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Response to Reviewers for Manuscript ID: OJAP-0169-2025

Original Article Title: "Ray-Tracing Based RIS Deployment Optimization for Indoor Coverage Enhancement"

Dear Editor,

We sincerely thank the Editor, Associate Editor, and Reviewers for their time, thoughtful feedback, and the opportunity to resubmit our manuscript. We have carefully addressed all comments and revised the manuscript accordingly.

We are submitting the following files:

(a) this point-by-point response to the reviewers' comments,

(b) a revised manuscript with changes highlighted in yellow, and

(c) a clean version of the revised manuscript without highlights.

Best regards,

Emre Kilcioglu and Claude Oestges

Reviewer 1:

This paper proposes a novel ray-tracing based joint optimization framework that simultaneously determines the RIS position, size, and target points to enhance indoor coverage, especially in blind spots due to blockage. The proposed method leverages ray-tracing simulations to provide physically consistent optimization based on a selected NLOS communication environment. The simulation results for different simulation parameters in an indoor office environment are reported, demonstrate that the improvement performance of coverage and signal quality in blind spots by optimizing RIS deployment parameters.

The paper is generally well structed and written, and presents a clear and concise description of the proposed method. Hence, the reviewer is rather positive to accept this paper after revisions. However, the reviewer wants to raise some important concerns, especially in the significance and detailed implementation of the paper.

Reviewer 1 - Comment 1: *In page 3, section 2, the authors choose the NVIDIA's open-source Sionna ray-tracing tool, can authors add some description compared with other RT tools, like, Wireless insite, to specify the advantage and efficiency of the Sionna.*

Author response: We thank the reviewer for this suggestion. We have added a comparative discussion at the beginning of Section II to clarify the reasoning for choosing Sionna RT over other commercial ray-tracing tools such as Wireless InSite. While both tools rely on physically consistent ray-tracing models, Sionna offers two key advantages: (1) it is fully open-source and customizable, allowing us to adapt the internal architecture and propagation settings to our RIS optimization framework, and (2) it supports GPU acceleration through TensorFlow, enabling us to process tens of thousands of rays in parallel, which significantly reduces simulation runtime. By contrast, Wireless InSite is closed-source, CPU-bound, and requires a commercial license. We believe this change better motivates our software selection and aligns with the reproducibility goals of the research.

Reviewer 1 - Comment 2: *The authors utilized two methods to determine the reflection behavior of the RIS, authors are suggested to provided some figures, like simulation result, to specify the features and differences of the two methods.*

Author response: We appreciate the reviewer's insightful comment regarding the RIS phase-profile design methods. They are described at the beginning of Section III of the manuscript.

- Gradient-based, which introduces a linear phase ramp across the RIS surface to steer reflections in a desired direction, based on the difference between the incident and reflected wave vectors,
- Distance-based, which aligns the total propagation path length (TX-RIS-target) at each tile to focus energy precisely at a desired target point.

While their effects on performance are already compared both analytically and visually in Section V through coverage maps (see Figs. 14, 15, 21, and 22 in the revised manuscript), we agree that a direct visual comparison of their phase profiles would enhance understanding.

Accordingly, we have added new subfigures to Figures 14 and 15, each showing the per-tile phase profile used in that scenario for each target point. We have also expanded the related discussion in Section V-E-5 to mention about these visualizations.

Reviewer 1 - Comment 3: *In practical scenario, real RIS prototype typical have initial response for each element. Besides, the RIS typical have limited phase resolution depending on RIS bits. How to add the RIS in RT simulation scenario via Sionna, and it may be different from RIS added into conventional Wireless insite software.*

Author response: We thank the reviewer for drawing attention to practical RIS hardware constraints. In our current project, we collaborate with our antenna team, whose prototype uses continuous-analog varactors. Therefore, we adopt a continuous-phase model in our simulations. NVIDIA Sionna's ray-tracing tool allows users to define an arbitrary two-dimensional array of complex reflection coefficients (both amplitude and phase) directly on each tile (see the Sionna RIS modeling documentations linked below). This modeling approach was already described starting from the third paragraph of Section II.

Discrete, bit-quantized RIS implementations can also be modeled by quantizing the continuous phase values to discrete levels based on the number of control bits (e.g., quantizing to the nearest 2π divided by 2^b for a b-bit RIS). Sionna then applies these per-tile coefficients during ray tracing without further approximation.

To better emphasize this modeling flexibility and its practical relevance, we have revised and clarified the third paragraph of Section II.

Related documentations of the Sionna RT regarding RIS modeling:

https://jhoydis.github.io/sionna-0.19.2-doc/em_primer.html

https://jhoydis.github.io/sionna-0.19.2-doc/api/rt.html#reconfigurable-intelligent-surfaces-ris

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Reviewer 1 - Comment 4: *The optimized parameters are calculated based on simulated coverage map, which requires modeling for actual scenario and exhaustive simulation, which may lead to large computation cost and overhead, especially for scenarios with many scatterers. So did the method have adjustable resolution, and did it influence the algorithm accuracy?*

Author response: We're grateful to the reviewer for pointing out the important trade-off between simulation resolution and computation cost. The Sionna RT coverage map module as implemented in the Scene.coverage_map() method (see the link below for the coverage map documentation of Sionna RT) provides several adjustable parameters that control the fidelity, granularity, and runtime of the coverage map calculation. The most relevant parameters are:

- max_depth: the maximum number of path bounces (reflections) considered per ray
- cm_cell_size: the size (in meters) of each grid cell in the coverage map
- num_samples: the total number of rays traced during simulation

Increasing the number of samples or decreasing the cell size results in higher-resolution and more accurate maps, at the cost of longer simulation times. In our study, we selected: max_depth = 6, cm_cell_size = [0.4, 0.4] meters, and num_samples = 20,000,000, which we found to provide a good balance between simulation granularity and runtime.

We emphasize that these parameters only affect the ray-tracing output and do not change anything related to the optimization algorithm we propose. Regardless of the coverage map resolution, our algorithm consistently identifies low-power cells, determines RIS target points, and optimizes the RIS configuration accordingly. We have added a new paragraph in the Simulation Parameters subsection of the manuscript to clarify these parameter choices.

Coverage map documentation of Sionna RT:

https://jhoydis.github.io/sionna-0.19.2-doc/api/rt.html#coverage-maps

https://jhoydis.github.io/sionna-0.19.2-doc/api/rt.html#sionna.rt.Scene.coverage_map

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Reviewer 1 - Comment 5: *The authors are suggested to list key parameters (like frequency, transmit power, RIS grid size, power threshold, etc.) in a table. Also, based on simulation results, the authors are suggest to provide a general guideline for the RIS location, size, and beamforming method.*

Author response: We're thankful for the reviewer's parameter table and deployment guideline suggestions. To improve clarity and reproducibility, we have added Table 2 in the Simulation Parameters subsection, which summarizes all key simulation parameters used in this study. A reference to this table is also included in the subsection text to help guide readers.

In addition, we have revised the Conclusion section to incorporate general design guidelines for RIS deployment based on the simulation results. These guidelines are scenario-dependent, which is specific to the U-shaped indoor office scenario studied in this paper, summarize practical insights into the optimal selection of RIS position, size, and beamforming method. Specifically: (1) the RIS should be mounted at locations with line-of-sight to both the transmitter and target points, with the final position selected to maximize the performance metric, (2) the RIS size should be increased until the performance improvement drops below a predefined performance improvement threshold, and (3) beamforming should be chosen based on the blind-spot geometry: gradient-based phase profiles provide more distributed coverage for broad or dispersed regions, while distance-based profiles offer improved energy focusing for small and confined areas. With your suggestion, we believe these additions significantly improve the practical relevance of the work.

Reviewer 1 - Comment 6: *Many RIS prototypes are designed to orthogonally polarized, which means the incident wave and reflected wave of the RIS are orthogonally polarized due to its design. Do you consider this issue, how to handle this issue in RT software?*

Author response: We appreciate the reviewer’s insightful comment regarding polarization issues of RISs. In the version of NVIDIA Sionna used in this study (v0.19.2), RIS elements are modeled using a single complex-valued reflection coefficient (amplitude and phase) per tile, with no support for polarization transformation. The RIS model applies this coefficient directly to the incident wave's electric field, preserving its polarization. For this reason, we assume co-polarized RIS operation throughout the simulations. While polarization effects are not within the scope of this work, we agree that this would be a valuable direction for future studies involving polarization-aware RIS designs or dual-polarized systems.

To reflect this assumption, we have added a clarifying footnote in Section II in page 4 where RIS modeling capabilities are described.

Reviewer 1 - Comment 7: *Do you consider the height of the RIS? The height of the Tx, RIS, and Rx may influence the coverage performance of RIS-aided systems due to difference of reflection paths.*

Author response: We thank the reviewer for this insightful comment. In our study, the vertical mounting height of the RIS is fixed at 1.5 meters, which matches the heights of both the transmitter and the target points. This allows a consistent comparison of path gains on a common horizontal plane. We clarify that the term "RIS height" used throughout the manuscript refers to the vertical aperture size of the RIS (i.e., its physical extent along the z-axis), whereas the mounting height denotes the z-coordinate of the RIS center in space.

Although a fixed mounting height is used in this paper, our approach is not limited to this setup. Any change in transmitter, RIS, or receiver elevation leads to a different coverage map computed by the ray-tracing tool. The proposed RIS optimization algorithm can then be applied to that new map without modification. Therefore, our framework generalizes naturally to other mounting height configurations and is not restricted to the specific elevation used in this study. We have added a new paragraph in the Simulation Parameters subsection to clearly distinguish between aperture size and mounting height and to explain how the ray-tracing model supports alternative height settings.

Reviewer 1 - Comment 8: *The authors are suggested to provide more take-home message in conclusion, such as the guideline for the RIS location, size, and beamforming method for the selected scenario based on the simulation results.*

Author response: Thank you for this valuable recommendation to strengthen the practical implications of our findings. In response to this comment as well as Comment 5, we have revised the Conclusion section to include scenario-specific design guidelines derived from our simulation results. These take-home messages summarize practical recommendations for selecting the RIS mounting position, aperture size, and beamforming strategy based on coverage needs.

Reviewer 2:

This paper proposes a ray-tracing framework for optimizing RIS deployment in indoor environments, focusing on joint design of position, size, and target points. While the topic is timely and the problem formulation has merit, the reviewer finds the current presentation and technical execution to require further refinement. Key concerns include insufficient motivation *for methodological choices, limited validation of assumptions, and ambiguities in interpreting critical figures.*

Reviewer 2 - Comment 1: ***[Page 4, Eq (1)]***

The reflection coefficient model for a single tile (RIS element) assumes a fixed amplitude profile. However, the reviewer notes that this may not fully account for practical considerations. While passive RIS elements inherently lack active amplification, their amplitude response can still exhibit angular dependency due to variations in incident angles. To enhance model accuracy and better reflect the directive properties of RIS, the authors are encouraged to incorporate angular-dependent attenuation effects into the reflection coefficient design. This adjustment would strengthen the alignment with real-world RIS behavior.

Author response: We appreciate the reviewer for this valuable comment. In this work, we adopt a fixed (unit) amplitude profile across the RIS tiles to isolate and analyze the pure effect of phase control on system performance and to maintain a manageable level of modeling complexity. This approach is commonly followed in ray-tracing based and optimization-focused RIS studies, where the dominant impact comes from phase alignment rather than small amplitude fluctuations.

For instance, in [1], the authors assume each RIS element is designed to maximize signal reflection and thus take the amplitude coefficient as unity for simplicity: "in practice, each element of the IRS is usually designed to maximize the signal reflection. Thus, we set $\beta_n = 1$." Similarly, [2] states that "in a conventional RIS implementation, it is the phase shift of the reflection coefficient of each element that is adjusted in order to achieve the desired effect on the wireless channels," further highlighting the modeling focus on only phase for simplicity.

Nevertheless, we fully agree that incorporating angular-dependent amplitude effects would increase physical realism. To explore this, we included a new simulation in our revised manuscript (Figures 16 and 17), where amplitude fluctuations were introduced by assigning each tile a random amplitude uniformly drawn from [0.7, 1]. The results demonstrate that both gradient-based and distance-based approaches are highly robust to such fluctuations, with performance degradation limited to only 1–1.5 dB in average path gain. The coverage maps also remain visually consistent.

These findings support the modeling choice of fixed amplitudes for phase-dominant optimization, especially in scenarios where angular-dependent attenuation is weak. Nonetheless, we agree that incorporating detailed amplitude effects could further enhance physical realism, and we identify this as a promising direction for future work, particularly when using hardware-calibrated or angle-sensitive RIS models.

We have added this discussion to Section V-E-6 under a new subsection titled "Effect of Amplitude Fluctuations on RIS Performance."

References:

[1] Q. Wu and R. Zhang, “Intelligent reflecting surface enhanced wireless network via joint active and passive beamforming,” IEEE Trans. Wireless Commun., vol. 18, no. 11, pp. 5394–5409, Nov. 2019.

[2] F. Rezaei, R. Ameri, and E. Basar, “RIS-assisted interference mitigation for uplink NOMA,” arXiv preprint arXiv:2301.13841, 2023.

Reviewer 2 - Comment 2: ***[Page 5, Sec III.A]***

The Gradient-Based Phase Profile design requires further clarification to improve readability. Specifically, the derivation of the incident phase gradient in Eq. (2) and its relationship to the final phase shift design are not explicitly detailed. The authors are advised to expand this section by explicitly connecting the phase gradient concept to the implemented phase shifts (e.g., through mathematical steps or a design framework). This would help readers better understand the methodology and its theoretical underpinnings.

Author response: We thank the reviewer for this constructive suggestion. To improve clarity and completeness, we have revised the end of Section III-A to explicitly describe how the phase gradient is applied across the RIS. Specifically, we now explain that the phase is initialized at the first tile and then incremented linearly across the grid based on the gradient direction and RIS grid spacing. We also include the mathematical expression for computing each tile’s phase shift from the gradient. This replaces the earlier brief description and clarifies the physical and mathematical link between the phase gradient and the final phase profile used for beam steering.

Reviewer 2 - Comment 3: ***[Page 5, Eq (12)]***

The distance-based phase profile model assumes constructive interference occurs when total propagation distances are equal. However, this may oversimplify practical scenarios. Due to the periodic nature of phase shifts, constructive interference could occur even with unequal distances. Additionally, environmental interactions (e.g., multipath effects) may lead to longer effective propagation paths. The authors are encouraged to revisit this model to account for these factors, ensuring it captures both phase periodicity and environmental propagation effects.

Author response: We appreciate the reviewer’s meaningful observation regarding the distance-based phase profile method. The distance-based phase profile method we use assigns phase shifts based on the sum of the TX-RIS and RIS-target distances, with the goal of aligning reflected wavefronts at the target point. While this formulation may appear to assume strict path length equality, in practice, the phase assignment is modulo-2π, which inherently captures the periodic nature of constructive interference. Therefore, we agree that unequal path lengths that differ by integer multiples of the wavelength still produce constructive interference.

Regarding environmental interactions, Sionna RT inherently models all multipath and higher-order reflections by summing the complex contributions of each traced ray, so environmental interactions are automatically captured by the ray-tracing tool during the simulation. Thus, our RIS optimization framework focuses on configuring the RIS for the dominant propagation path (i.e., line-of-sight path), while the full environmental response, including multipath effects, is captured during simulation by the ray-tracing tool. We have added a new paragraph at the end of Section III-B to clarify these two points.

Reviewer 2 - Comment 4: ***[Page 7, Algorithm 2]***

The algorithm employs an exhaustive search to determine the optimal RIS width. While effective for the presented simulations, this approach may face scalability challenges in scenarios with unpredictable or wide-ranging candidate values. The authors should discuss the computational complexity of this method and propose strategies to enhance scalability (e.g., heuristic optimizations or theoretical bounds to narrow the search space). Such additions would better motivate the algorithm's practicality for real-world deployment.

Author response: We appreciate the reviewer's important observation regarding the scalability of our exhaustive search approach. The current implementation uses an exhaustive search over discrete RIS width values to identify the configuration that maximizes the performance metric. In our setup, this search is computationally feasible due to two key factors: (1) RIS candidate positions are pre-filtered based on line-of-sight visibility to both the transmitter and all target points, and (2) the RIS width search space is discretized at 0.2 m intervals, making the number of evaluations manageable even in large indoor scenarios.

However, we agree that finer-grained optimization (e.g., at millimeter-level resolution) or larger deployment scenarios could increase computational cost. In such cases, several strategies can be considered to enhance scalability:

- Heuristic search strategies, such as greedy algorithms,
- Early stopping, where the search terminates if performance improvement falls below a selected performance improvement threshold,
- Coarse-to-fine grid search, where RIS width candidates are sampled more sparsely at first, followed by local refinement around the best region,
- Analytical bounds based on coverage radius or path geometry to prune unpromising regions.

In fact, our implementation already includes an early stopping mechanism via a minimum performance improvement threshold. This allows the algorithm to terminate the search once further increases in RIS width no longer produce significant performance improvements in the performance metric compared to the selected threshold. If finer search resolution is desired, this early stopping approach can be combined with the additional strategies mentioned above for further computational efficiency. A new paragraph has been added to the end of Section IV to describe these considerations and potential extensions.

Reviewer 2 - Comment 5: ***[Page 10, Figure 7]***

The relationship between RIS dimensions and performance could be more clearly presented. Since tile size is fixed, for a larger height, the same expansion in width can leads larger number of additional tiles thus a better performance can be well expected. The reviewer believes directly correlating the number of tiles (elements) to the performance metric would improve interpretability. Additionally, the unit of the performance metric currently uses dB, which is not a correct unit for power. Clarifying this would avoid potential confusion.

Author response: We appreciate the reviewer's insightful suggestions regarding performance and RIS dimension relationship and unit clarification. We thank the reviewer for this constructive and insightful comment. As correctly pointed out, the total number of RIS tiles increases with RIS width under a fixed RIS vertical dimension (height), which contributes to higher reflected energy and thus improved coverage. However, extending the RIS horizontally (RIS width) allows the reflected beam to reach deeper into previously uncovered blind spots, whereas increasing the vertical size (RIS height) primarily enhances gain toward already covered regions. This makes RIS width a more meaningful and practical optimization parameter in our scenario.

Regarding the unit of the performance metric: we acknowledge that the previous labeling may have caused confusion. To ensure consistency and scalability, we revised the labels of the coverage maps to work with path gain rather than absolute power levels. Path gain, defined as the inverse of path loss, is unitless in linear scale and expressed in dB in our analysis. This shift makes the performance evaluation independent of a specific transmit power level. For instance, if a transmitter operates at 10 mW (10 dBm), one can simply add 10 dBm to the path gain maps to obtain the received power levels.

Accordingly, the performance metric is now defined as the average path gain (in dB) of the low-power cells, and we have updated terminology across the whole manuscript, including changing “minimum power threshold” to “minimum path gain threshold” for clarity and consistency. Additionally, we have added a new paragraph in the Simulation Parameters subsection starting with “To ensure scalability...”.

Reviewer 2 - Comment 6: ***[Page 10, Figures 8 & 9]***

The interpretation of these figures requires further elaboration. The impact of parameter N on performance is not explicitly discussed, making it challenging to understand the figure. The authors should provide a clearer explanation of the trends, including axis labels, annotations, or a brief discussion linking N to the observed results. This would significantly enhance the figures’ value to readers.

Author response: We acknowledge that it would be nice to see the impact of the number of target points N on the performance. Figures 8 and 9 were originally intended to visualize the optimal RIS configurations (including the number of target points N) for each width. However, we agree that they did not explicitly isolate the effect of N on system performance.

To address this, we have added two new figures (Figures 11 and 12) that analyze the variation of the performance metric and coverage ratio as functions of N, for fixed RIS widths of 1 m and 2 m. These are presented separately for the gradient-based and distance-based approaches. Each point is annotated with the optimal RIS position that yields the highest performance for the corresponding number of target points. Additionally, a binary poor coverage map (Fig. 10) has been included to visualize the low-power cells and the selected target point when N = 1.

The related discussion has been added in Section V-E-3 under a new subsection titled "Effect of Number of Target Points on the Performance", which highlights the performance trends and trade-offs introduced by varying N.