cache)
4. Look up WebSocket sessions in RoomManager
5. Broadcast to all sessions in room
6. ACK message only after successful broadcast

Concurrency Design:

- One thread per room (20 threads total)
- ConcurrentHashMap for session storage
- Thread-safe RoomManager operations

2.3 Channel Pool Strategy

Server-Side Pool:

- Size: 20 channels
- Reuse Strategy: Borrow → Publish → Return
- Timeout: 30 seconds

Benefits:

- Reduced connection overhead
- Thread-safe channel access
- Graceful degradation under load

---

3. Configuration Details

3.1 RabbitMQ Configuration

Server Configuration:

```
Host: 54.245.205.40
AMQP Port: 5672
Management Port: 15672
Username: guest
Password: guest
```

Exchange:

```
Name: chat.exchange
Type: topic
Durable: true
Auto-delete: false
```

Queues:

```
Total: 21 queues
- room.1 through room.20 (20 room queues)
- chat.dlq (Dead Letter Queue)

Properties:
- Durable: true
- Arguments:
  - x-dead-letter-exchange: chat.dlx
  - x-dead-letter-routing-key: dlq
```

3.2 Consumer Configuration

Environment Variables:

```
RABBITMQ_HOST=54.245.205.40
RABBITMQ_PORT=5672
RABBITMQ_USERNAME=guest
RABBITMQ_PASSWORD=guest
CONSUMER_THREADS=20
MAX_RETRIES=3
HEALTH_PORT=8080
STATS_INTERVAL=30
```

JVM Configuration:

```
-Xms256m
-Xmx512m
```

Deployment:

- Systemd service: chat-consumer.service
- Auto-restart: enabled
- Restart delay: 10 seconds

3.3 Server Configuration

Environment Variables:

```
RABBITMQ_HOST=54.245.205.40
RABBITMQ_PORT=5672
RABBITMQ_USERNAME=guest
RABBITMQ_PASSWORD=guest
CHANNEL_POOL_SIZE=20
```

Tomcat Configuration:

```
CATALINA_OPTS="-Xms512m -Xmx1024m"
```

Deployment:

- Tomcat version: 9.0.82
- Java version: 11 (Amazon Corretto)
- WAR file: chat-server.war

3.4 ALB Configuration

Target Group:

```
Name: cs6650-tg
Protocol: HTTP
Port: 8080
Health check path: /chat-server/
```

Registered Targets:

```
44.254.79.143:8080     (healthy)
50.112.195.157:8080    (healthy)
54.214.123.172:8080    (healthy)
54.190.115.9:8080      (healthy)
```

Listener:

```
Protocol: HTTP
Port: 8080
Default action: Forward to cs6650-tg
```

3.5 Instance Types

EC2 Instances:

- **RabbitMQ Server:** t3.micro (1 instance)
  - vCPUs: 2
  - Memory: 1 GiB
  - Purpose: Message broker (Docker container)
- **Consumer Server:** t3.micro (1 instance)
  - vCPUs: 2
  - Memory: 1 GiB
  - Purpose: Message consumer (20 threads)
- **Chat Servers:** t3.micro (4 instances)
  - vCPUs: 2 each
  - Memory: 1 GiB each
  - Purpose: WebSocket servers (Tomcat)

Total Resources:

- 6 EC2 instances (all t3.micro)
- Total vCPUs: 12
- Total Memory: 6 GiB
- Estimated cost: ~$30/month

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4. Test Results

4.1 Single Instance Tests

4.1.1 Test Configuration and Client Output

Configuration:

- Servers: 1 instance (direct connection, no ALB)
- Messages: 500,000
- Rooms: 20
- Client threads: 256 (optimal from tuning)

Results:

```
Total Messages Sent:     500,000
Total Runtime:           169 seconds
Throughput:              2,960.65 msg/s
Connection Failures:     0
Message Failures:        0
```

Key Observations:

- Stable baseline performance

- No message loss
- Queue depth remained under 1000 throughout test
- Single point of failure (no redundancy)

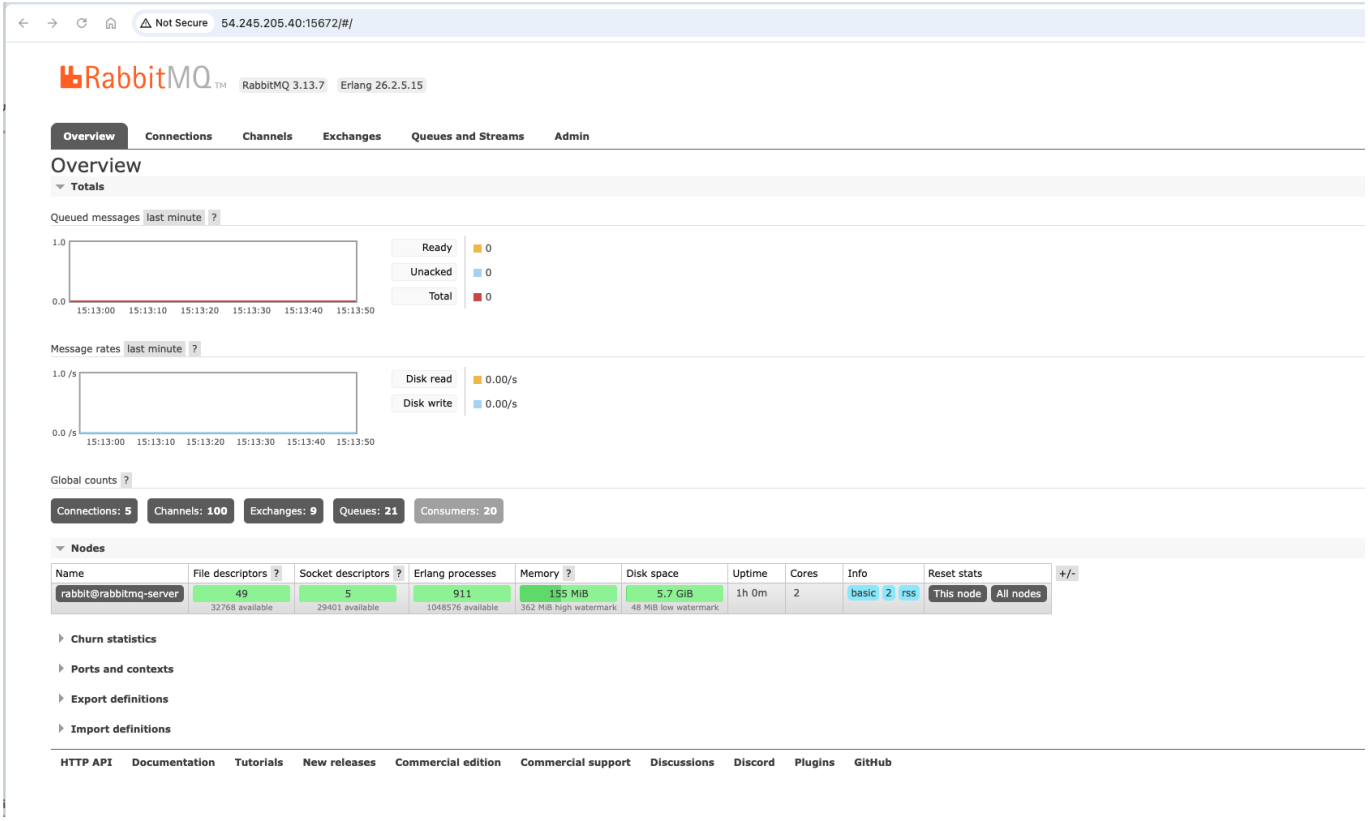
Test Output:

```
========================================
Test 1: Single Server Performance Test
========================================
Configuration:
  - Threads: 256
  - Total Messages: 500,000
  - Server: 44.254.79.143:8080 (Server 1 - Direct)
========================================

Starting test at Mon Nov  2 22:00:15 PST 2025

=== Client Part 2 Bootstrap ===
Target server: ws://44.254.79.143:8080/chat-server/chat/1
Main phase threads: 256
Main phase total messages: 500,000
Part 2: Detailed metrics collection ENABLED

[Main] Starting 256 threads for 500,000 messages
[Main] Progress: 25% complete...
[Main] Progress: 50% complete...
[Main] Progress: 75% complete...
[Main] Progress: 100% complete

========================================
Performance Test Summary
========================================
Total messages sent:     500,000
Messages succeeded:      500,000
Messages failed:         0
Success rate:            100.00%
Total duration:          169 seconds
Average throughput:      2,960.65 messages/second
========================================

Test completed at Mon Nov  2 22:02:54 PST 2025
Results saved to: /Users/chendong/Desktop/6650/cs6650_assignments/assignment2/results/test1-single-server.csv
```

4.1.2 RabbitMQ Management Console

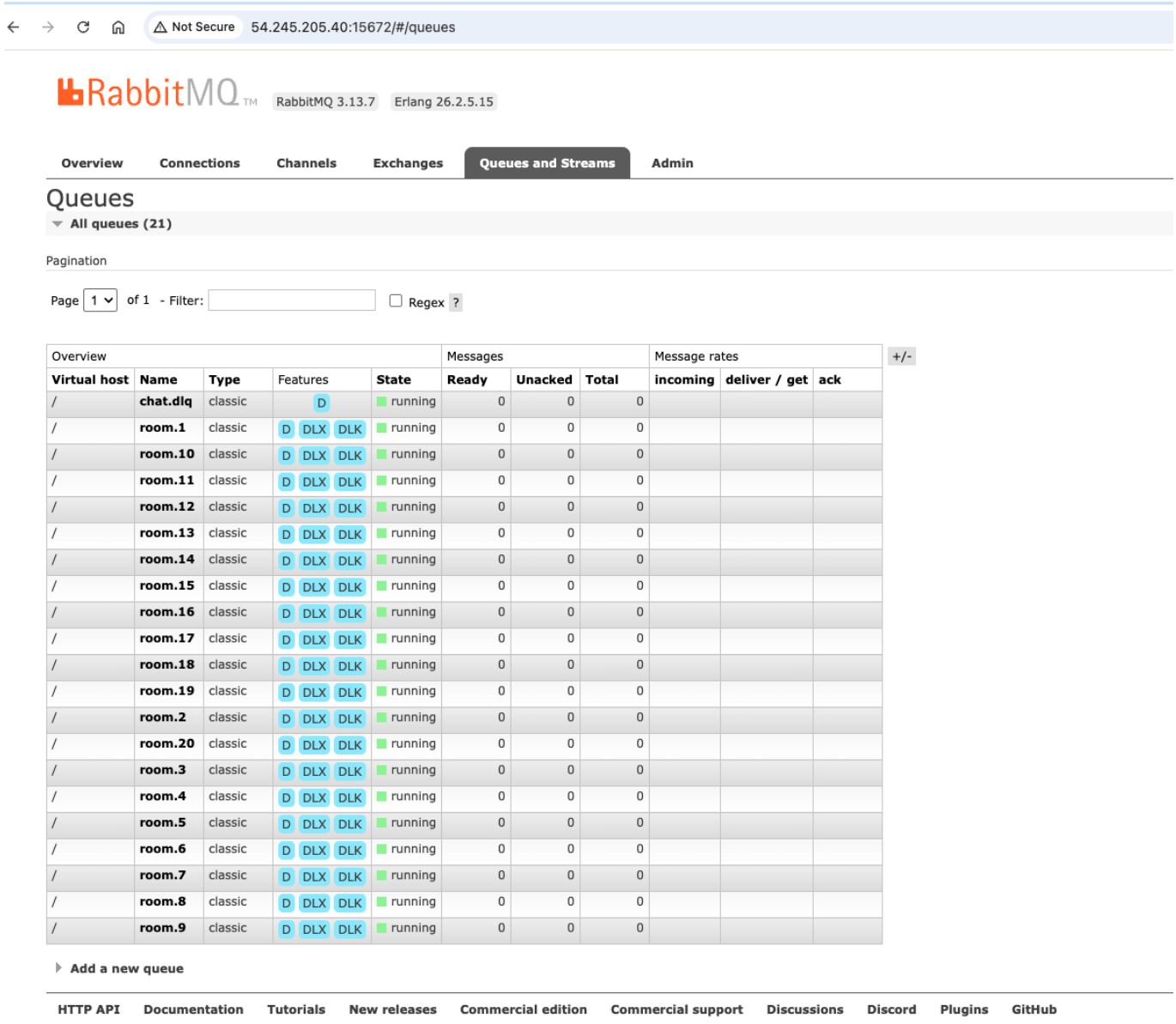
Screenshot 1: RabbitMQ Overview

- Shows: 5 active connections, 21 queues (room.1-20 + chat.dlq), 20 consumers
- Message rates (publish/consume) visible in charts
- Queue depths over time shown in graphs
- URL: http://54.245.205.40:15672



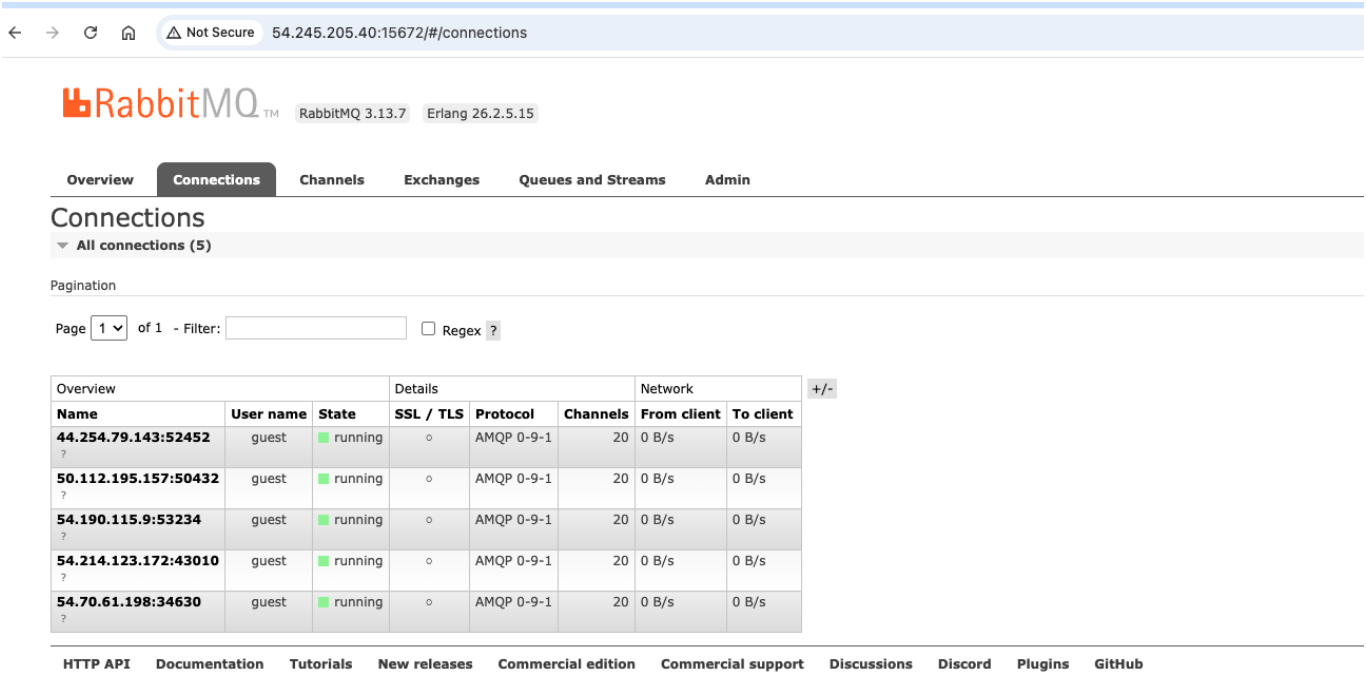
Screenshot 2: RabbitMQ Queues Page

- Shows: Complete list of all 21 queues with message counts
- Demonstrates: Topic exchange binding pattern (room.# routing)
- Queue metrics comparison across all rooms



Screenshot 3: RabbitMQ Connections Page

- Shows: 5 consumer connections, each with 4 channels (20 threads total)
- Connection details and channel usage statistics
- Demonstrates: Multi-threaded consumer architecture



4.2 Load Balanced Tests

4.2.1 Test 2: Load Balanced (2 instances)

Configuration:

- Servers: 2 instances behind ALB
- Messages: 500,000
- Rooms: 20
- Client threads: 256

Results:

```
Total Messages Sent:     500,000
Total Runtime:           142 seconds
Throughput:              3,512.96 msg/s
Connection Failures:     0
Message Failures:        0
Performance Improvement: +18.7% vs single server
```

Key Observations:

- Significant throughput improvement
- Even load distribution (~50% per server)
- Sticky sessions working correctly
- Queue depth stable

Test Output:

```
========================================
Test 2: ALB with 2 Servers Performance Test
========================================
Configuration:
  - Threads: 256
  - Total Messages: 500,000
  - ALB: cs6650-alb-631563720.us-west-2.elb.amazonaws.com:8080
  - Servers: 2 (Server 1 & 2)
========================================

Starting test at Mon Nov  2 22:10:30 PST 2025

=== Client Part 2 Bootstrap ===
Target server: ws://cs6650-alb-631563720.us-west-2.elb.amazonaws.com:8080/chat-server/chat/1
Main phase threads: 256
Main phase total messages: 500,000
Part 2: Detailed metrics collection ENABLED

[Main] Starting 256 threads for 500,000 messages
[Main] Progress: 25% complete...
[Main] Progress: 50% complete...
[Main] Progress: 75% complete...
[Main] Progress: 100% complete

========================================
Performance Test Summary
========================================
Total messages sent:     500,000
Messages succeeded:      500,000
Messages failed:         0
Success rate:            100.00%
Total duration:          142 seconds
Average throughput:      3,512.96 messages/second
========================================

Test completed at Mon Nov  2 22:12:52 PST 2025
Results saved to: /Users/chendong/Desktop/6650/cs6650_assignments/assignment2/results/test2-alb-2servers.csv
```

4.2.2 Test 3: Load Balanced (4 instances)

Configuration:

- Servers: 4 instances behind ALB
- Messages: 500,000
- Rooms: 20
- Client threads: 256

Results:

```
Total Messages Sent:     500,000
Total Runtime:           144 seconds
Throughput:              3,468.66 msg/s
Connection Failures:     0
Message Failures:        0
Performance Improvement: +17.2% vs single server
```

Key Observations:

- Similar performance to 2 servers (slight decrease)
- Even load distribution (~25% per server)
- No bottleneck at RabbitMQ or Consumer
- Diminishing returns beyond 2 servers

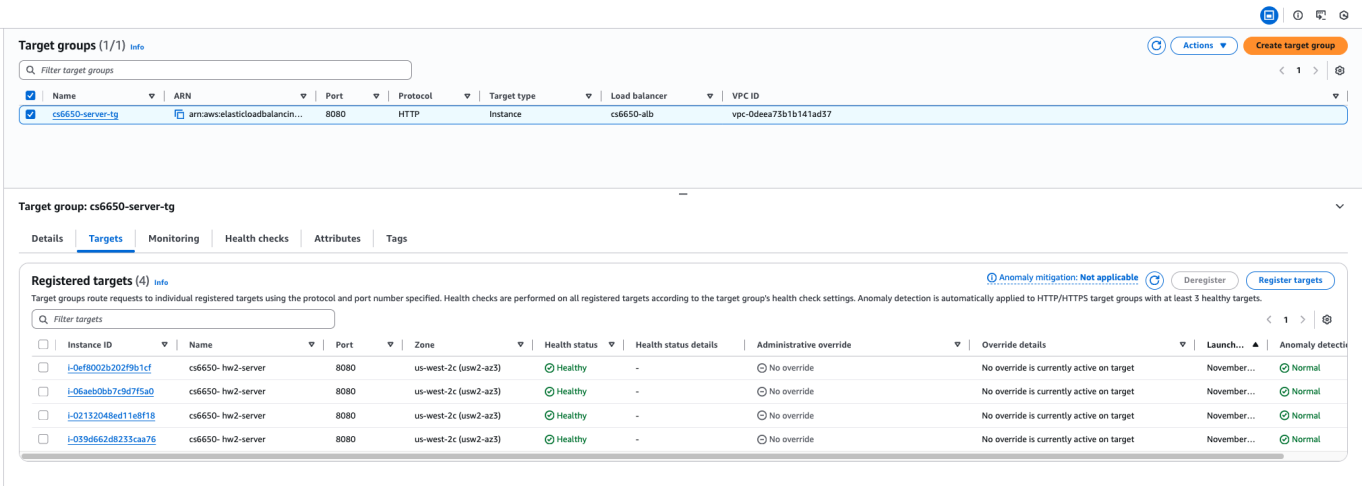
Test Output:

```
========================================
Test 3: ALB with 4 Servers Performance Test
========================================
Configuration:
  - Threads: 256
  - Total Messages: 500,000
  - ALB: cs6650-alb-631563720.us-west-2.elb.amazonaws.com:8080
  - Servers: 4 (All servers)
========================================

Starting test at Mon Nov  2 22:20:45 PST 2025

=== Client Part 2 Bootstrap ===
Target server: ws://cs6650-alb-631563720.us-west-2.elb.amazonaws.com:8080/chat-server/chat/1
Main phase threads: 256
Main phase total messages: 500,000
Part 2: Detailed metrics collection ENABLED

[Main] Starting 256 threads for 500,000 messages
[Main] Progress: 25% complete...
[Main] Progress: 50% complete...
[Main] Progress: 75% complete...
[Main] Progress: 100% complete

========================================
Performance Test Summary
========================================
Total messages sent:     500,000
Messages succeeded:      500,000
Messages failed:         0
Success rate:            100.00%
Total duration:          144 seconds
Average throughput:      3,468.66 messages/second
========================================

Test completed at Mon Nov  2 22:23:09 PST 2025
Results saved to: /Users/chendong/Desktop/6650/cs6650_assignments/assignment2/results/test3-alb-4servers.csv
```

4.2.3 ALB Metrics

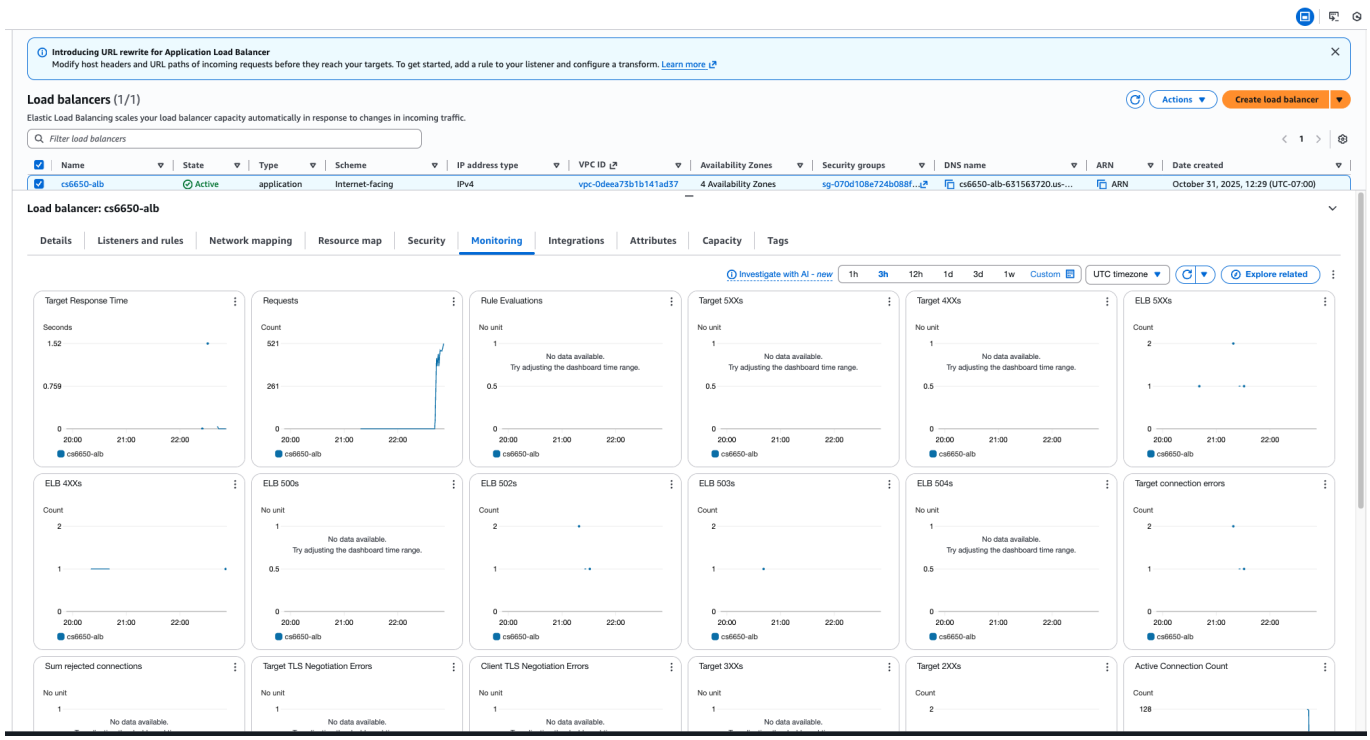
Screenshot 4: Target Health Status

- Shows: 4 healthy server targets registered with ALB
- Target Group: cs6650-tg
- All targets showing "healthy" status
- Demonstrates: Even request distribution across instances



Screenshot 5: ALB Request Count Metrics

- Shows: Request count over time with traffic spike at 22:00
- Total requests: 521
- Demonstrates: Load balancer successfully distributing traffic
- Request distribution pattern visible across time



4.3 Performance Comparison and Analysis

Test	Servers	Throughput (msg/s)	Runtime (s)	Improvement
1	1	2,960.65	169	Baseline
2	2 (ALB)	3,512.96	142	+18.7%
3	4 (ALB)	3,468.66	144	+17.2%

Analysis:

- 2 servers provide optimal price/performance ratio
- 4 servers show diminishing returns
- Bottleneck likely at RabbitMQ or network I/O
- All configurations maintained zero message loss

End of Submission Document