Internet of Things
Challenge 1

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1 Optimizing Sink Position in a Wireless Sensor Network

1.1 Problem Data

System Parameters:

```
b = 2000          # Packet size [bit]
Ec = 50e-9        # Circuitry Energy [J/bit]
Eb = 5e-3         # Inital Sensor Energy [J]
T = 10 * 60       # Period [s]
k = 1e-9          # Transmission Energy Constant [J/bit/m^2]
```

Sensor Positions:

```
sensors = np.array([
    [1, 2], [10, 3], [4, 8], [15, 7], [6, 1],
    [9, 12], [14, 4], [3, 10], [7, 7], [12, 14]
])
```

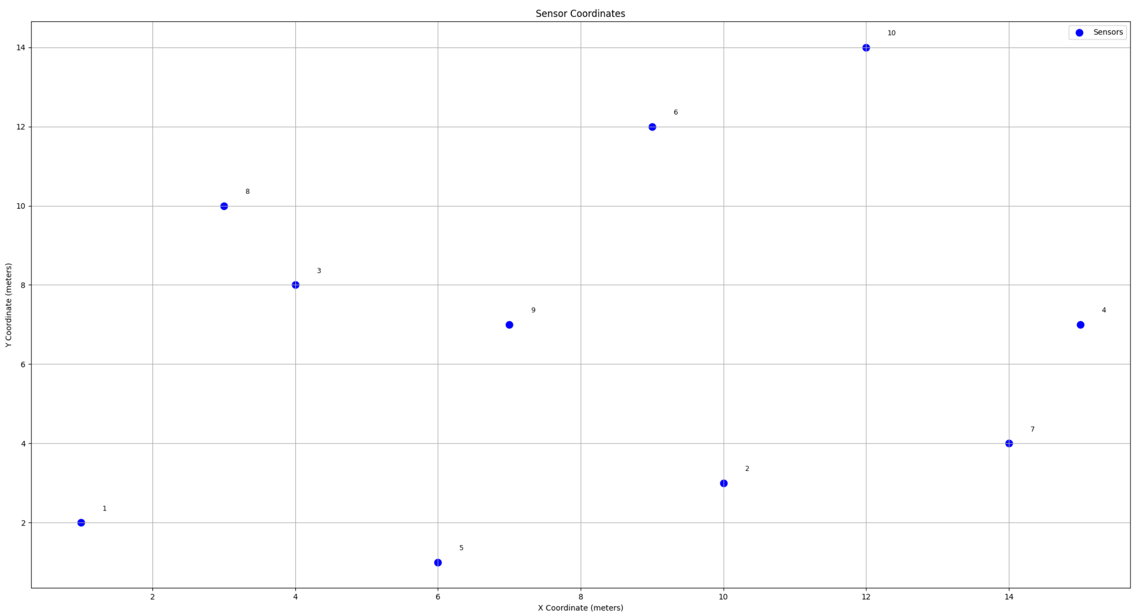

Figure 1: Sensor positions in the parking area

1.2 A. Find the Lifetime of the System

The objective is to compute the system lifetime when the sink is placed at the fixed position $(x_s, y_s) = (20, 20)$. The system lifetime is defined as the time until the first sensor depletes its battery, which corresponds to the worst-case sensor $\implies$ the one consuming the most energy per transmission cycle.

```python
# Function to compute energy consumption for each sensor given the
    sink position
def energy_per_sensor(sink):
    sink_x, sink_y = sink
    distances = np.sqrt((sensors[:, 0] - sink_x) ** 2 + (sensors[:,
    1] - sink_y) ** 2)
    # Energy consumption per sensor: circuitry + transmission
    E = b * Ec + b * k * distances ** 2
    return E

sink_fixed = (20, 20)
E_each_sensor = energy_per_sensor(sink_fixed)

# Compute how many cycles each sensor can perform before battery
    depletion
N_cycles_per_sensor = Eb / E_each_sensor

# System lifetime is determined by the sensor that depletes first (
    minimum cycles)
lifetime = np.min(N_cycles_per_sensor) * T
```

Result: The system lifetime with the sink located at $(20, 20)$ is:

$$\boxed{2040.82 \text{ seconds } (\approx\ 0.57 \text{ hours})}$$

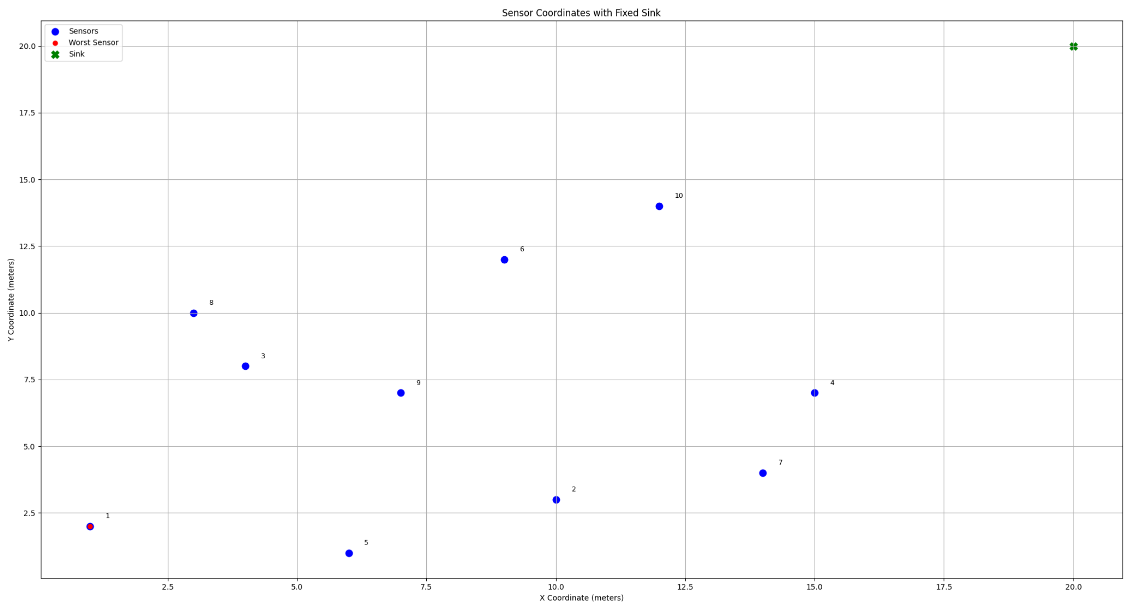

Figure 2: Sensor network with the sink at (20, 20) and the worst-case sensor highlighted

1.3 B. Find the Optimal Position of the Sink

The goal is to minimize the energy consumption of the worst-case sensor by optimizing the sink position within the network.
Mathematically, this optimization problem is defined as:

$$\min_{(x_s,y_s)} \left[\max_i \left(E_i(x_s, y_s)\right)\right]$$

where the energy consumption of each sensor is given by:

$$E_i(x_s, y_s) = b \cdot E_c + b \cdot k \cdot d_i^2$$

and d_i represents the Euclidean distance between sensor i and the sink at position (x_s, y_s).
The following Python code performs the optimization using the `SLSQP` method:

```python
from scipy.optimize import minimize

# Objective function: minimize the maximum energy consumption across all sensors
# for a given sink position (x_s, y_s)
def objective(sink):
    return np.max(energy_per_sensor(sink))

# Perform the optimization to find the optimal sink position
result = minimize(
    objective,          # Function to minimize
    np.array([20, 20]), # Initial guess for the sink position
    method='SLSQP',     # Sequential Least Squares Programming optimizer
    tol=1e-12           # High precision tolerance
)

# Extract the optimal sink coordinates (x_s, y_s) from the optimization result
optimal_sink = result.x
```

Result: The optimal sink position that minimizes the worst-case energy consumption is

$$\boxed{(6.87, 7.66)}$$

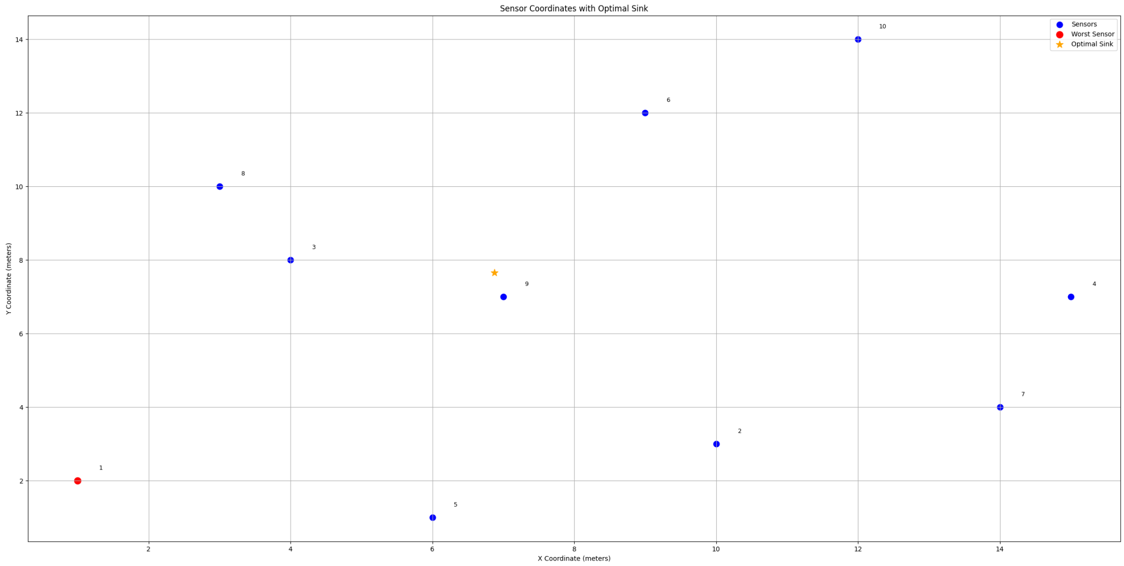

Figure 3: Sensor network with optimal sink position minimizing worst-case energy consumption

1.4 C. Discuss the Trade-Offs

Trade-offs:

- **Fixed Sink:**
  - Simple, low cost, and easy to manage.
  - Ensures a balanced distance from all sensors when placed optimally.
  - System lifetime is limited by the farthest sensor.
- **Dynamic Sink:**
  - Potentially balances energy usage over time by adjusting its position.
  - Requires mobility mechanisms and complex control algorithms.
  - If the movement is significant, it may increase the energy consumption of some distant sensors, deteriorating the overall system lifetime.
  - Frequent repositioning may not bring noticeable improvements if the optimal fixed position already minimizes the worst-case energy consumption.

Conclusion: In this specific scenario, the optimal fixed sink position already minimizes the energy consumption of the worst sensor by balancing distances. Dynamically moving the sink might momentarily improve energy usage for some sensors but would simultaneously increase consumption for others, potentially worsening the system lifetime. Therefore dynamic positioning does not significantly outperform a well-optimized fixed position. A stationary sink remains the best choice in this case, ensuring maximum lifetime and minimal complexity.