Title of the project: 5G Private Network Deployment Optimization Based on RWSSA in Open-Pit Mine
Group - 58

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Abstract:
The objective of this project is to implement and analyse an enhanced version of the Sparrow Search Algorithm (SSA) for optimizing 5G base station placement in a constrained environment. This involves simulating real-world deployment scenarios where the goal is to maximize signal coverage over a predefined area while avoiding overlap and adhering to various spatial constraints.
The algorithm incorporates realistic communication parameters like signal radius and effective range, and includes anti-clustering penalties and smooth convergence mechanisms. The enhanced SSA introduces role-based behaviours—producers and scroungers—as well as anti-predator movements to prevent local minima trapping. Additional features such as grid-based fitness evaluation, spatial visualization of coverage, and heatmap-based performance metrics were implemented.

Plan of Work:

1. **Understanding the problem:**
   - Identifying Dimensions to be optimized like Total coverage, Pit coverage, Clustering penalties, cost and Radius of base stations.
2. **Algorithm Analysis:**
   - Understanding the Sparrow Search Algorithm (SSA), which is inspired by the foraging and anti-predation behaviour of sparrows.
   - Incorporating base roles: producers (explorers) and scroungers (followers).The sparrows (representing 5G tower configurations) use a **fitness function** to evaluate the effectiveness of tower placement.
   - **Global Exploration (Discoverers Searching the Entire Mine)**
   - **Local Exploration (Joiners Fine-Tuning Around Discoverers)**
   - **Discoverers' Position Update Formula:**
   - $X_{ij}(t+1) = X_{ij}(t) \times \exp(-i / (\alpha \times T))$**, below the safety threshold, else**
     - $X_{ij}(t+1) = X_{ij}(t) + Q \times L$ **.**
   - **Scroungers' Position Update Formula:**
   - $X_{ij}(t+1) = Q \times \exp((Xw_j - X_{ij}(t)) / i^2)$**, if low fitness values, else**
   - $X_{ij}(t+1) = X\_best_j + |X_{ij}(t) - X\_best_j| \times A / A^T$

- **Implementation:**

- Understanding the Fitness Function in 5G Base Station Deployment:
    - The **fitness function** evaluates the quality of a solution (where the base stations are placed). The goal is to **max the fitness value.**
    - **High coverage** (more area covered by base stations) ✅
    - **Low interference** (less overlap between stations) ❌
    - **Low cost** (fewer or optimally placed stations) 💰
    - 30*total_coverage+ 20.0 * pit_reward +station_reward + efficiency_reward -5.0*placement_penalty -100.0 * clustering_penalty - scaled_cost + min_coverage_reward
- Custom implementation of SSA using Python with support for key parameters:
    - Signal Radius (Rs), Effective Range (Re), Lambda (λ).
    - Grid-based probability mapping for joint coverage evaluation.
- Handling constraints such as:
    - Restricted zones (obstacles).
    - Boundary avoidance buffers.
    - Minimum inter-station spacing to reduce clustering.
- Integration of cost modelling that considers both the number of base stations and signal radius, with premium costs for larger coverage radiuses to reflect real-world deployment economics.

- **Visualization & Analysis:**
    - Generated dynamic heatmaps representing signal coverage across the deployment area.
    - Circle overlays for Rs and Re to visualize inner and outer coverage.
    - Development of an interactive Streamlit application providing a user-friendly interface for algorithm parameter tuning, real-time visualization of optimization progress, and comprehensive result analysis.
- **Applications and Challenges:**
    - Balancing between coverage and clustering using fitness weights.
    - The implementation required balancing vectorized operations for performance with readable code that expresses the algorithm's intent.
    - The fitness function's components (coverage rewards, pit coverage priorities, clustering penalties, cost factors) exhibited high sensitivity to small parameter changes.

Reference paper: Z. Chang, Q. Gu, C. Lu, Y. Zhang, S. Ruan and S. Jiang, "5G Private Network Deployment Optimization Based on RWSSA in Open-Pit Mine," in *IEEE Transactions on Industrial Informatics*, vol. 18, no. 8, pp. 5466-5476, Aug. 2022, doi: 10.1109/TII.2021.3132041.