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A PROPOSAL ON

OPTIMIZATION OF INDOOR WIFI ROUTER PLACEMENT USING GENETIC ALGORITHM-BASED SIMULATION

[CT-654]

SUBMITTED TO

DEPARTMENT OF ELECTRONICS AND COMPUTER ENGINEERING
Chyasal, Lalitpur

Mridul Sharma (HCE079BCT019)
Raghav Dahal (HCE079BCT028)
Riwaj Karki (HCE079BCT031)
Suchan Karki (HCE079BCT042)

2 January, 2026

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”A Third-Year Project Proposal Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Computer Engineering”

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

API	Application Programming Interface
AP	Access Point
CAD	Computer-Aided Design
DB	Database
DFD	Data Flow Diagram
FSPL	Free Space Path Loss
GA	Genetic Algorithm
GUI	Graphical User Interface
IoT	Internet of Things
ISP	Internet Service Provider
JSON	JavaScript Object Notation
ML	Machine Learning
RSS	Received Signal Strength
ROI	Return on Investment
SDLC	Software Development Life Cycle
SOHO	Small Office/Home Office
SQL	Structured Query Language
UI	User Interface
WiFi	Wireless Fidelity
WSN	Wireless Sensor Network

1. INTRODUCTION

1.1 Background

The proliferation of wireless networks in residential, commercial, and industrial environments has made WiFi a critical utility. However, signal quality and coverage remain persistent challenges due to suboptimal router placement, architectural obstacles, and interference. Traditional approaches to WiFi planning often rely on heuristic methods or manual trial-and-error, which are inefficient and may not yield optimal coverage, especially in complex indoor layouts. This project proposes a scalable, user-driven software solution that automates the optimization process for general indoor environments using a simulated propagation model, eliminating the need for costly pre-deployment physical surveys.

1.2 Problem Statement

Determining the optimal number and positions of WiFi routers in an indoor space to ensure strong signal coverage across all required areas while minimizing cost and interference is a complex combinatorial optimization problem. Manual placement leads to uneven coverage, dead zones, and inefficient resource usage. Existing commercial tools are often expensive and require specialized expertise. There is a need for an accessible, automated system that allows users to input their floor plan and receive a data-driven, optimized router placement recommendation.

1.3 Objectives

- Develop an intuitive software platform for simulating indoor WiFi coverage and optimizing router placement via Genetic Algorithm.
- Evaluate and visualize the optimized placement through comparative metrics and heatmap-based reporting against standard baseline approaches.

1.4 Scope

The scope of this project encompasses the development of a 2D floor plan analysis system focused on single-floor indoor environments. The system will optimize WiFi coverage using a generic propagation model applicable to standard 2.4GHz/5GHz frequencies, incorporating predefined material-based attenuation values for architectural obstacles such as walls, doors, and windows. All evaluations will be conducted through simulation without the need for physical hardware deployment, with final outputs comprising recommended router coordinates and quantitative coverage metrics.

Explicitly excluded from the scope are 3D or multi-floor optimization, real-time signal measurement or live network integration, router model- or antenna-specific optimizations, and the modeling of dynamic interference from external networks or devices. This delineation ensures the project remains focused on delivering a practical, simulation-driven tool for preliminary WiFi network planning within a well-defined and achievable framework.

1.5 Applications

The proposed system offers practical utility across multiple domains. For home network planning, it assists homeowners in strategically placing mesh network nodes or multiple routers to eliminate dead zones and ensure robust whole-home coverage. In Small Office/Home Office (SOHO) environments, it provides a cost-effective solution for designing professional-grade wireless networks that balance performance with infrastructure investment. Internet Service Providers (ISPs) can leverage the tool for pre-deployment analysis, allowing technicians to generate preliminary placement plans before physical installation, thereby reducing site visits and improving deployment efficiency. Furthermore, the system serves as a valuable educational tool for students in computer engineering and networking, offering hands-on demonstration of key concepts in computational optimization, genetic algorithms, and wireless signal propagation through interactive simulation.

2. LITERATURE REVIEW

The optimization of router and access point placement in wireless networks has become a critical research area due to the growing demand for reliable, high-coverage, and energy-efficient wireless communication in indoor and IoT environments. Recent studies have focused on developing automated, intelligent, and interactive methods to determine optimal node placement, balancing coverage, cost, interference, and power consumption. This review synthesizes key contributions in the fields of Wireless Sensor Networks (WSNs), Wi-Fi access point optimization, and IoT infrastructure planning, with emphasis on algorithmic approaches and practical deployment frameworks.

Alanezi et al. (2020) proposed an interactive Computer-Aided Design (CAD) approach for optimal router placement in indoor Wireless Sensor Networks for IoT-enabled smart buildings [1]. Their method combines automated grid-based router suggestion with designer intervention, allowing experts to refine network topology based on experience and practical constraints. The system uses Free Space Path Loss (FSPL) modeling and a ranked candidate selection mechanism to ensure full coverage with a minimized number of routers. Case studies demonstrated a reduction in router count compared to fully automated CAD tools, highlighting the value of human-in-the-loop optimization in complex indoor environments.

Pu et al. (2018) introduced a Fast Water-filling Algorithm with Group Power Constraint (FWA-GPC) for Wi-Fi access point optimization in indoor positioning systems [2]. Unlike conventional methods that treat power consumption independently, FWA-GPC integrates power constraints directly into the AP selection process, maximizing location fingerprint discrimination while minimizing energy use. The algorithm supports spare AP deployment for fault tolerance and uses a modified water-filling model adapted from adaptive channel allocation. Experiments in two indoor environments showed significant improvements in positioning accuracy and power efficiency compared to random, Max Mean, and InfoGain-based approaches.

Dewi and Marpaung (2023) applied a Genetic Algorithm (GA) to optimize Wi-Fi access point placement in an office environment, aiming to enhance signal coverage and quality [3]. Using coverage area and signal strength as fitness criteria, the GA iteratively improved AP positions, increasing coverage from 60

Wang and Kao (2012) also employed a Genetic Algorithm for multi-objective Wi-Fi AP deployment, considering coverage rate, capacity fulfillment, and budget constraints [4]. Their model supported multiple AP types with different costs and coverage ranges, as well as the possibility of deploying multiple APs at a single location. Experimental results showed that the GA could provide flexible deployment plans based on weighted objectives, offering a balance between performance and cost. The study highlighted the adaptability of evolutionary algorithms in handling diverse real-world deployment scenarios.

Chariete et al. (2016) presented a discrete optimization approach for indoor Wi-Fi planning, integrating AP placement, power setting, azimuth, radiation pattern, and channel allocation [5]. Using Tabu Search and Genetic Algorithms, their method maximized coverage and minimized interference and AP count. A key contribution was the use of adaptive mesh generation around wall edges to account for diffraction and transmission effects, improving coverage accuracy. Tests in a five-story building demonstrated high coverage rates (97

Additional studies have explored complementary techniques. For instance, [6] developed an interactive tool for WSN backbone synthesis, while [7] used Simulated Annealing for mesh router placement. [8] leveraged building duct systems as waveguides for WSN communication, offering an alternative to traditional placement. These works collectively illustrate the diversity of approaches—from exact MILP formulations to heuristic and metaheuristic methods—in addressing the router/AP placement problem.

Despite these advances, several challenges remain: most methods assume static environments, overlook real-time interference dynamics, and require significant computational resources for large-scale deployments. Future research directions include integrating machine learning for adaptive placement, incorporating multi-technology APs (e.g., 802.11ac/ad), and developing scalable cloud-based planning tools for smart cities and large IoT infrastructures.

3. REQUIREMENT ANALYSIS AND SYSTEM DESIGN

3.1 Requirement Analysis

3.1.1 Functional Requirements

The system's functional requirements define the essential capabilities and features it must possess to achieve its objectives. It ensures the system can transform a raw floor plan into a validated, optimized WiFi deployment plan.

i) **Floor Plan Management:**
The system shall allow users to upload floor plan images (JPG, PNG).

ii) **Scale Calibration:**
The system shall allow users to calibrate the image scale by marking two points and entering a real-world distance.

iii) **Annotation Module:**
The system shall provide tools to annotate:
a)Internet Gateway location.
b)WiFi demand points (e.g., desks, lounges).
c) Obstacles (walls, doors, windows) with material type selection.

iv) **Grid Conversion:**
The system shall automatically convert the annotated plan into a discrete grid model for simulation.

v) **Signal Simulation Engine:**
The system shall compute the Received Signal Strength (RSS) at every grid point using the defined propagation model.

vi) **Genetic Algorithm Optimizer:**
The system shall execute the GA to find optimal router positions from a set of candidate locations.

vii) **Baseline Analysis:**
The system shall generate and evaluate random and uniform router placements for comparison.

viii) **Visualization and Reporting:**
The system shall generate a heatmap overlay on the floor plan and display a comparative results table (Coverage percentage, Routers Used, Avg. Signal).

3.1.2 Non-Functional Requirements

The non-functional requirements define the qualitative attributes of the system, focusing on how it performs, how it is experienced by users, and how it is built and maintained. These requirements ensure the system is not only functional but also practical, reliable, and sustainable.

i) **Usability:**
The user interface shall be intuitive, requiring minimal technical knowledge from the user.

ii) **Performance:**
The optimization process for a standard residential floor plan (2000 sq. ft.) shall complete within 2 minutes.

iii) **Accuracy:**
The simulation model shall be internally consistent; the optimized solution shall outperform baseline methods by a statistically significant margin (p ¡ 0.05).

iv) **Portability:**
The core simulation and optimization logic shall be developed in a platform-independent language (e.g., Python).

v) **Maintainability:**
The code shall be modular, well-documented, and follow standard coding conventions.

3.2 Feasibility Analysis

i) **Technical Feasibility:**
The proposed technology stack (Python, standard libraries) is mature and well-suited for numerical computation (NumPy), algorithm implementation, and basic GUI development (Tkinter/PyQt or web framework). The core algorithms (GA, propagation model) are standard and implementable.

ii) **Operational Feasibility:**
The system automates a complex task, reducing the need for expert knowledge. The workflow is designed to be straightforward for end-users.

iii) **Economic Feasibility:**
The project will use open-source tools and libraries, resulting in near-zero software costs. Development costs are limited to human effort, making it highly economical compared to commercial site-survey software.

iv) **Schedule Feasibility:**
The modular breakdown of the project aligns well with a typical academic semester timeline. Clear deliverables for each module (UI, simulation, GA, integration) allow for parallel development and incremental testing.

4. SYSTEM DESIGN

The system design encompasses three key models: a Use Case Diagram to define user interactions and system functionalities, Data Flow Diagrams (Levels 0 and 1) to illustrate the system's data processing architecture, and a Sequence Diagram to detail the chronological workflow of the optimization process from user input to final output.

4.1 Use Case Diagram

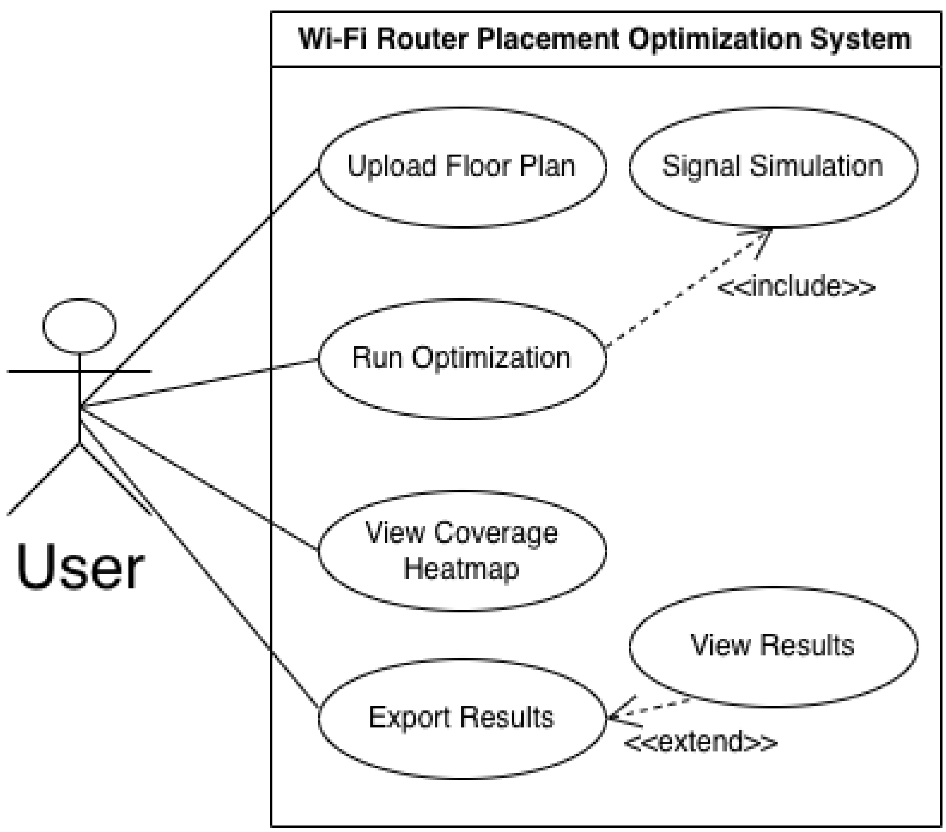

Figure 4.1: Use Case Diagram of the Wi-Fi Router Placement Optimization System

The use case diagram illustrates a Wi-Fi Router Placement Optimization System designed to assist users in determining optimal indoor Wi-Fi router locations based on a given floor plan. The system focuses on simulation-based analysis and optimization to maximize wireless coverage in indoor environments.

The system involves a single primary actor, the **User**, who interacts with the system through a graphical interface. The user initiates the workflow by uploading a floor plan image, which represents the layout of the indoor environment. Since raw images are not inherently interpretable by the system, further interactions allow the user to trigger processing and optimization functions.

The **Upload Floor Plan** use case allows the user to provide a 2D floor plan image of the indoor space. The **Run Optimization** use case enables the system to execute the router placement optimization process. This use case `<<includes>>` the **Signal Simulation** use case, which is responsible for estimating signal strength across the environment by considering distance-based path loss and obstacle-induced attenuation.

After the optimization process completes, the user can access the **View Coverage Heatmap** use case to visually analyze signal coverage across different areas of the floor plan. The **View Results** use case presents numerical and comparative performance metrics such as coverage percentage and average signal strength. The **Export Results** use case `<<extends>>` the **View Results** use case, allowing users to optionally save the generated results and visualizations for documentation or further analysis.

Overall, the use case diagram highlights a user-driven workflow where simulation and optimization processes are executed internally by the system, enabling informed decision-making regarding efficient Wi-Fi router placement.

4.2 DFD Level 0 (Context Diagram)

The Data Flow Diagram Level 0 (Context Diagram) depicts the WiFi Router Placement Optimization System as a single, cohesive unit interacting primarily with the User external entity. This highest-level representation defines the system boundary and core data exchanges: the user provides essential inputs including a Floor Plan Image, detailed Annotations (gateway, demand points, obstacles), and Optimizing Parameters for the Genetic Algorithm. In return, the system delivers actionable outputs in the form of Optimized Router Positions, visual Coverage Heatmaps, and a comprehensive Final Report.

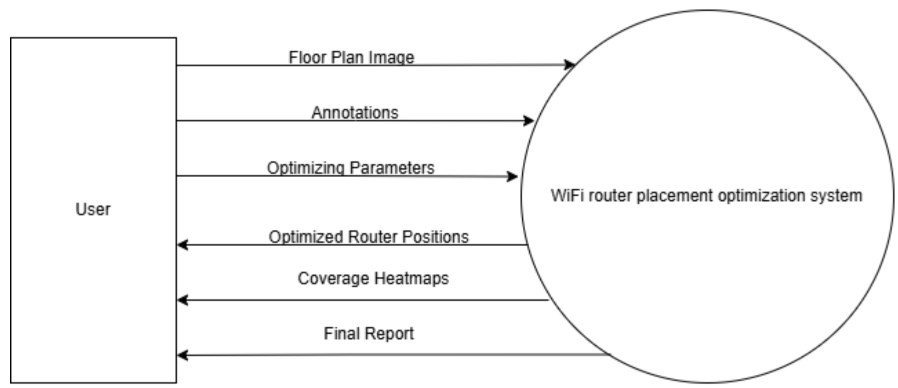

Figure 4.2: DFD Level 0 - Context Diagram

This diagram serves as the foundational blueprint, abstracting all complex internal processes such as scale calibration, signal simulation, and genetic algorithm optimization to clearly establish what the system consumes and produces. It focuses exclusively on data flow across the system boundary, effectively delineating the project's scope and setting the stage for subsequent decomposition into more detailed DFD levels that will reveal the internal data transformations, processes, and storage mechanisms.

4.3 DFD Level 1

The Data Flow Diagram Level 1 decomposes the WiFi Router Placement Optimization System into four core internal processes and five data stores, revealing the structured flow of data within the system boundary. The workflow begins at 1.0 Process Inputs, where the user uploads a floor plan with annotations, which is then calibrated, converted into a grid model, and saved to D1 (Floor Plan DB). This process queries D2 (Material Info) for attenuation values and passes the prepared grid model to 2.0 Simulate Signal.

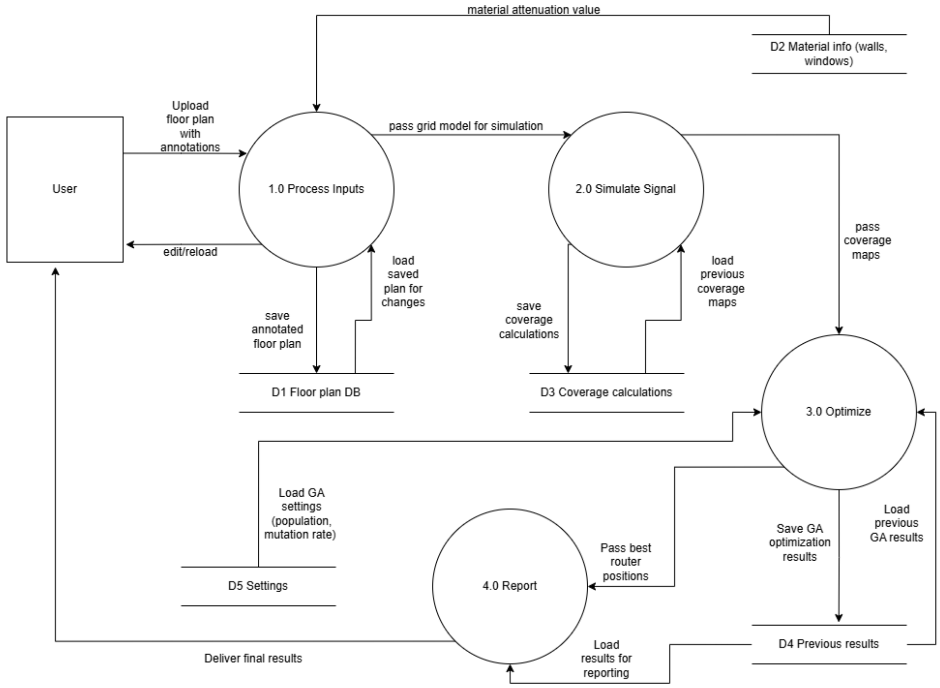

Figure 4.3: DFD Level 1 - Major Processes

The simulation engine calculates signal coverage across the grid, saves these calculations to D3, and forwards the coverage maps to 3.0 Optimize. The optimizer retrieves configuration from D5 (Settings) and previous results from D4, executes the Genetic Algorithm, saves the new optimization results, and sends the best router positions to 4.0 Report. Finally, the reporting module loads all relevant data from the stores, generates the final outputs optimized positions, heatmaps, and reports and delivers them to the user, completing the data transformation pipeline from raw input to actionable network planning intelligence.

4.4 Sequence Diagram

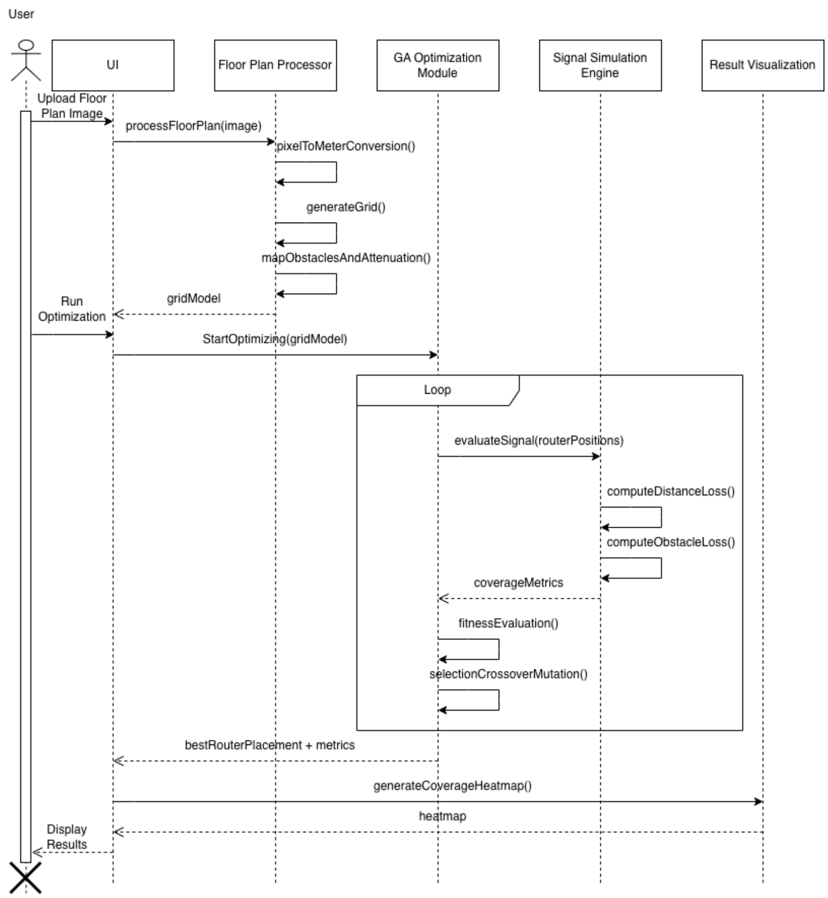

Figure 4.4: Sequence Diagram for Wi-Fi Router Placement Optimization System

The sequence diagram illustrates the interaction flow for executing the Wi-Fi router placement optimization process. The diagram represents how the user, interface, and internal system components collaborate to process the floor plan, simulate signal propagation, and determine optimal router locations.

The interaction begins when the **User** uploads a floor plan image through the **User Interface**. The interface forwards the image to the **Floor Plan Processing** module, which converts the visual representation into a structured grid model with obstacle and attenuation information. Once processing is complete, the generated grid model is returned to the user interface.

Next, the user initiates the optimization process. The user interface sends the processed grid model to the **Genetic Algorithm Optimization Module**, which begins evaluating candidate router placements. During this phase, the optimization module repeatedly interacts with the **Signal Simulation Engine** to estimate signal strength and coverage for each candidate solution.

After completing the evolutionary optimization process, the genetic algorithm module returns the best router placement along with performance metrics to the user interface. The interface then invokes the **Result Visualization** module to generate a coverage heatmap and present numerical results. Finally, the processed results are displayed to the user for analysis and optional export.

5. METHODOLOGY

5.1 System Architecture

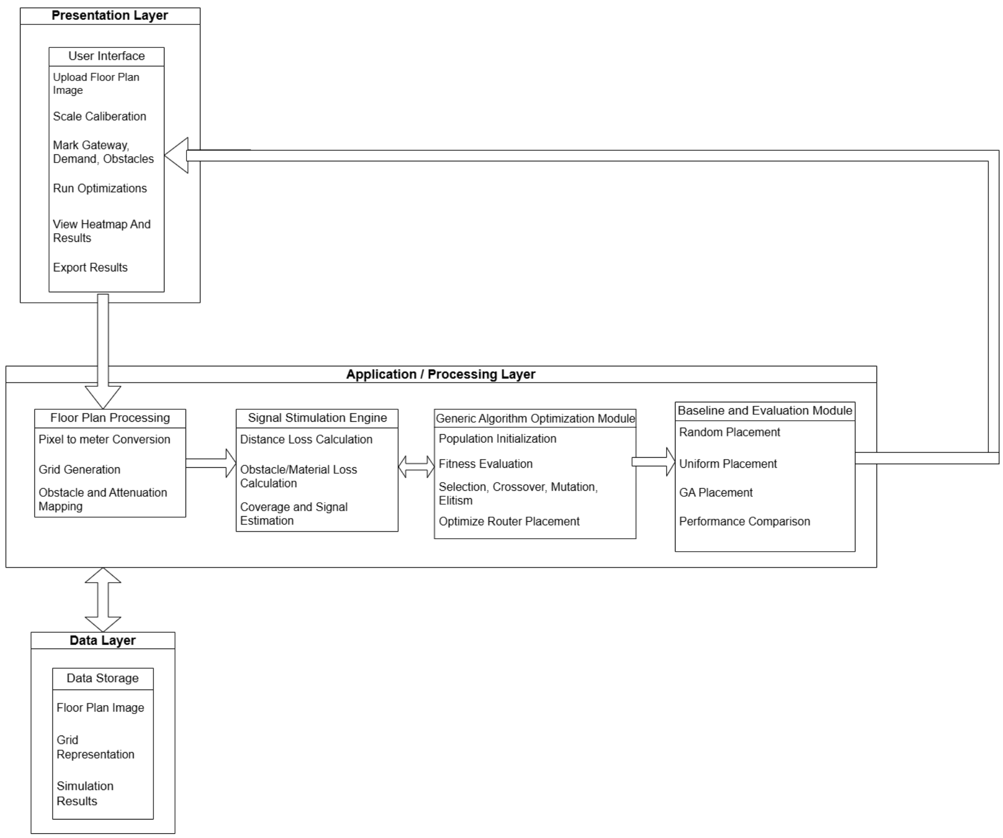

Figure 5.1: Basic System Architecture of the Simulation-Based Indoor Wi-Fi Router Placement Optimization System

5.1.1 Basic System Architecture

The proposed system follows a layered architecture consisting of three main layers: Presentation Layer, Application/Processing Layer, and Data Layer, as shown in the system architecture diagram.

Presentation Layer

The Presentation Layer represents the interaction point between the user and the system. It is responsible for collecting inputs and displaying outputs. Through the user interface, the user uploads the two-dimensional floor plan image, performs scale calibration by specifying real-world distances, and marks essential elements such as the internet gateway, Wi-Fi demand points, and obstacles including walls, doors, and windows. After the optimization process is completed, this layer visualizes the results in the form of coverage heatmaps, router placement overlays, and numerical performance metrics. This layer does not perform any computation and only communicates user inputs and results to and from the processing layer.

Application / Processing Layer

The Application/Processing Layer contains the core computational components of the system and executes the main algorithms.

The Floor Plan Processing Module receives the annotated floor plan and converts pixel-based coordinates into real-world measurements using scale calibration. It discretizes the indoor environment into a grid-based model and maps obstacles with their corresponding attenuation values. Based on this grid representation, a finite set of valid candidate router locations is generated.

The Signal Simulation Engine estimates Wi-Fi signal strength across the grid. It calculates distance-based signal loss and additional attenuation caused by obstacles and building materials. Using these values, it determines signal strength, coverage status, and overall coverage percentage for each grid cell.

The Genetic Algorithm Optimization Module utilizes the simulation results to optimize router placement. Candidate solutions, represented as chromosomes, are evaluated using a fitness function based on coverage performance. The algorithm iteratively applies genetic operators such as selection, crossover, mutation, and elitism to improve router placement. This module repeatedly interacts with the signal simulation engine, forming an optimization loop until an optimal or near-optimal solution is obtained.

The Baseline and Evaluation Module compares the optimized router placement with simpler baseline strategies such as random placement and uniform placement. It evaluates and contrasts performance metrics to clearly demonstrate the effectiveness of the genetic algorithm-based optimization.

Data Layer

The Data Layer manages all persistent data used and generated by the system. It stores the uploaded floor plan image, grid representation, obstacle information, and simulation results. All processing modules read from and write to this storage layer to ensure data consistency, reproducibility, and ease of analysis.

5.1.2 Methodology- Algorithms and Expressions

The operational flow of the proposed system follows a structured pipeline, starting from floor plan input and ending with result visualization and evaluation.

Step 1: Floor Plan Input and Scale Calibration

The user uploads a two-dimensional floor plan image in JPG or PNG format. Since the image is represented in pixel coordinates, scale calibration is required to convert pixel distances into real-world measurements.

The user selects two known points on the floor plan and enters the actual distance between them in meters. Let d_{px} denote the pixel distance between the two points and d_m denote the real-world distance. The pixel-to-meter conversion factor is computed as:

$$\text{Pixels per meter} = \frac{d_{px}}{d_m} \tag{5.1}$$

This conversion establishes a calibrated coordinate system for the simulation.

Step 2: Grid Generation and Environment Modeling

The calibrated floor plan is discretized into a two-dimensional grid, where each grid cell represents a small physical area (e.g., $1\,m \times 1\,m$). Each grid cell is classified as free space, wall, door, or window.

Each obstacle type is assigned an attenuation value representing signal loss. Free space has zero attenuation, while walls, doors, and windows introduce increasing levels of signal loss. This grid-based representation acts as the internal simulation model.

Step 3: Candidate Router Location Generation

To avoid infinite placement possibilities, the system generates a finite set of valid candidate router locations. Routers are allowed only in free-space cells, while wall cells and invalid regions are excluded. To realistically model wall-mounted routers, free-space cells adjacent to walls are preferred.

The candidate location set is defined as:

$$C = \{c_1, c_2, c_3, \ldots, c_m\} \tag{5.2}$$

where each c_i represents a valid grid coordinate.

Step 4: Signal Strength Estimation

For a router r located at (x_r, y_r) and a grid cell p at (x_p, y_p), the distance between them is computed as:

$$d(r, p) = \sqrt{(x_p - x_r)^2 + (y_p - y_r)^2} \tag{5.3}$$

The distance-based signal loss is given by:

$$L_{\text{distance}} = k \times d(r, p) \tag{5.4}$$

where k is a distance loss constant.

If the signal path crosses n obstacles, the obstacle-based loss is:

$$L_{\text{obstacle}} = \sum_{i=1}^{n} A_i \tag{5.5}$$

where A_i is the attenuation of the i^{th} obstacle.

The total signal strength is computed as:

$$S(r,p) = S_0 - L_{\text{distance}} - L_{\text{obstacle}} \tag{5.6}$$

For multiple routers, the effective signal strength at a grid cell is:

$$S(p) = \max_{r} \big(S(r,p)\big) \tag{5.7}$$

A grid cell is considered covered if:

$$S(p) \geq S_{\text{threshold}} \tag{5.8}$$

The coverage percentage is calculated as:

$$\text{Coverage\%} = \frac{\text{Number of covered free-space cells}}{\text{Total number of free-space cells}} \times 100 \tag{5.9}$$

Step 5: Genetic Algorithm Optimization

Each chromosome represents a router placement plan with a fixed number of routers K:

$$\text{Chromosome} = [c_a, c_b, \ldots, c_K] \tag{5.10}$$

To reduce redundant coverage, an overlap penalty is applied when routers are placed too close to each other. The fitness function is defined as:

$$\text{Fitness} = \text{Coverage\%} - \beta \times \text{OverlapPenalty} \tag{5.11}$$

where β is a weighting constant.

The genetic algorithm applies selection, crossover, mutation, and elitism iteratively until convergence or a maximum number of generations is reached.

Step 6: Baseline Comparison and Output

The optimized placement is compared with random placement and uniform grid-based placement using the same number of routers. The final outputs include coverage heatmaps, router placement overlays, coverage percentage, average signal strength, minimum signal at demand points, and runtime.

5.1.3 Overall Data Flow

The process begins with uploading a 2D floor plan image and performing scale calibration to convert pixel distances into real-world measurements. The user then annotates the plan by marking the gateway, demand points, and obstacles. Based on this input, a grid model is generated and valid candidate router locations are identified. Signal strength is simulated across the grid, and a genetic algorithm iteratively optimizes router placement using coverage-based fitness evaluation. Baseline placement methods are executed for comparison, after which the system evaluates performance metrics and generates visualization outputs such as heatmaps and router placement overlays before exporting the results.

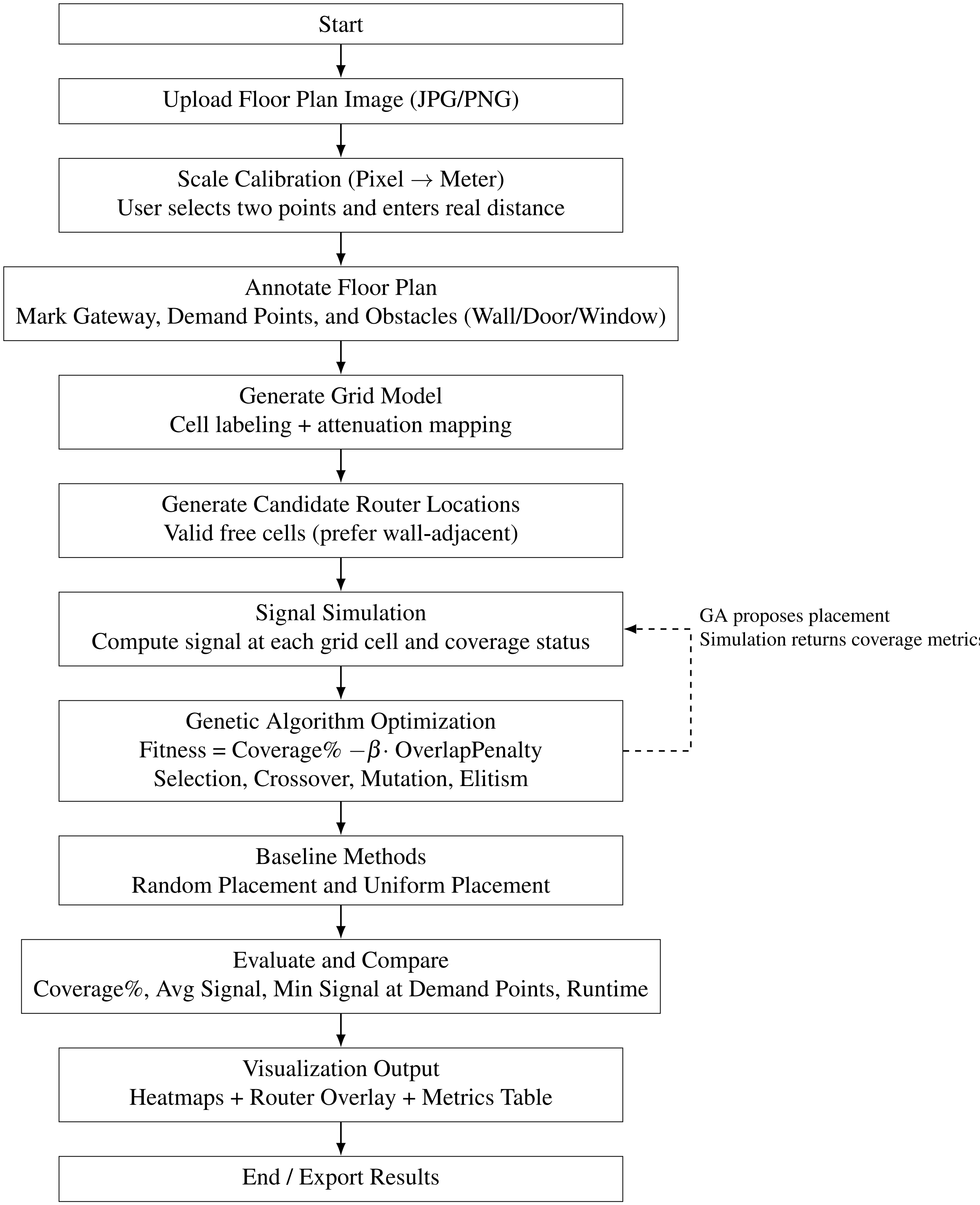

Figure 5.2: Operational Data Flow

5.1.4 SDLC Model Used

The Iterative SDLC model is adopted for this project.

Justification:

- Requirements may evolve during simulation tuning and testing.
- GA parameters and signal models require repeated refinement.
- Each iteration improves system accuracy, stability, and performance.

Phases include:

- Requirement analysis
- Design
- Implementation
- Testing and refinement

5.1.5 Tools Used

Table 5.1: Tools and technologies used in the proposed system

Category	**Tools**
Programming	Python
UI Development	Tkinter / PyQt
Image Processing	OpenCV
Numerical Computation	NumPy
Visualization	Matplotlib
Documentation	LaTeX

5.2 Risk Mitigation

This project involves simulation-based modeling, algorithmic optimization, and user-provided inputs, which may introduce technical and operational risks. The following risk mitigation strategies are incorporated to ensure system reliability, correctness, and feasibility.

Input and Calibration Errors

Incorrect floor plan images or improper scale calibration may lead to inaccurate simulation results. To mitigate this risk, the system validates image formats and ensures that the entered real-world distance during calibration is positive and within a reasonable range. Users are prompted to recheck calibration values if inconsistencies are detected.

Inaccurate Obstacle Modeling

Incorrect or incomplete marking of walls, doors, or windows can affect signal attenuation modeling. This risk is mitigated by enforcing predefined obstacle categories with fixed attenuation values. If certain obstacles are missing or ambiguous, default assumptions are applied and documented to maintain simulation continuity.

Unrealistic Signal Propagation

Simplified signal propagation models may not perfectly reflect real-world conditions. To reduce this risk, bounded parameter values are used for distance loss and obstacle attenuation, preventing extreme or unstable signal strength calculations. The simulation focuses on relative comparison rather than absolute signal accuracy.

Genetic Algorithm Convergence Issues

Genetic Algorithms may converge prematurely or get trapped in local optima. This risk is mitigated by incorporating mutation to maintain population diversity and elitism to preserve the best solutions across generations. A maximum generation limit is also enforced to control runtime.

Misleading Optimization Results

Optimized results may appear effective without proper reference. To mitigate this risk, the system includes baseline comparison methods such as random placement and uniform placement. Performance improvements are evaluated relative to these baselines to ensure meaningful optimization.

Reproducibility and Data Loss

Loss of intermediate data or inability to reproduce results may affect evaluation. This risk is mitigated through structured data storage, where the floor plan, grid model, simulation parameters, and results are stored and reused for verification and analysis.

Overall, the modular system architecture and validation-driven workflow reduce technical risks and ensure that the proposed system remains reliable, interpretable, and suitable for academic evaluation.

6. TIME ESTIMATION

6.1 Project Timeline

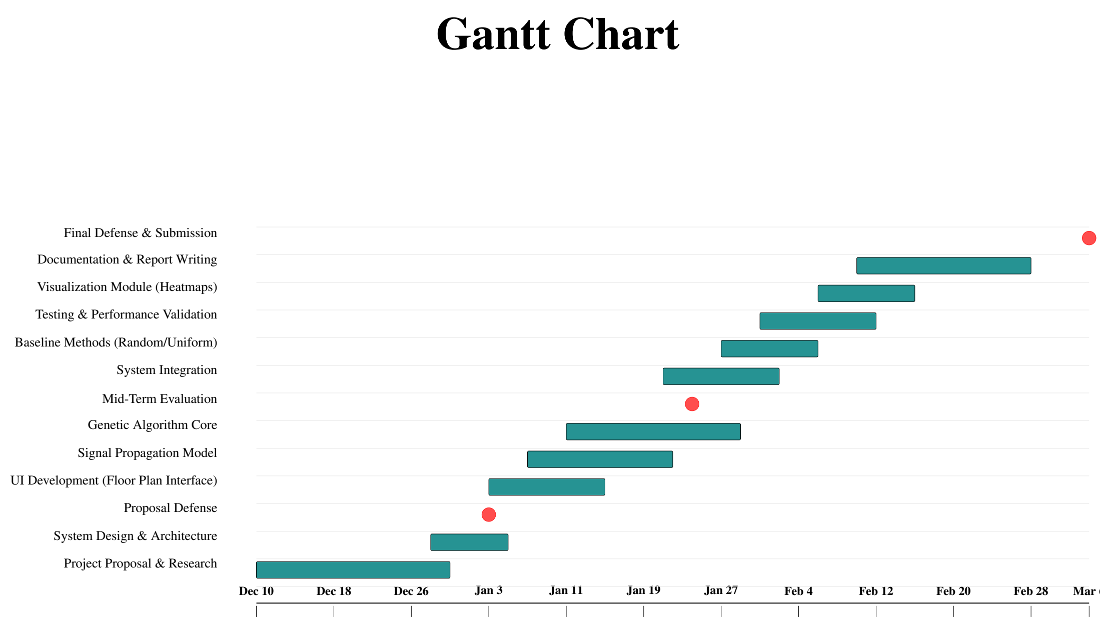

Figure: Project Timeline Gantt Chart

7. EXPECTED OUTCOMES

- A fully functional software application with a working GUI, simulation engine, GA optimizer along with side-by-side heatmap comparisons for different placement strategies on sample floor plans.

- Expected results from simulation tests:
  Baseline (Random Placement): 55-65% coverage.
  Baseline (Uniform Grid): 65-75%coverage.
  Proposed GA System: 80-85% coverage with the same or fewer routers, demonstrating a clear improvement of 15-20 percentage points.

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