Homework 3

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Report

1. Introduction

This report analyzes a C-based multithreaded system simulating a satellite support service managed by engineers. The program handles concurrency using POSIX threads (pthread), semaphores (sem_t), and mutexes (pthread_mutex_t). It models the scenario where multiple satellite requests (with varying priorities) are processed by a limited number of engineers.

2. System Overview

The system consists of:

- A **shared priority queue** for satellite requests.
- A **fixed pool of engineers** (NUM_ENGINEERS = 3), implemented as threads.
- Each **satellite** is also represented as a thread and is associated with a priority and timeout mechanism.
- The system uses synchronization mechanisms to ensure thread-safe access to shared data.

3. Purpose and Role of Each Synchronization Primitive

3.1 Mutexes

engineerMutex

- **Purpose**: Synchronizes access to the availableEngineers variable and the shutdownFlag.
- **Usage**:
  - Prevents race conditions when engineers check or update availableEngineers.
  - Ensures correct evaluation of the shutdown state and queue status.

queueMutex

- **Purpose**: Protects the **priority request queue** from concurrent modifications.
- **Usage**:
  - Locks access when a satellite enqueues its request or when an engineer dequeues a request.
  - Ensures thread-safe modifications to the linked list structure.

3.2 Semaphores

sem_t newRequest

- **Purpose**: Signals engineers that a new satellite request has arrived.
- **Usage**:
  - Posted (sem_post) by the satellite thread after it enqueues its request.
  - Waited on (sem_wait) by engineers to detect new incoming requests.

- Also used during shutdown to unblock any waiting engineer threads.

sat[i].handled_sem (Per-satellite semaphore)

- **Purpose**: Used by engineers to signal that a specific satellite request is being handled.
- **Usage**:
  - The satellite thread waits (sem_timedwait) on this semaphore for up to TIMEOUT seconds.
  - If no engineer handles the request within the timeout, the satellite times out and removes itself from the queue.
  - Engineers post (sem_post) to this semaphore when they start processing the satellite's request.

4. Function Descriptions and Their Purpose

4.1 main()

- Initializes mutexes and semaphores.
- Creates threads for engineers and satellites.
- Signals system shutdown after all satellites are processed.
- Joins threads and performs cleanup.

4.2 satellite(void* arg)

- Simulates a satellite request:
  - Assigns a random priority.
  - Enqueues itself in the priority queue.
  - Waits for an engineer to handle it using a timed semaphore wait.
  - If not handled in time, removes itself from the queue and logs a timeout message.

4.3 engineer(void* arg)

- Represents an engineer continuously processing satellite requests:
  - Waits on newRequest semaphore.
  - Acquires engineerMutex to check for shutdown and queue state.
  - Dequeues a satellite if available, signals the satellite’s semaphore, and simulates work with sleep.
  - Increments and decrements the count of availableEngineers.

4.4 enqueue(PriorityQueue* pq, Satellite* satellite)

- Adds a satellite to the priority queue in descending priority order.
- Uses linked list logic to maintain the queue order.

4.5 dequeue(PriorityQueue* pq)

- Removes and returns the highest-priority satellite from the queue.

4.6 removeFromQueue(PriorityQueue* pq, int id)

- Removes a satellite from the queue based on its ID.
- Called if the satellite times out before being serviced.

4.7 engineer_cleanup(void* arg)

- Called on thread cancellation/cleanup.
- Frees the dynamically allocated engineer ID pointer.

5. Test scenarios

Greater number –> higher priority

Timeout 2 sec

Case 1

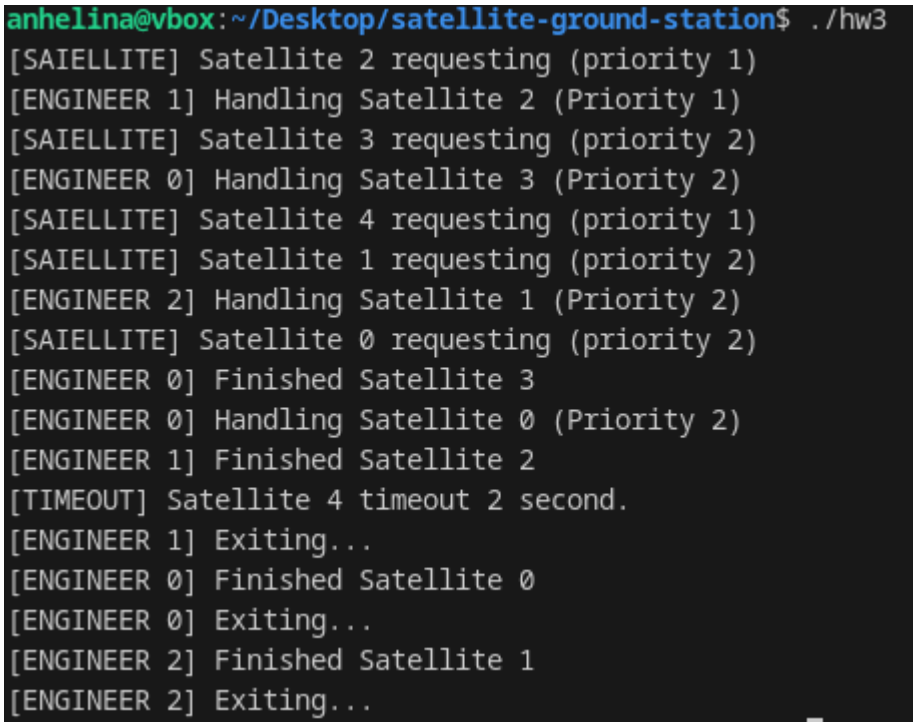
- 5 satellites and 3 engineers are defined.
- Satellites are assigned random priority values.
- Satellite 0 (priority 3), satellite 1 (priority 4), satellite 2 (priority 2), satellite 3 (priority 4), satellite 4 (priority 2), request a connection one after another. Based on the priority values they are put in the queue.
- Satellites 1,3,0 are picked by engineers as highest prioritized
- None of engineers were able to finish their job within 2 seconds timeout
- So, Satellite 2's and 4`s timeouts expire and they drop out.
- Finally, all engineers complete their tasks and exit.

```
anhelina@vbox:~/Desktop/satellite-ground-station$ ./hw3
[SAIELLITE] Satellite 0 requesting (priority 3)
[SAIELLITE] Satellite 1 requesting (priority 4)
[SAIELLITE] Satellite 2 requesting (priority 2)
[SAIELLITE] Satellite 3 requesting (priority 4)
[SAIELLITE] Satellite 4 requesting (priority 2)
[ENGINEER 2] Handling Satellite 1 (Priority 4)
[ENGINEER 1] Handling Satellite 3 (Priority 4)
[ENGINEER 0] Handling Satellite 0 (Priority 3)
[TIMEOUT] Satellite 2 timeout 2 second.
[TIMEOUT] Satellite 4 timeout 2 second.
[ENGINEER 2] Finished Satellite 1
[ENGINEER 1] Finished Satellite 3
[ENGINEER 0] Finished Satellite 0
[ENGINEER 0] Exiting...
[ENGINEER 2] Exiting...
[ENGINEER 1] Exiting...
```

Case 2

- 5 satellites and 3 engineers are defined.
- Satellites are assigned random priority values.
- Satellite 2, with priority 1, requests an update.

- One of the three engineers immediately picks up and starts processing this request.
- Satellite 3, with priority 2, requests an update.
- One of the two available engineers immediately picks up and starts processing this request.
- Satellite 4 (priority 1), satellite 1 (priority 2), request a connection one after another. Based on the priority values they are put in the queue.
- Satellite 1 is picked as a higher priority
- Satellite 0, with priority 2, requests an update and is placed in a queue
- Engineer 0 finishes his work and pick satellite 0
- Satellite 4's timeout expires and it drops out
- Finally, all engineers complete their tasks and exit.



Timeout 5 sec

Case 3

- 5 satellites and 3 engineers are defined.
- Satellites are assigned random priority values.
- Satellite 0, with priority 2, requests an update.
- One of the three engineers immediately picks up and starts processing this request.
- Satellite 1 (priority 2), satellite 2 (priority 2), satellite 3 (priority 1), satellite 4 (priority 3), request a connection one after another. Based on the priority values they are put in the queue.
- Satellite 4 and 1 were picked sequentially according to priorities and FIFO principle

- Engineer 0 finishes his work and pick satellite 2
- Engineer 1 finishes his work and pick satellite 1
- One by one engineers finish their work and exit

```
anhelina@vbox:~/Desktop/satellite-ground-station$ ./hw3
[SAIELLITE] Satellite 0 requesting (priority 2)
[ENGINEER 0] Handling Satellite 0 (Priority 2)
[SAIELLITE] Satellite 1 requesting (priority 2)
[SAIELLITE] Satellite 2 requesting (priority 2)
[SAIELLITE] Satellite 3 requesting (priority 1)
[SAIELLITE] Satellite 4 requesting (priority 3)
[ENGINEER 1] Handling Satellite 4 (Priority 3)
[ENGINEER 2] Handling Satellite 1 (Priority 2)
[ENGINEER 0] Finished Satellite 0
[ENGINEER 0] Handling Satellite 2 (Priority 2)
[ENGINEER 1] Finished Satellite 4
[ENGINEER 1] Handling Satellite 3 (Priority 1)
[ENGINEER 2] Finished Satellite 1
[ENGINEER 2] Exiting...
[ENGINEER 1] Finished Satellite 3
[ENGINEER 1] Exiting...
[ENGINEER 0] Finished Satellite 2
[ENGINEER 0] Exiting...
```

Case 4

Purpose of this case is to show that principle of FIFO works for equal priority (2) satellites

```
anhelina@vbox:~/Desktop/satellite-ground-station$ ./hw3
[SAIELLITE] Satellite 4 requesting (priority 2)
[SAIELLITE] Satellite 3 requesting (priority 1)
[SAIELLITE] Satellite 2 requesting (priority 4)
[SAIELLITE] Satellite 1 requesting (priority 3)
[SAIELLITE] Satellite 0 requesting (priority 2)
[ENGINEER 2] Handling Satellite 2 (Priority 4)
[ENGINEER 0] Handling Satellite 1 (Priority 3)
[ENGINEER 1] Handling Satellite 4 (Priority 2)
[ENGINEER 0] Finished Satellite 1
[ENGINEER 0] Handling Satellite 0 (Priority 2)
[ENGINEER 1] Finished Satellite 4
[ENGINEER 1] Handling Satellite 3 (Priority 1)
[ENGINEER 2] Finished Satellite 2
[ENGINEER 2] Exiting...
[ENGINEER 0] Finished Satellite 0
[ENGINEER 0] Exiting...
[ENGINEER 1] Finished Satellite 3
[ENGINEER 1] Exiting...
```

6. Key Concepts Demonstrated

- **Producer-consumer synchronization** using semaphores.
- **Priority-based scheduling** using a custom priority queue.
- **Thread-safe shared resource access** using mutexes.
- **Timeout handling** with per-thread semaphores and sem_timedwait.
- **Thread cleanup and memory management** for dynamically allocated thread arguments.

7. Conclusion

This program effectively demonstrates a real-world simulation of priority-based task handling with concurrency control. The use of mutexes ensures shared data consistency, while semaphores provide efficient inter-thread communication. The satellite timeout mechanism adds robustness by preventing indefinite waiting, and the orderly shutdown sequence prevents deadlocks or resource leaks.