Experiment No. 05

Semester	B.E. Semester VIII – Computer Engineering
Subject	Distributed Computing Lab
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Title: Multiple Nodes and Local Clocks in Distributed Computing.

Explanation:

1. Introduction

In distributed computing, there is no global clock to synchronize events across multiple nodes. Instead, each node maintains its **local clock**, which may drift due to differences in processing speed and network latency. This lab demonstrates a **random message-passing system** where nodes communicate asynchronously, assigning timestamps based on their local clocks.

2. Objective

The goal of this experiment is to:

- Simulate multiple nodes with independent local clocks.
- Demonstrate message passing between nodes at random intervals.
- Show how timestamps are assigned and updated using **logical clocks**.
- Observe the effect of clock drift and synchronization through communication.

3. Concepts and Theory

3.1 Distributed Systems and Local Clocks

A distributed system consists of multiple independent nodes that communicate over a network. Each node maintains its **own clock**, which may not be synchronized with others. Since there is no shared global clock, timekeeping in distributed systems is challenging.

3.2 Logical Clocks

Logical clocks are mechanisms that help maintain event ordering in distributed systems. The **happened-before relation (→)** states:

- If an event **A** occurs before **B** in the same node, then **A → B**.
- If a node sends a message with timestamp **T**, the receiver updates its clock to **max(local_clock, T) + 1**.

This ensures **causal consistency** among events.

4. Code Explanation

4.1 Node Class

Each node in the system:

- Maintains a localClock initialized to the system time.
- Sends messages at random intervals (1-4 seconds).
- Assigns a timestamp to each message before sending it.
- Receives messages and updates its local clock based on the received timestamp using the **logical clock update rule**.

Clock Synchronization Rule

When a node receives a message with timestamp **T**, it updates its clock as:

localClock=max(localClock,T)+1localClock = max(localClock, T) + 1localClock=max(localClock,T)+1

4.2 Message Passing Mechanism

Nodes randomly choose another node to send a message to. The receiver updates its clock based on the received timestamp. This simulates asynchronous communication in a distributed system.

4.3 Distributed System Setup

- A fixed number of nodes (5 in this case) are created.
- Each node runs as a separate thread, simulating concurrent execution.
- The system runs for **20 seconds**, allowing multiple message exchanges.
- The execution is managed using **Java's ExecutorService**.

5. Observations and Results

After running the program, the console output shows:

1. **Message passing between nodes** with timestamps.
2. **Clock drift** due to independent updates at each node.
3. **Synchronization through message exchange**, ensuring timestamps remain consistent.

6. Conclusion

This experiment illustrates:

- The **importance of logical clocks** in maintaining event order in a distributed system.
- How **message passing helps synchronize** local clocks.
- The **effect of random delays** in communication.
- A **real-world simulation** of asynchronous distributed computing.

In real-world distributed systems, advanced clock synchronization methods like **NTP (Network Time Protocol)** or **Lamport Timestamps** can be used to improve accuracy.

Code:

```
import java.util.Random;
import java.util.concurrent.ExecutorService;
import java.util.concurrent.Executors;
import java.util.concurrent.TimeUnit;

class Node implements Runnable {
```

```
    private final int id;
    private long localClock;
    private final Random random = new Random();

    public Node(int id) {
        this.id = id;
        this.localClock = System.currentTimeMillis(); // Initialize with system time
    }

    private void sendMessage(Node receiver) {
        long timestamp = localClock;
        System.out.println("Node " + id + " sent a message to Node " + receiver.id + "
at " + timestamp);
        receiver.receiveMessage(this, timestamp);
    }

    private void receiveMessage(Node sender, long timestamp) {
        System.out.println("Node " + id + " received a message from Node " + sender.id
+ " with timestamp " + timestamp);
        synchronizeClock(timestamp);
    }

    private void synchronizeClock(long receivedTimestamp) {
        localClock = Math.max(localClock, receivedTimestamp) + 1;
        System.out.println("Node " + id + " updated its local clock to " + localClock);
    }

    @Override
    public void run() {
        try {
            while (true) {
                Thread.sleep(random.nextInt(3000) + 1000); // Random interval between
1-4 sec
                localClock += random.nextInt(10); // Simulate local clock drift
                Node receiver = DistributedSystem.getRandomNode(id);
                if (receiver != null) {
                    sendMessage(receiver);
                }
            }
        } catch (InterruptedException e) {
            Thread.currentThread().interrupt();
        }
    }
}

public class DistributedSystem {
    private static final int NODE_COUNT = 5;
    private static final Node[] nodes = new Node[NODE_COUNT];
```

```
    private static final Random random = new Random();

    public static void main(String[] args) {
        ExecutorService executor = Executors.newFixedThreadPool(NODE_COUNT);
        for (int i = 0; i < NODE_COUNT; i++) {
            nodes[i] = new Node(i);
            executor.execute(nodes[i]);
        }
        try {
            Thread.sleep(20000); // Run for 20 seconds
        } catch (InterruptedException e) {
            Thread.currentThread().interrupt();
        }
        executor.shutdownNow();
    }

    public static Node getRandomNode(int excludeId) {
        while (true) {
            int randomIndex = random.nextInt(NODE_COUNT);
            if (randomIndex != excludeId) {
                return nodes[randomIndex];
            }
        }
    }
}
```

Output:

```
PS E:\GIt\Sem-8\DC\Lab5> java DistributedSystem
Node 4 sent a message to Node 2 at 1739422024007
Node 2 received a message from Node 4 with timestamp 1739422024007
Node 0 sent a message to Node 3 at 1739422024013
Node 3 received a message from Node 0 with timestamp 1739422024013
Node 3 updated its local clock to 1739422024014
Node 2 updated its local clock to 1739422024008
Node 0 sent a message to Node 1 at 1739422024017
Node 1 received a message from Node 0 with timestamp 1739422024017
Node 1 updated its local clock to 1739422024018
Node 1 sent a message to Node 3 at 1739422024026
Node 3 received a message from Node 1 with timestamp 1739422024026
Node 3 updated its local clock to 1739422024027
Node 2 sent a message to Node 4 at 1739422024009
Node 4 received a message from Node 2 with timestamp 1739422024009
Node 4 updated its local clock to 1739422024010
Node 4 sent a message to Node 2 at 1739422024014
Node 2 received a message from Node 4 with timestamp 1739422024014
Node 2 updated its local clock to 1739422024015
Node 3 sent a message to Node 0 at 1739422024028
Node 0 received a message from Node 3 with timestamp 1739422024028
Node 0 updated its local clock to 1739422024029
Node 4 sent a message to Node 1 at 1739422024023
Node 1 received a message from Node 4 with timestamp 1739422024023
Node 1 updated its local clock to 1739422024027
Node 0 sent a message to Node 3 at 1739422024035
Node 3 received a message from Node 0 with timestamp 1739422024035
Node 3 updated its local clock to 1739422024036
Node 3 sent a message to Node 2 at 1739422024043
Node 2 received a message from Node 3 with timestamp 1739422024043
Node 2 updated its local clock to 1739422024044
Node 1 sent a message to Node 2 at 1739422024029
Node 2 received a message from Node 1 with timestamp 1739422024029
Node 2 updated its local clock to 1739422024045
Node 4 sent a message to Node 1 at 1739422024032
Node 1 received a message from Node 4 with timestamp 1739422024032
Node 1 updated its local clock to 1739422024033
Node 2 sent a message to Node 4 at 1739422024053
Node 4 received a message from Node 2 with timestamp 1739422024053
Node 4 updated its local clock to 1739422024054
Node 1 sent a message to Node 2 at 1739422024040
Node 2 received a message from Node 1 with timestamp 1739422024040
Node 2 updated its local clock to 1739422024054
Node 0 sent a message to Node 3 at 1739422024035
Node 3 received a message from Node 0 with timestamp 1739422024035
```

```
Node 3 updated its local clock to 1739422024044
Node 3 sent a message to Node 4 at 1739422024052
Node 4 received a message from Node 3 with timestamp 1739422024052
Node 4 updated its local clock to 1739422024055
Node 4 sent a message to Node 3 at 1739422024060
Node 3 received a message from Node 4 with timestamp 1739422024060
Node 3 updated its local clock to 1739422024061
Node 0 sent a message to Node 3 at 1739422024039
Node 3 received a message from Node 0 with timestamp 1739422024039
Node 3 updated its local clock to 1739422024062
Node 1 sent a message to Node 3 at 1739422024045
Node 3 received a message from Node 1 with timestamp 1739422024045
Node 3 updated its local clock to 1739422024063
Node 4 sent a message to Node 0 at 1739422024068
Node 0 received a message from Node 4 with timestamp 1739422024068
Node 0 updated its local clock to 1739422024069
Node 2 sent a message to Node 1 at 1739422024060
Node 1 received a message from Node 2 with timestamp 1739422024060
Node 1 updated its local clock to 1739422024061
Node 0 sent a message to Node 4 at 1739422024076
Node 4 received a message from Node 0 with timestamp 1739422024076
Node 4 updated its local clock to 1739422024077
Node 3 sent a message to Node 2 at 1739422024070
Node 2 received a message from Node 3 with timestamp 1739422024070
Node 2 updated its local clock to 1739422024071
Node 2 sent a message to Node 3 at 1739422024075
Node 3 received a message from Node 2 with timestamp 1739422024075
Node 3 updated its local clock to 1739422024076
Node 4 sent a message to Node 3 at 1739422024080
Node 3 received a message from Node 4 with timestamp 1739422024080
Node 3 updated its local clock to 1739422024081
Node 1 sent a message to Node 3 at 1739422024068
Node 3 received a message from Node 1 with timestamp 1739422024068
Node 3 updated its local clock to 1739422024082
Node 3 sent a message to Node 2 at 1739422024087
Node 2 received a message from Node 3 with timestamp 1739422024087
Node 2 updated its local clock to 1739422024088
Node 4 sent a message to Node 1 at 1739422024083
Node 1 received a message from Node 4 with timestamp 1739422024083
Node 1 updated its local clock to 1739422024084
Node 2 sent a message to Node 3 at 1739422024093
Node 3 received a message from Node 2 with timestamp 1739422024093
```

```
Node 3 updated its local clock to 1739422024094
Node 3 sent a message to Node 1 at 1739422024096
Node 1 received a message from Node 3 with timestamp 1739422024096
Node 1 updated its local clock to 1739422024097
Node 0 sent a message to Node 3 at 1739422024084
Node 3 received a message from Node 0 with timestamp 1739422024084
Node 3 updated its local clock to 1739422024097
Node 2 sent a message to Node 1 at 1739422024095
Node 1 received a message from Node 2 with timestamp 1739422024095
Node 1 updated its local clock to 1739422024098
Node 4 sent a message to Node 2 at 1739422024086
Node 2 received a message from Node 4 with timestamp 1739422024086
Node 2 updated its local clock to 1739422024096
Node 1 sent a message to Node 4 at 1739422024105
Node 4 received a message from Node 1 with timestamp 1739422024105
Node 4 updated its local clock to 1739422024106
Node 0 sent a message to Node 4 at 1739422024089
Node 4 received a message from Node 0 with timestamp 1739422024089
Node 4 updated its local clock to 1739422024107
Node 2 sent a message to Node 4 at 1739422024096
Node 4 received a message from Node 2 with timestamp 1739422024096
Node 4 updated its local clock to 1739422024108
Node 1 sent a message to Node 4 at 1739422024106
Node 4 received a message from Node 1 with timestamp 1739422024106
Node 4 updated its local clock to 1739422024109
Node 3 sent a message to Node 2 at 1739422024106
Node 2 received a message from Node 3 with timestamp 1739422024106
Node 2 updated its local clock to 1739422024107
Node 4 sent a message to Node 1 at 1739422024115
Node 1 received a message from Node 4 with timestamp 1739422024115
Node 1 updated its local clock to 1739422024116
Node 1 sent a message to Node 0 at 1739422024117
Node 0 received a message from Node 1 with timestamp 1739422024117
Node 0 updated its local clock to 1739422024118
Node 2 sent a message to Node 0 at 1739422024112
Node 0 received a message from Node 2 with timestamp 1739422024112
Node 0 updated its local clock to 1739422024119
PS E:\GIt\Sem-8\DC\Lab5>
```