Sri Sivasubramaniya Nadar College of Engineering, Kalavakkam
(An Autonomous Institution, Affiliated to Anna University, Chennai)

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

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Assignment: Simulation of IP-Based Routing in a Multi-Node Network Using SimPy

Application: Multi-Network Data Communication System

An organization consists of multiple departments connected through a network of routers. Each department has a separate IP network, and end devices communicate with devices located within the same network or in different networks.

When a packet is generated, the network must examine the **destination IP address**, identify the corresponding destination network, and forward the packet through appropriate routers. Each router uses its routing table to select the next-hop router until the packet reaches its destination.

As a Network Engineer, develop a **discrete-event simulation using SimPy** to model a multi-node IP network. The simulation should represent end nodes, routers, communication links, packet generation, routing-table lookup, next-hop selection, router processing delay, link transmission delay, and packet delivery.

1a. SimPy-Based Network Node Simulation

Using the **SimPy Environment**, create a network consisting of multiple end nodes and routers.

Develop a SimPy-based network node module with the following functionalities:

1. Create a `simpy.Environment()` to manage the simulation events.

2. Create at least:
    - Six end nodes
    - Three routers
3. Assign each node:
    - Node ID
    - IP Address
    - Node Type
4. Use SimPy processes to generate packets at specified simulation times.
5. Each generated packet should contain:
    - Packet ID
    - Source IP Address
    - Destination IP Address
    - Payload
    - Packet Generation Time
    - Current Hop Count
    - Routing Path
6. Use `yield env.timeout()` to simulate packet generation intervals and communication delays.
7. Record the simulation time at which each packet is generated.

1b. SimPy-Based Router and Routing Process

Develop a **Router class or process using SimPy** to simulate packet forwarding.

Each router should:

1. Maintain a routing table containing:
    - Destination Network
    - Next-Hop Router
2. Receive packets through a simulated communication link.
3. Examine the destination IP address of the packet.
4. Identify the destination network using the IP address and subnet information.
5. Search the routing table for a matching destination network.
6. Select the appropriate next-hop router.
7. Simulate router processing delay using:

```
yield env.timeout(router_processing_delay)
```

8. Increase the packet hop count.
9. Add the router name to the packet routing path.
10. Forward the packet to the next router using a SimPy process.
11. Drop the packet if no matching route is available.

1c. SimPy-Based Communication Link Simulation

Develop a SimPy-based communication link between network devices.

The communication link should:

1. Connect:

    - End Node to Router
    - Router to Router
    - Router to Destination Node
2. Simulate link transmission delay using `yield env.timeout()`.
3. Record the time at which a packet enters and leaves the communication link.
4. Deliver the packet to the next node after the simulated delay.
5. Maintain the packet path during transmission.

The communication process may be represented as:

```
Packet Generated
       ↓
SimPy Timeout (Link Delay)
       ↓
Router Processing
       ↓
Routing Table Lookup
       ↓
SimPy Timeout (Processing Delay)
       ↓
Next-Hop Selection
       ↓
Forward Packet
```

1d. Network Topology and IP Address Configuration

Create the following multi-node network topology in the SimPy simulation:

```
Network A                 Network B                 Network C

PC1 ---- R1 ------------ R2 ------------ R3 ---- PC5
PC2       |               |               |
          |               |               |
         PC3             PC4             PC6
```

IP Address Configuration

Node	Node Type	IP Address	Network
PC1	End Node	192.168.1.10	192.168.1.0/24
PC2	End Node	192.168.1.20	192.168.1.0/24
PC3	End Node	192.168.1.30	192.168.1.0/24
R1	Router	192.168.1.1	Network A
PC4	End Node	192.168.2.10	192.168.2.0/24
R2	Router	192.168.2.1	Network B
PC5	End Node	192.168.3.20	192.168.3.0/24
PC6	End Node	192.168.3.30	192.168.3.0/24
R3	Router	192.168.3.1	Network C

1e. Routing Table Configuration

Configure the following routing tables in the SimPy simulation.

Router R1

Destination Network	Next Hop
192.168.1.0/24	Directly Connected
192.168.2.0/24	R2
192.168.3.0/24	R2

Router R2

Destination Network	Next Hop
192.168.1.0/24	R1
192.168.2.0/24	Directly Connected
192.168.3.0/24	R3

Router R3

Destination Network	Next Hop
192.168.1.0/24	R2
192.168.2.0/24	R2
192.168.3.0/24	Directly Connected

1f. SimPy-Based Packet Routing Scenarios

Using SimPy processes and events, simulate the following scenarios.

Scenario 1 – Same Network Communication

Generate packets from:

```
PC1 (192.168.1.10) → PC2 (192.168.1.20)
```

The simulation should identify that both devices belong to the same network.

Analyze:

- Packet generation time
- Selected routing path
- Hop count
- Packet delivery time
- End-to-end delay

Scenario 2 – Adjacent Network Communication

Generate packets from:

`PC1 (192.168.1.10) → PC4 (192.168.2.10)`

The expected routing path is:

`PC1 → R1 → R2 → PC4`

Simulate:

- Link delay
- Router processing delay
- Routing-table lookup
- Next-hop selection

Analyze:

- Number of routers traversed
- Hop count
- End-to-end delay
- Router processing time

Scenario 3 – Multi-Hop Routing

Generate packets from:

`PC2 (192.168.1.20) → PC5 (192.168.3.20)`

The expected path is:

`PC2 → R1 → R2 → R3 → PC5`

Use SimPy events to simulate packet movement through each router.

Analyze:

- Router-wise forwarding events
- Hop count
- Simulation time at each event
- Total end-to-end delay

Scenario 4 – Reverse Path Routing

Generate packets from:

`PC6 (192.168.3.30) → PC3 (192.168.1.30)`

Expected routing path:

`PC6 → R3 → R2 → R1 → PC3`

Analyze whether the routing tables correctly support packet delivery in the reverse direction.

Scenario 5 – Unreachable Destination

Generate packets from:

`PC1 (192.168.1.10) → 192.168.4.10`

The network `192.168.4.0/24` is not configured in any router's routing table.

The SimPy simulation should:

1. Generate the packet.
2. Forward it to the first router.
3. Perform routing-table lookup.
4. Identify that no valid route exists.
5. Drop the packet.
6. Record the packet-drop event and simulation time.

1g. Test Cases for Laboratory Verification

Test Case	Source	Destination	Expected Routing Path	Expected Result
TC1	PC1	PC2	PC1 → PC2	Successfully Delivered
TC2	PC1	PC4	PC1 → R1 → R2 → PC4	Successfully Delivered
TC3	PC2	PC5	PC2 → R1 → R2 → R3 → PC5	Successfully Delivered
TC4	PC6	PC3	PC6 → R3 → R2 → R1 → PC3	Successfully Delivered
TC5	PC1	192.168.4.10	No Valid Route	Packet Dropped

1h. Sample Simulation Parameters

Use the following values for the SimPy simulation:

Parameter	Value
Number of End Nodes	6
Number of Routers	3

Parameter	Value
Number of Networks	3
Network Prefix	/24
Router Processing Delay	5 ms
Link Transmission Delay	10 ms
Packet Generation Interval	100 ms
Packet Size	512 bytes
Number of Packets per Test	5

Sample Output – SimPy Routing Simulation

```
SIMPY IP ROUTING SIMULATION

Simulation Time: 0.000 s
Packet P1 Generated

Source IP      : 192.168.1.20
Destination IP : 192.168.3.20

Time: 0.010 s
Packet P1 reached Router R1

Time: 0.015 s
R1 Processing Packet P1

Routing Decision:
Destination Network : 192.168.3.0/24
Next Hop            : R2

Time: 0.025 s
Packet P1 reached Router R2

Time: 0.030 s
R2 Processing Packet P1

Routing Decision:
Destination Network : 192.168.3.0/24
Next Hop            : R3

Time: 0.040 s
Packet P1 reached Router R3

Time: 0.045 s
R3 Processing Packet P1

Destination Network Directly Connected

Time: 0.055 s
```

```
Packet P1 Delivered to PC5

Routing Path:
PC2 → R1 → R2 → R3 → PC5

Hop Count          : 3
End-to-End Delay   : 55 ms

Status: DELIVERED
```

Performance Observation Table – Sample Reference Values

Test Case	Routing Path	Routers Traversed	Hop Count	Packets Sent	Packets Delivered	Packets Dropped	Avg. End-to-End Delay
TC1	PC1 → PC2	0	0	5	5	0	10 ms
TC2	PC1 → R1 → R2 → PC4	2	2	5	5	0	40 ms
TC3	PC2 → R1 → R2 → R3 → PC5	3	3	5	5	0	55 ms
TC4	PC6 → R3 → R2 → R1 → PC3	3	3	5	5	0	55 ms
TC5	No Valid Route	1	0*	5	0	5	N/A

*The packet is dropped when the router cannot find a matching destination network.

Analysis

Analyze the simulation based on:

1. How SimPy events model packet movement between nodes.
2. How `yield env.timeout()` represents:
    - Link transmission delay
    - Router processing delay
    - Packet generation interval
3. How the destination IP address is used to identify the destination network.
4. How routing tables determine the next-hop router.
5. The relationship between hop count and end-to-end delay.
6. The difference between same-network and multi-network communication.
7. The effect of additional routers on packet delivery time.
8. How the simulation handles packets with unreachable destination IP addresses.

Expected Deliverables

- SimPy-based Network Simulation Program
- SimPy Environment Configuration
- Network Node and Router Classes
- IP Address Configuration
- Routing Tables
- Packet Generation Process
- Router Forwarding Process
- Sample Input and Output
- Test Case Results
- Performance Observation Table
- Routing Path Analysis
- Conclusion

Note

Students should record the following in the laboratory record:

1. Aim
2. Problem Analysis
3. SimPy-based Algorithm/Flowchart
4. Network Topology and IP Configuration
5. Routing Table Configuration
6. SimPy-Based Node and Router Design
7. Source Code
8. Sample Input and Output
9. Test Cases and Results
10. Performance Observation Table
11. Routing Analysis
12. Conclusion

Expected Learning Outcome – K4

Students will **analyze IP-based packet routing in a multi-node network using SimPy** by modelling packet generation, discrete simulation events, routing-table lookup, next-hop selection, hop-by-hop forwarding, and packet delivery. Students will evaluate the impact of **routing paths, hop count, router processing delay, and link delay** on end-to-end network performance.