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 a Multi-Technology Wireless Network Using SimPy

Application: Smart Campus Communication Network

A smart campus consists of multiple interconnected devices such as smartphones, laptops, environmental sensors, smart lights, wearable devices, and security systems. These devices use different wireless communication technologies based on their communication requirements.

For example, **Wi-Fi** is used for high-speed communication between laptops, mobile devices, and access points; **Bluetooth** is used for short-range communication between smartphones and wearable devices; and **Zigbee** is used for low-power communication between sensors, smart lights, and environmental monitoring devices.

As a Network Engineer, develop a **SimPy-based simulation** of a wireless network consisting of multiple nodes communicating with each other. Assign **Wi-Fi, Bluetooth, and Zigbee technologies** to different nodes and simulate packet generation, transmission, communication delay, packet loss, and reception. Analyze the performance of different wireless technologies under varying network conditions.

1a. Wireless Node Simulation Using SimPy

Develop a **Wireless Node module using SimPy** with the following functionalities:

1. Create multiple wireless nodes in the simulated network.
2. Assign a unique:

    - Node ID
    - Node Type
    - Wireless Technology
3. Configure each node with one of the following communication technologies:
    - Wi-Fi
    - Bluetooth
    - Zigbee
4. Assign appropriate communication parameters for each technology, such as:
    - Communication range
    - Data transmission rate
    - Packet size
    - Transmission delay
    - Packet-loss probability
5. Generate data packets periodically using a SimPy process.
6. Each packet should contain:
    - Packet ID
    - Source Node ID
    - Destination Node ID
    - Wireless Technology
    - Generation Time
    - Payload
7. Select a destination node based on the communication scenario.
8. Record the number of:
    - Packets generated
    - Packets transmitted
    - Packets successfully delivered
    - Packets lost

1b. Wireless Channel Simulation Using SimPy

Develop a **Wireless Channel module using SimPy** with the following functionalities:

1. Receive packets transmitted by wireless nodes.
2. Verify whether the source and destination nodes are within the communication range.
3. Identify the wireless technology used for communication.
4. Simulate the transmission delay based on the selected technology.
5. Introduce random packet loss during transmission.
6. Deliver successfully transmitted packets to the destination node.
7. Drop packets when:
    - The destination is outside the communication range.
    - A simulated packet-loss event occurs.
8. Record:
    - Transmission time
    - Packet delivery time
    - Packet loss
    - Communication technology used

1c. Wireless Receiver Node Simulation

Develop a **Receiver Node module using SimPy** with the following functionalities:

1. Receive packets from other nodes.
2. Record the packet arrival time.
3. Calculate the transmission delay using:

Packet Delay=Packet Arrival Time−Packet Generation Time

4. Verify the source and destination information.
5. Record successfully received packets.
6. Identify missing or lost packets using packet sequence numbers.
7. Maintain statistics for:
    - Packets received
    - Packets lost
    - Average delay
    - Minimum delay
    - Maximum delay
    - Packet Delivery Ratio

1d. Assign Wireless Technologies to Different Nodes

Create a network with at least **nine wireless nodes** and assign communication technologies as follows:

Wi-Fi Nodes

- Node W1 – Laptop
- Node W2 – Smartphone
- Node W3 – Smart Camera

Bluetooth Nodes

- Node B1 – Smartphone
- Node B2 – Smart Watch
- Node B3 – Wireless Sensor

Zigbee Nodes

- Node Z1 – Temperature Sensor
- Node Z2 – Smart Light
- Node Z3 – Environmental Sensor

1e. Simulate Communication Scenarios

Perform the following communication scenarios.

Scenario 1 – Wi-Fi Communication

Simulate communication between Wi-Fi-enabled devices.

Example:

```
Laptop (W1) → Smartphone (W2)
```

Analyze:

- Packet delivery
- Transmission delay
- Packet loss
- Throughput

Scenario 2 – Bluetooth Communication

Simulate short-range communication between Bluetooth-enabled devices.

Example:

```
Smartphone (B1) → Smart Watch (B2)
```

Analyze:

- Communication delay
- Packet delivery
- Packet loss
- Effect of communication range

Scenario 3 – Zigbee Communication

Simulate low-power communication between Zigbee-enabled IoT devices.

Example:

```
Temperature Sensor (Z1) → Smart Light (Z2)
```

Analyze:

- Packet delivery
- Transmission delay
- Packet loss
- Performance under low data rate conditions

Scenario 4 – Multiple Nodes Communicating Simultaneously

Simulate multiple nodes generating packets simultaneously.

Example:

```
W1 → W2
W3 → W1
B1 → B2
B3 → B1
Z1 → Z2
```

```
Z3 → Z1
```

Analyze:

- Total packets transmitted
- Total packets received
- Packet loss
- Communication delay
- Performance of each wireless technology

Scenario 5 – Out-of-Range Communication

Place selected source and destination nodes outside the communication range.

Example:

```
Bluetooth Node B1 → Bluetooth Node B3
```

The simulation should identify that the destination node is outside the Bluetooth communication range and drop the packet.

Analyze:

- Packets dropped due to range limitations
- Effect of node distance on communication reliability

1f. Sample Data for Laboratory Verification

Node Configuration

Node ID	Device	Technology	Communication Range	Data Rate
W1	Laptop	Wi-Fi	100 m	50 Mbps
W2	Smartphone	Wi-Fi	100 m	50 Mbps
W3	Smart Camera	Wi-Fi	100 m	50 Mbps
B1	Smartphone	Bluetooth	10 m	2 Mbps
B2	Smart Watch	Bluetooth	10 m	2 Mbps
B3	Wireless Sensor	Bluetooth	10 m	2 Mbps
Z1	Temperature Sensor	Zigbee	50 m	250 Kbps
Z2	Smart Light	Zigbee	50 m	250 Kbps
Z3	Environmental Sensor	Zigbee	50 m	250 Kbps

Test Cases for Laboratory Verification

TC1 – Wi-Fi Communication

Parameter	Value
Source Node	W1

Parameter	Value
Destination Node	W2
Number of Packets	20
Packet Size	1 KB
Packet Generation Interval	0.2 s
Packet Loss Probability	2%
Random Delay	5–20 ms

Expected Result:

- Most packets should be successfully delivered.
- Wi-Fi should show relatively low delay and high throughput.

TC2 – Bluetooth Communication

Parameter	Value
Source Node	B1
Destination Node	B2
Number of Packets	15
Packet Size	256 bytes
Packet Generation Interval	0.5 s
Packet Loss Probability	5%
Random Delay	10–50 ms

Expected Result:

- Packets should be delivered when nodes are within range.
- Higher delay may be observed compared to Wi-Fi.

TC3 – Zigbee Communication

Parameter	Value
Source Node	Z1
Destination Node	Z2
Number of Packets	20
Packet Size	100 bytes
Packet Generation Interval	1 s
Packet Loss Probability	3%
Random Delay	20–100 ms

Expected Result:

- Most packets should be delivered.
- Zigbee communication should show lower throughput but suitable performance for sensor communication.

TC4 – Simultaneous Communication

Parameter	Value
Number of Active Nodes	6
Wi-Fi Connections	W1 → W2, W3 → W1
Bluetooth Connections	B1 → B2, B3 → B1
Zigbee Connections	Z1 → Z2, Z3 → Z1
Simulation Time	30 seconds

Expected Result:

- Multiple packets are transmitted simultaneously.
- Compare delay and packet delivery for Wi-Fi, Bluetooth, and Zigbee.

TC5 – Out-of-Range Communication

Parameter	Value
Source Node	B1
Destination Node	B3
Distance	25 m
Bluetooth Range	10 m
Number of Packets	10

Expected Result:

```
Packet Transmission Failed
Reason: Destination Node Outside Communication Range
```

Sample Output – Wi-Fi Node

```
SIMPY WIRELESS NETWORK SIMULATION

Node ID       : W1
Technology    : Wi-Fi
Destination   : W2

Packet 1 Generated at 0.20 s
Packet 1 Transmitted

Packet 1 Received by W2
Arrival Time : 0.215 s
Delay        : 15 ms

Packet 2 Generated at 0.40 s
Packet 2 Transmitted
```

```
Packet 2 Received by W2
Arrival Time : 0.412 s
Delay        : 12 ms

...

Total Packets Generated : 20
Packets Delivered       : 19
Packets Lost            : 1
Packet Delivery Ratio   : 95%
```

Sample Output – Bluetooth Node

```
BLUETOOTH COMMUNICATION

Source Node      : B1
Destination Node : B2

Packet 1 Generated
Packet 1 Transmitted

Packet Received Successfully
Delay : 35 ms

...

Packets Generated : 15
Packets Received  : 14
Packets Lost      : 1

Average Delay     : 32 ms
```

Sample Output – Zigbee Node

```
ZIGBEE COMMUNICATION

Source Node      : Z1
Destination Node : Z2

Packet 1 Generated
Packet Transmitted

Packet Received Successfully
Delay : 75 ms

...

Packets Generated : 20
Packets Received  : 19
```

```
Packets Lost      : 1

Average Delay     : 72 ms
```

Performance Observation Table – Sample Results

Technology	Packets Generated	Packets Received	Packets Lost	Packet Delivery Ratio	Avg. Delay	Throughput
Wi-Fi	20	19	1	95%	14.8 ms	48.2 Mbps
Bluetooth	15	14	1	93.33%	34.6 ms	1.75 Mbps
Zigbee	20	19	1	95%	72.4 ms	210 Kbps

Calculation of Performance Metrics

1. Packet Delivery Ratio

Packet Delivery Ratio=Packets ReceivedPackets Generated×100\text{Packet Delivery Ratio} = \frac{\text{Packets Received}}{\text{Packets Generated}} \times 100

For Wi-Fi:

1920×100=95%\frac{19}{20} \times 100 = 95\%

2. Packets Lost

Packets Lost=Packets Generated−Packets Received\text{Packets Lost} = \text{Packets Generated} - \text{Packets Received}

3. Average Delay

Average Delay=Sum of Packet DelaysPackets Received\text{Average Delay} = \frac{\text{Sum of Packet Delays}}{\text{Packets Received}}

4. Throughput

Throughput=Successfully Received DataTotal Simulation Time\text{Throughput} = \frac{\text{Successfully Received Data}}{\text{Total Simulation Time}}

Extended Performance Observation Table

The following table can also be used for a more detailed laboratory analysis.

Technology	Generated	Received	Lost	Loss Ratio	Delivery Ratio	Min. Delay	Max. Delay	Avg. Delay	Throughput
Wi-Fi	20	19	1	5%	95%	6 ms	22 ms	14.8 ms	48.2 Mbps

Technology	Generated	Received	Lost	Loss Ratio	Delivery Ratio	Min. Delay	Max. Delay	Avg. Delay	Throughput
Bluetooth	15	14	1	6.67%	93.33%	12 ms	48 ms	34.6 ms	1.75 Mbps
Zigbee	20	19	1	5%	95%	28 ms	98 ms	72.4 ms	210 Kbps

Sample Results for Simultaneous Communication (TC4)

Technology	Active Nodes	Packets Generated	Packets Received	Packets Lost	Delivery Ratio	Avg. Delay
Wi-Fi	2	40	37	3	92.5%	18.6 ms
Bluetooth	2	30	27	3	90%	42.3 ms
Zigbee	2	40	37	3	92.5%	85.7 ms

Out-of-Range Communication Result (TC5)

Source	Destination	Technology	Distance	Range	Packets Sent	Packets Received	Packets Lost
B1	B3	Bluetooth	25 m	10 m	10	0	10

Expected Output:

```
Source Node      : B1
Destination Node : B3
Technology       : Bluetooth
Distance         : 25 m
Communication Range : 10 m

Packet Transmission Failed
Reason: Destination Node Outside Communication Range

Packets Generated : 10
Packets Received  : 0
Packets Lost      : 10
Packet Delivery Ratio : 0%
```

Result Analysis

Parameter	Wi-Fi	Bluetooth	Zigbee
Data Rate	High	Medium	Low
Communication Range	High	Low	Medium
Average Delay	Lowest	Moderate	Highest
Throughput	Highest	Moderate	Lowest

Parameter	Wi-Fi	Bluetooth	Zigbee
Suitable Application	Video/Data Transfer	Wearables	IoT Sensors

Analysis and Comparison

Analyze the simulation results based on:

1. **Communication Range:** Compare the communication ranges of Wi-Fi, Bluetooth, and Zigbee.
2. **Packet Delivery:** Compare the packet delivery ratios.
3. **Transmission Delay:** Identify the technology with the lowest and highest average delay.
4. **Packet Loss:** Analyze the impact of packet-loss probability on each technology.
5. **Throughput:** Compare the data transmission capabilities of the three technologies.
6. **Multiple Communication:** Analyze network performance when multiple nodes communicate simultaneously.
7. **Range Limitation:** Examine the effect of node distance on successful packet delivery.
8. **Technology Selection:** Recommend a suitable wireless technology for:
    - High-speed data communication
    - Short-range personal communication
    - Low-power IoT and sensor networks

Conclusion

- **Wi-Fi** provides the **highest throughput and lowest delay**, making it suitable for high-speed applications such as video streaming and smart cameras.
- **Bluetooth** is suitable for **short-range communication** between personal devices and wearable systems.
- **Zigbee** provides **low data rate and higher delay**, but is well suited for low-power IoT and sensor-based applications.
- Communication range significantly affects packet delivery, as demonstrated in the out-of-range Bluetooth scenario.

Note

Students should record the following in the laboratory record:

1. Aim
2. Problem Analysis
3. SimPy-based Algorithm/Flowchart
4. Wireless Node Simulation Program
5. Wireless Channel Simulation Program
6. Receiver Node Simulation Program
7. Sample Input and Output
8. Screenshots of Simulation Execution
9. Test Cases and Results
10. Performance Observation Table
11. Comparative Analysis

12. Conclusion

Expected Learning Outcome – K4

Students will **analyze a multi-node wireless network** by modelling packet generation, transmission, delay, packet loss, and communication range using **SimPy**. Students will compare the performance of **Wi-Fi, Bluetooth, and Zigbee** and evaluate their suitability for different real-world wireless communication applications.