WiFi Access Point Optimization in an Office Building

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This code addresses the problem of optimizing WiFi coverage in a multi-floor office building. The goal is to **minimize the number of WiFi access points** (APs) installed while ensuring that every desk in the building is within a specified distance threshold for good signal strength.

Problem Description

- **Objective**: Minimize the number of WiFi access points while ensuring full coverage.
- **Constraints**:
  - Every desk must be within a certain distance (750 cm) of at least one access point.
  - Access points can only cover desks within this distance threshold.
- **Building Specifications**:
  - Floors: 7
  - Rows per floor: 20
  - Columns per floor: 7
  - Floor height: 3 meters
  - Row length: 1.5 meters
  - Column width: 2.5 meters

Approach

The problem is formulated as a **set covering problem** and solved using linear programming with the PuLP library. The key steps include:

1. **Modeling the Building Layout**: Generating the locations of all desks and potential access point positions.
2. **Calculating Distances**: Computing the Euclidean distance between every desk and every access point.
3. **Formulating the Optimization Problem**: Defining variables, objective function, and constraints.
4. **Solving the Problem**: Using PuLP to find the optimal placement of access points.
5. **Visualizing the Solution**: Plotting the desks and chosen access points in a 3D space.

Code Explanation

Importing Libraries

```
import pulp
import random
import math
```

```
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
```

- **pulp**: For formulating and solving the optimization problem.
- **random** and **math**: For generating locations and calculating distances.
- **matplotlib.pyplot** and **Axes3D**: For plotting the 3D visualization.

Setting Parameters

```
random.seed(1)
```

Setting seed for random generation for a predictable, repetitive result.

```
floors = 7
rows = 20
columns = 7
num_points = 200
floor_height = 3
row_length = 1.5
column_width = 2.5
random_generated_ap_locations = False
S = 750
```

- **Building Dimensions**: Defined by `floors`, `rows`, and `columns`.
- **Physical Dimensions**: Real-world distances between points in the grid.
- **Distance Threshold (S)**: Maximum distance for good signal strength in centimeters.

Functions

1. `plot_solution`

Plots the desks and access points in 3D space.

```
def plot_solution(access_points, desks, chosen_access_point_keys):
    # Function body
```

- **Desks**: Plotted as blue squares.
- **Chosen Access Points**: Plotted as large green circles.
- **Unused Access Points**: Plotted as small red circles.

2. `calculate_distance`

Calculates the Euclidean distance between a desk and an access point.

```python
def calculate_distance(desk, access_point):
    # Function body
```

- Considers the physical dimensions (`floor_height`, `row_length`, `column_width`).
- Returns the distance in centimeters.

3. `generate_desk_locations`

Generates the positions of all desks in the building.

```python
def generate_desk_locations(floors=floors, rows=rows, columns=columns):
    # Function body
```

- Desks are placed at every grid point defined by the building dimensions.

4. `generate_access_points`

Generates potential positions for access points.

```python
def generate_access_points(num_points=num_points, floors=floors,
rows=rows, columns=columns,
random_locations=random_generated_ap_locations):
    # Function body
```

- If `random_locations` is `False`, access points are placed systematically throughout the building.
- Access points are slightly elevated (`floor + 0.8`) to simulate ceiling placement.

5. `calculate_distances`

Calculates distances between every desk and every access point.

```python
def calculate_distances(desk_locations, access_point_locations):
    # Function body
```

- Creates a distance matrix for use in the optimization problem.

The Optimization Problem

```python
def problem():
    # Function body
```

Steps:

1. **Generate Locations**:

   ```
   desk_locations = generate_desk_locations()
   access_point_locations = generate_access_points()
   desks = desk_locations.keys()
   access_points = access_point_locations.keys()
   ```

2. **Calculate Distances**:

   ```
   distance_matrix = calculate_distances(desk_locations,
   access_point_locations)
   ```

3. **Create Coverage Matrix**:

   ```
   a = {
       i: {j: 1 if distance_matrix[i][j] <= S else 0 for j in desks}
       for i in access_points
   }
   ```

   - `a[i][j] = 1` if access point `i` can cover desk `j`.

4. **Initialize the Problem**:

   ```
   plp = pulp.LpProblem("AssignmentProblem", pulp.LpMinimize)
   ```

5. **Define Variables**:

   ```
   y = pulp.LpVariable.dicts("y", (access_points), 0, 1, pulp.LpBinary)
   ```

   - `y[i]`: Binary variable indicating whether access point `i` is installed.

6. **Objective Function**:

   ```
   plp += pulp.lpSum(y[i] for i in access_points)
   ```

   - Minimize the total number of access points installed.

7. **Constraints**:

```
for j in desks:
    plp += pulp.lpSum(a[i][j] * y[i] for i in access_points) >= 1
```

   - Each desk must be covered by at least one access point.

8. **Solve the Problem**:

```
plp.solve()
```

9. **Output the Results**:

```
print("Status:", pulp.LpStatus[plp.status])
print("Minimum number of access points:", pulp.value(plp.objective))
chosen_access_points = [i for i in access_points if pulp.value(y[i])
== 1]
print("Chosen Access Points:", chosen_access_points)
```

10. **Plot the Solution**:

```
plot_solution(access_point_locations, desk_locations,
chosen_access_points)
```

Running the Optimization

```
problem()
```

- Executes the entire optimization process and outputs the results.

Visualization

The solution is visualized using a 3D scatter plot:

- **Blue Squares**: Desks.
- **Green Circles**: Chosen access points.
- **Red Circles**: Unused potential access points.

This helps in understanding the spatial distribution of desks and access points.

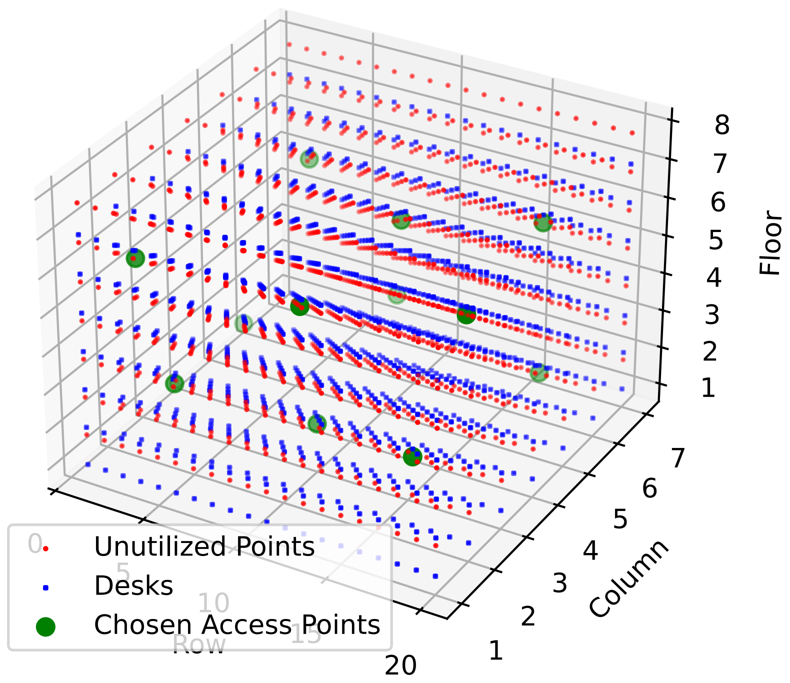
Example Output

```
Status: Optimal
Minimum number of access points: 42.0
Chosen Access Points: ['AP-1-2-2', 'AP-1-5-5', ..., 'AP-7-17-3']
```

- **Status**: Indicates that an optimal solution was found.
- **Minimum number of access points**: The least number required to cover all desks.
- **Chosen Access Points**: List of access points that need to be installed.

Visualized output

View in interactive form. Download the html file and open it with your browser.



Conclusion

The code efficiently solves the WiFi access point placement problem by:

- **Minimizing Costs**: Reducing the number of access points lowers installation and maintenance costs.
- **Ensuring Coverage**: All desks are within the required distance for good WiFi signal strength.
- **Scalability**: The approach can be adapted for buildings of different sizes and configurations.

By utilizing linear programming and spatial analysis, the solution provides a practical method for network planning in large office environments.

The code is accessible on GitHub