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A Java-Based Simulator for Optimized 3D IoT Node Deployment and Adaptive Connectivity in Smart Healthcare Environments

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***Abstract*—This demo paper presents a Java-based simulator that enables optimized deployment and adaptive management of IoT nodes in healthcare environments using 3D Voronoi diagrams, hybrid algorithms, and Reconfigurable Intelligent Surfaces (RIS). It supports planning, validation, and analysis through real-time simulation and analytics.**

I. Overview

The proposed simulation platform offers an integrated framework for modeling, deploying, and analyzing IoT networks in dynamic indoor environments, with a focus on healthcare [1]. The system enables users to construct detailed environments either interactively or by importing 3D LiDAR or photogrammetry scans in formats such as `.ply` or `.pcd`.

Node types supported include static sensors, mobile agents such as ceiling-rail robots and programmable Reconfigurable Intelligent Surfaces (RIS) panels [2]. A hybrid optimization engine employs 3D Voronoi diagrams alongside Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) algorithms to compute optimal node placements, balancing coverage, latency, and energy cost. The optimization problem is formulated using (1)

$$\max \mathscr{F}(X) = w_c C(X) - w_l L(X) - w_e E(X) \tag{1}$$

where $C(X)$ is spatial coverage, $L(X)$ denotes latency, and $E(X)$ reflects energy usage, weighted by priorities w_c, w_l, w_e.

The 3D Voronoi tessellation used for deployment follows (2)

$$V_i = \{p \in \mathbb{R}^3 \mid d(p,n_i) \leq d(p,n_j), j \neq i\} \tag{2}$$

Simulation dynamics include node failure handling, obstacle navigation, and real-time RIS control to mitigate signal degradation [3]. RIS configurations are adjusted based on (3)

$$\theta^* = \arg\max_{\theta} \sum_{i,j} R(i,j,\theta) \tag{3}$$

to maximize connectivity quality among node pairs.

Figure 1(a) displays the deployment of static nodes, ceiling-rail robots, Autonomous Guided Vehicles (AGVs), RIS panels, and obstacles, with blue regions showing optimized 3D Voronoi coverage and magenta lines indicating mobile path planning. Figure 1(b) presents a point-cloud reconstruction of the environment overlaid with the simulated IoT infrastructure.

II. Innovation

Deploying resilient IoT networks in indoor healthcare spaces is challenging due to variable layouts, interference, and constant

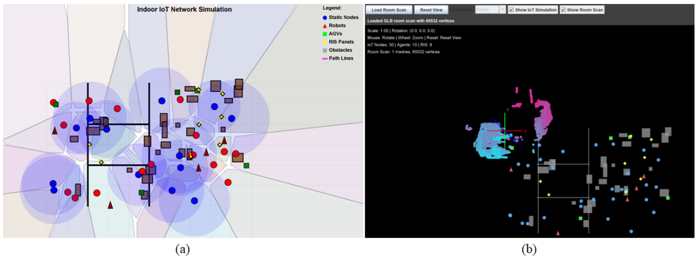

Fig. 1. (a) Indoor IoT deployment with node types and coverage zones. (b) 3D point-cloud scan overlay with infrastructure.

environmental change [4]. Existing static deployment methods fail to adapt in real time.

This platform introduces a novel, research-stage integration of 3D Voronoi spatial modeling, hybrid evolutionary optimization, and RIS-assisted connectivity tuning, elements not previously unified in a healthcare IoT context. The use of mobile agents and adaptive RIS management enables self-healing behavior in the face of failures or disruptions, providing a level of flexibility that extends beyond traditional static frameworks.

III. Relevance to SDN/NFV Community

This platform presents a pre-commercial research prototype that abstracts IoT infrastructure as dynamically configurable functions, effectively aligning with the principles of Network Functions Virtualization (NFV).

By demonstrating programmable RIS-based link management, dynamic node orchestration, and virtualized placement strategies, the demo provides compelling insights for SDN/NFV researchers exploring network automation, edge orchestration, and adaptive connectivity in indoor, mission-critical scenarios such as smart hospitals.

IV. Demo Proposal Summary

The demonstration will showcase a working prototype that models, deploys, and simulates resilient IoT networks in a realistic indoor healthcare setting using real-world scan data and optimization techniques. Also, it is based on a functional prototype developed for academic experimentation and is not part of any commercial deployment or product offering.

Configuration and Elements:

- **Environment Setup:** A 3D scan of a hospital ward is imported, visualized as a point-cloud mesh.
- **Deployment:** A hybrid PSO-GA algorithm computes optimal node placements based on multi-objective constraints.
- **Real-Time Simulation:** Includes AGV/robot mobility, RIS configuration updates, and dynamic event injection.
- **Analytics Dashboard:** Live charts display coverage, latency, energy use, resilience, and network QoS in real time.
- **Export Functions:** Simulation results are exported in CSV/PDF formats along with annotated environment visualizations.

Figure 2(a)–(d) highlight trade-offs in IoT connectivity. Coverage and connectivity decline over time due to node depletion, while higher energy use reduces coverage. Mobility adapts to changes but excessive movement lowers resilience. These results underscore the balance between reliability, energy efficiency, and adaptive mobility in maintaining robust network performance.

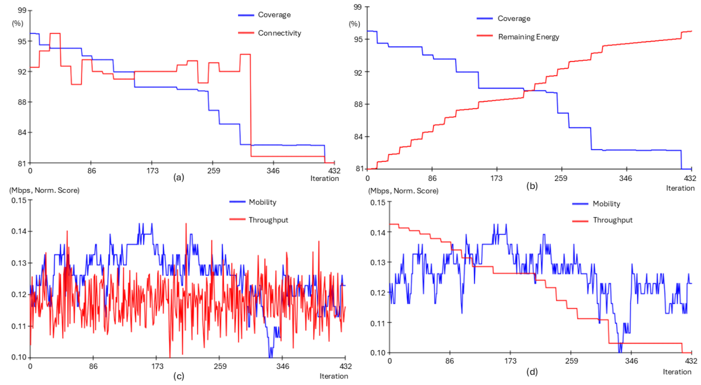

Fig. 2. (a) Coverage vs. Connectivity. (b) Coverage vs. Energy. (c) Mobility vs. Throughput. (d) Mobility vs. Resilience.

Figure 3(a)–(f) present performance metrics. Coverage varies spatially, throughput remains consistently high, and QoS delays follow a stable distribution. Mobility and resilience scores reflect adaptive and robust behavior, while energy consumption confirms efficiency. The results demonstrate the system's effective balance between connectivity, performance, adaptability, and energy-aware operation.

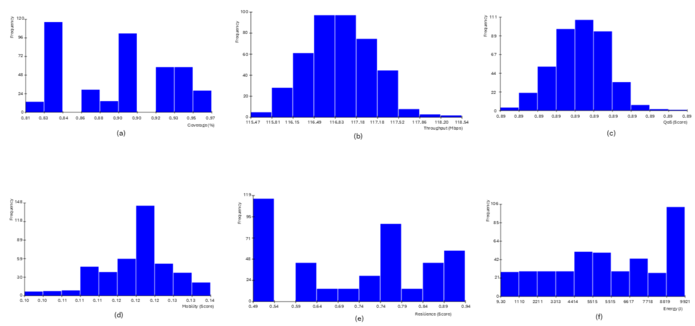

Fig. 3. (a) Coverage Distribution. (b) Throughput. (c) QoS Delay. (d) Mobility Score. (e) Resilience Score. (f) Energy Consumption.

V. Conclusion

This demo presents a novel simulation tool that brings together spatial optimization, mobility-aware node deployment, and adaptive RIS tuning to address the unique networking demands of smart healthcare environments. The platform serves as a research enabler.

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