Ray-tracing Based RIS Size, Position and Target Points Optimization for Coverage Enhancement

Inputs:

- **The scene geometry:** A 3D representation of the area where coverage is to be enhanced, including obstacles, walls, etc.
- **Transmitter (TX) position:** Coordinates of the transmitter in the scene.
- **Minimum power threshold** P_{th}: The threshold for acceptable signal power, below which cells are considered low-power.
- **Range of possible target points** $\mathcal{N}$: The set of possible cluster counts to be used in K-means algorithm, e.g., $\mathcal{N} = \{1, 2, \ldots, 5\}$.
- **Set of possible RIS widths** $\mathcal{W}$: The set of candidate RIS widths, e.g., $\mathcal{W} = \{0.2, 0.4, \ldots, 3.0\}$ m.
- **Minimum performance improvement threshold** $\Delta\mathcal{M}_{\mathrm{min}}$: The minimum performance improvement required to justify increasing the RIS width.

Optimization Parameters:

- **Optimal number of target points** N^{opt}.
- **Optimal RIS width** $W_{\mathrm{RIS}}^{\mathrm{opt}}$.
- **Optimal RIS position** $\mathbf{r}_{\mathrm{RIS}}^{\mathrm{opt}}$.

Steps:

1. Compute the transmitter-only coverage map $\mathbf{P}_{\mathrm{TX}}(x, y)$.
2. Set a minimum power threshold P_{th} for acceptable signal quality.
3. Identify low-power cells in $\mathbf{P}_{\mathrm{TX}}(x, y)$ where the power level is below the minimum power threshold P_{th}, denoted as $\mathcal{C}_{\mathrm{low}}$:

$$\mathcal{C}_{\mathrm{low}} = \{(x, y) \mid \mathbf{P}_{\mathrm{TX}}(x, y) < P_{\mathrm{th}}\}$$

4. **For each** number of target points $N \in \mathcal{N}$:

   (a) Apply K-means algorithm to $\mathcal{C}_{\mathrm{low}}$ to group the low-power cells into N clusters and obtain N centroids:

   $$\text{K-means}(N, \mathcal{C}_{\mathrm{low}}) \rightarrow \text{Centroids } \{\mathbf{c}_1, \mathbf{c}_2, \ldots, \mathbf{c}_N\}$$

   where each centroid $\mathbf{c}_i$ represents a target point where coverage enhancement is needed.

(b) Identify the set of feasible RIS positions $\mathcal{R}_N$ that provide line-of-sight (LoS) to both the transmitter and all N target points:

$$\mathcal{R}_N = \{\mathbf{r}_{\text{RIS}} \mid \text{LoS}(\mathbf{r}_{\text{RIS}}, \mathbf{TX}) \wedge \text{LoS}(\mathbf{r}_{\text{RIS}}, \mathbf{c}_i) \ \forall \mathbf{c}_i\}$$

(c) **For each** RIS width $W_{\text{RIS}} \in \mathcal{W}$:

i. Compute the combined coverage $\mathbf{P}_{\text{comb}}(x, y)$ at each low-power cell, considering both TX and RIS contributions, for each RIS position $\mathbf{r}_{\text{RIS}} \in \mathcal{R}_N$.

ii. Calculate the performance metric $\mathcal{M}(\mathbf{r}_{\text{RIS}}, N, W_{\text{RIS}})$ for all parameter combinations as the average power of low-power cells after placing the RIS at $\mathbf{r}_{\text{RIS}}$:

$$\mathcal{M}(\mathbf{r}_{\text{RIS}}, N, W_{\text{RIS}}) = \frac{1}{|\mathcal{C}_{\text{low}}|} \sum_{(x,y)\in\mathcal{C}_{\text{low}}} \mathbf{P}_{\text{comb}}(x, y)$$

5. **Determine the optimal RIS configuration:**

(a) Identify the RIS configuration $(\mathbf{r}_{\text{RIS}}^{W_{\text{RIS}}}, N^{W_{\text{RIS}}}, W_{\text{RIS}})$ that maximizes the performance metric $\mathcal{M}$ for each W_{RIS}:

$$(\mathbf{r}_{\text{RIS}}^{W_{\text{RIS}}}, N^{W_{\text{RIS}}}) = \arg \max_{\mathbf{r}_{\text{RIS}}\in\mathcal{R}_N, N\in\mathcal{N}} \mathcal{M}(\mathbf{r}_{\text{RIS}}, N, W_{\text{RIS}})$$

(b) Select the smallest RIS width $W_{\text{RIS}}^{\text{opt}}$ for which increasing the RIS width further does not yield a performance improvement exceeding $\Delta\mathcal{M}_{\min}$. Assign corresponding parameters $\mathbf{r}_{\text{RIS}}^{\text{opt}} = \mathbf{r}_{\text{RIS}}^{W_{\text{RIS}}^{\text{opt}}}$ and $N^{\text{opt}} = N^{W_{\text{RIS}}^{\text{opt}}}$.

6. For multi-RIS deployment extension, each RIS is assigned to a subset of target points and the algorithm optimizes the size and position of each RIS independently.