T.C.

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CSE4197 – Analysis and Design Document

Title of the Project

“Nature-Inspired Algorithms to Optimize the Base Station Location Allocation Problem “

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1. Introduction

1.1 Problem Description and Motivation

In the ever-expanding telecom industry, extending communication networks efficiently to new areas is crucial. Our project tackles the strategic positioning of base stations, a vital aspect in establishing a comprehensive and cost-effective communication network. The positioning of base stations becomes particularly challenging when considering the need for managing tele traffic in emergency scenarios. Our focus is on finding a balance between achieving wide coverage, reducing costs, and enhancing operational efficiency, all while prioritizing community safety. This balance is vital for societal security, efficiency, and cost-effectiveness, with a special focus on ensuring rapid response to emergency calls.

The necessity of communication technologies in our daily lives underscores the importance of robust infrastructure systems. Accurate base station placement plays a critical role in the efficiency of emergency services. This project seeks to optimize base station locations for cost-effectiveness and maximum efficiency, especially in routing emergency calls and ensuring swift responses. Our innovative approach to this problem not only aims for economic efficiency but also strives to make a positive social impact, particularly in handling critical communications such as 112 emergency calls. We will explore the effectiveness of the nature-inspired algorithm which is Genetic Algorithm (GA) in base station positioning and emergency call routing. The project's insights are poised to offer strategic, innovative solutions for the telecom industry, potentially easing financial burdens for operators while enhancing customer satisfaction and public safety.

1.2 Scope of the Project

The primary objective of our project is to increase the effectiveness of emergency communication systems by placing base stations in strategic locations and utilizing sophisticated, dynamic routing algorithms. This algorithm is specifically made to adjust to varying volumes of emergency calls, maximizing network efficiency and preserving energy economy. There are two key phases of the project:

- **Base Station Placement Optimization:** This phase involves the development of advanced algorithms, particularly applying the Genetic Algorithm (GA), to determine the most effective locations for base stations. GA will be used with the primary goal of increasing coverage and improving response efficiency to make sure the network infrastructure is strong enough to handle highly demanding emergency situations. The Genetic Algorithm will be employed to iteratively evolve solutions towards ideal base station placements, drawing inspiration from the principles of natural selection. This method works especially well in complex environments because it makes it possible to explore a large area of potential solutions and find placements that provide the best possible combination of dependability, cost-effectiveness, and coverage.

- **Emergency Call Routing Strategy Development**: Following the base station placement, the project will focus on creating flexible routing algorithms that can adapt to changing call volumes. These algorithms aim to ensure rapid and efficient routing of emergency calls during different times of the day. Simulations of various time-based scenarios, reflecting real-world conditions, will be conducted to evaluate the network's resilience and capacity.

The project will compare these nature-inspired routing methods with traditional algorithms to identify areas of improvement and establish best practices. Extensive documentation will be maintained throughout the project to detail the techniques, algorithms, and outcomes at every stage, ensuring reproducibility and transparency.

This comprehensive approach not only aims to enhance emergency response capabilities but also contributes to the overall efficiency and sustainability of telecom networks.

1.3 Definitions, Acronyms, and Abbreviations

- **Base Station (BS)**: A fixed point of communication within a network that provides connectivity to mobile devices.
- **Genetic Algorithm (GA)**: An optimization technique that simulates the process of natural selection.
- **Tele traffic**: The study of the volume, flow, and type of traffic in telecommunications networks.

- **112 Emergency Calls**: The European Union's emergency call number, used for reaching emergency services.
- **Routing Algorithm**: A set of rules that determines the path of data packets within a network.
- **Simulation**: The process of modeling a real-world system or process over time.

2. Related Work

Base station location and channel allocation in a cellular network with emergency coverage requirements [1]

In the critical examination of literature concerning the efficiency of emergency services and the optimization of base station placement, the 2005 paper by M.R. Akella et al. on Emergency Notification & Response (EN&R) systems emerges as a particularly pertinent study. This research focuses on EN&R services crucial for assisting individuals in distress, such as during vehicular incidents, and plays a pivotal role in understanding the integration of telecommunications infrastructure in emergency scenarios. Our project, while drawing parallels to this study, also presents notable distinctions. Unlike EN&R systems that predominantly rely on in-vehicle Automatic Crash Notification (ACN) devices for emergency communication, our project adopts a more encompassing approach. We focus on the broader aspect of allocating base stations strategically for directing emergency calls. This approach is designed to address and mitigate challenges such as device damage due to vehicular impacts, power failures, or issues of weak signal strength – problems identified by Akella et al. in their study. By employing nature-inspired algorithms, our project aims to offer more robust and resilient solutions to these telecommunications challenges.

Furthermore, our project places significant emphasis on the optimal placement of base stations, especially in rural areas where base stations are fewer and their strategic placement is consequently more critical. This aspect of our project underscores the importance of telecommunication infrastructure in areas typically underserved by current technologies. In terms of similarities, both the EN&R systems discussed by Akella et al. and our project utilize the fundamental components of telecommunications infrastructure. This includes mobile stations, base stations, mobile switching centers, and public switched telephone networks, all crucial for establishing a reliable and effective communication network. Both bodies of work highlight the necessity of rapid and efficient communication networks in emergency scenarios, acknowledging the critical role these networks play in ensuring timely response and support during crises. Through these comparisons, our project distinguishes itself in its approach and focus, while aligning with the broader goal of enhancing emergency communication through advanced telecommunication infrastructure.

An Efficient Algorithm to Solve Base Station Location and Channel Assignment Problems in a Cellular Network [2]

Sheldon Lou and Robert Aboolian offer a novel method for cellular network base station placement and channel assignments optimization. In particular in areas with high traffic, this research tackles the problem of minimizing call blockage and lowering installation costs. The authors examine a range of approaches, including mathematical programming models and heuristic algorithms that have been used in comparable situations in the past. Their proposal is a new non-linear integer programming model that focuses on 'demand areas', which represent the service requirements of mobile users in a given geographic area. The solution method deviates from standard techniques, introducing a sequential solving of two problems, Problem P(θ) and Problem Q(θ), enhancing computational efficiency. A unique "Greedy Allocator" algorithm is introduced, iteratively assigning channels to base stations to maximize the reduction in the objective function. The paper offers theoretical validations for the optimality of this algorithm and its effectiveness in solving the combined base station placement and channel assignment issue. The authors conclude by emphasizing the algorithm's proficiency and suggest future research directions, including applications to multiple cluster problems and CDMA systems. This study's approach contrasts with previous works in its algorithmic strategy and optimization criteria, providing a distinct perspective on addressing cellular network challenges.

Optimal Network Design: The Base Station Placement Problem [3]

In the study "Optimal Network Design: the Base Station Placement Problem" by Shih-Tsung Yang and Anthony Ephremides, the focus is on the strategic placement of base stations in cellular networks, aiming to maximize the minimum throughput among mobile users. This objective shares similarities with our project in several key aspects. Both studies emphasize the critical role of base station placement in enhancing the overall efficiency and performance of telecommunications networks, albeit with different primary goals.

Yang and Ephremides employ a mathematical model that hinges on random walk mobility and throughput optimization, reflecting a deep engagement with the technical intricacies of network design. Similarly, our project utilizes sophisticated methodologies, albeit through nature-inspired algorithms like the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Ant Colony Optimization (ACO).

These algorithms, although different in approach, align with the intent of Yang and Ephremides' work in their commitment to optimizing network performance.

Additionally, both studies acknowledge how crucial it is to take communication traffic into account when deciding where to locate base stations. In contrast to Yang and Ephremides, who concentrate on the distribution of mobile communication traffic, our project takes emergency call routing into account, demonstrating the flexibility and adaptability of telecommunication infrastructure in a range of situations.

These studies are related because they both aim to enhance service delivery through the expansion of telecommunications infrastructure. They both place a high priority on strategic planning and the application of cutting-edge computational techniques to improve network capacity, indicating a shared appreciation of the significance of efficient telecommunications systems in the modern world. This alignment highlights a more general trend in telecoms research toward creative approaches to network optimization, with both studies offering insightful analysis and useful techniques to this developing area.

The location-allocation problem of drone base stations [4]

In the comprehensive study "The location-allocation problem of drone base stations" by Cihan Tugrul Cicek et al., the exploration of optimizing wireless communication networks introduces a unique perspective that, while distinct, shares several similarities with our project on terrestrial base station placement. Both studies are fundamentally driven by a commitment to enhance the efficiency and coverage of telecommunications networks, albeit through different technological avenues. Cicek et al.'s focus on Drone Base Stations (DBSs) and our project's emphasis on terrestrial base stations both address the crucial need for strategic placement within the network, showcasing an overarching goal of improving network performance.

There is a common thread of innovation in both studies, as each employ advanced computational models to tackle complex network optimization problems. Cicek et al. utilize a Mixed Integer Non-Linear Program (MINLP) to solve the dynamic 3D location problem of DBSs, mirroring our project's use of nature-inspired algorithm which is Genetic Algorithm (GA) for optimizing terrestrial base station placement. This reflects a shared approach of employing sophisticated, algorithm-based solutions to enhance network design.

Furthermore, both studies acknowledge how critical it is to modify network infrastructure to accommodate particular user needs and environmental factors. The study conducted by Cicek et al. on DBSs offers network coverage that is flexible and adaptable, just as our project seeks to maximize the placement of terrestrial base stations for efficient emergency communication. This flexibility is essential because network demands and constraints can differ greatly in both urban and rural environments.

The two studies contribute significantly to the field of telecommunications, despite their different technological focuses. Our project is grounded in traditional base station technology, whereas Cicek et al. explore the potential of aerial drone technology. Each study exhibits a forward-thinking approach to network optimization, underscoring the diverse yet convergent paths in telecommunications research that aim to enhance connectivity and service reliability in our increasingly connected world.

3. System Design

3.1 System Model

This section elucidates the critical aspects of our proposed model for solving the base station allocation problem. With the goal of enhancing the efficacy of emergency call routing services, we focus on the strategic optimization of base station placements. Optimal positioning is crucial for expanding coverage and reducing telecommunication costs.

Data Set and Location Selection

Our project necessitates the creation of a data set that corresponds to the demographic and geographical structure of selected regions. This data set includes the potential locations of base stations and their coordinate information within these regions. For instance:

- **Location 1 – Basıbüyük [5]**: This area, with a population density of 21.71 persons/km² and a population of 21,951, underscores the necessity for well-planned urbanization and telecommunication infrastructure. [6]
- **Location 2 – Reşadiye [7]**: With a population of 2,508 and a density of 1.29 persons/km², this region exhibits a more rural character. The low density presents the imperative to design strategic base station placements that can cover widespread populations across extensive areas.[8]
- **Location 3 – Tepeüstü [9]**: A densely populated area with 13,700 individuals resulting in a density of 318.61 persons/km², indicating a high demand for coverage and the expected high traffic load for base stations.

In the creation and processing of data sets for these regions, we will utilize the Python programming language and the Folium library. Folium serves as a robust tool for the visual representation of locations through interactive maps, providing us with significant advantages in analyzing potential base station sites. This library offers the opportunity for in-depth and interactive examination during the processing and analysis of geographical data.

Algorithm Selection

At this stage of our project, we have decided to use the Genetic Algorithm (GA) to select the most efficient combinations of potential locations. GA's capability to solve complex problems in large search spaces and its overall solution quality make it an ideal choice for such issues [10]. Given the breadth of the solution space and the diversity of potential solutions, GA is one of the most powerful tools for determining optimal placement combinations. The selection of the genetic algorithm also offers the flexibility to rapidly review various location options and select the most suitable ones.

Scenario Analysis

We conduct scenario analyses based on real-world examples to accurately assess the performance of our algorithm. These scenarios simulate the traffic density patterns that base stations in selected regions might encounter at different times of the day.

The analyses include:

- **Daytime Scenario**: This scenario models the situation where base stations must meet high traffic demand during hours of peak population density and daily activities. This represents the increased demand that might occur during business hours, school dismissals, or special events. The daytime scenario assesses how base stations maintain coverage during peak usage times and whether emergency calls are processed swiftly.
- **Nighttime Scenario**: Conversely, this scenario measures the performance of base stations during nighttime hours when traffic density relatively decreases. The nighttime scenario is designed to test the system's efficiency and reliability, even under lower demand. In particular, it focuses on ensuring the fast and accurate routing of emergency calls, even when fewer calls are received.

Both scenarios are critical for evaluating the adaptation of our algorithm to different traffic patterns and demand levels, as well as the overall flexibility of our system. Additionally, these scenarios allow for a detailed examination of how the algorithm's routing structure for emergency calls performs at different times of the day and under varying population densities.

These scenario-based analyses provide valuable insights into how our project will function under realistic conditions and validate the effectiveness of our algorithm selection and parameter settings.

3.2 Details of algorithm

Genetic Algorithm (GA) and Its Application to Base Station Allocation Problem

Genetic Algorithm (GA) is a search and optimization method based on the principles of natural selection and genetic inheritance. The use of GA for the base station allocation problem offers an effective approach to solving the issue. The complexity of this problem, which involves numerous potential combinations of base station placements, makes GA ideally suited for effectively exploring this extensive solution space.

```
Algorithm: GA(n, χ, μ)

// Initialize generation 0:

k := 0;

Pk := a population of n randomly-generated individuals;

// Evaluate Pk:

Compute fitness(i) for each i ∈ Pk;

do

{ // Create generation k + 1:

// 1. Copy:

Select (1 − χ) × n members of Pk and insert into Pk+1;

// 2. Crossover:

Select χ × n members of Pk; pair them up; produce offspring; insert the offspring
into Pk+1;

// 3. Mutate:

Select μ × n members of Pk+1; invert a randomly-selected bit in each;
```

Figure 1: “Pseudocode Example of Typical Genetic Algorithm” [10]

Phases of GA and Its Application to Base Station Allocation:

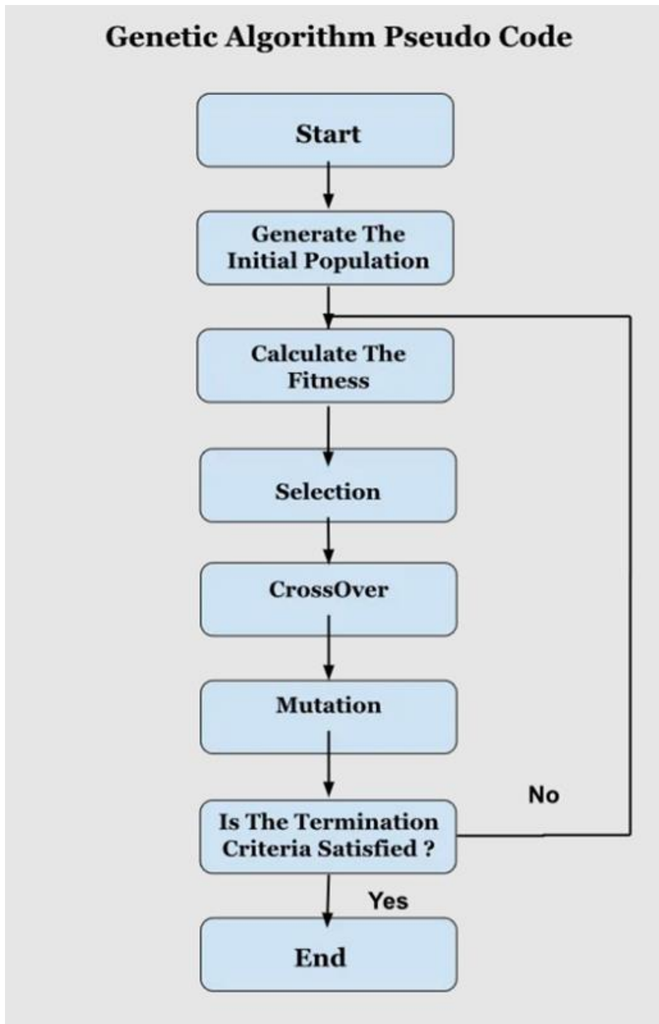

Figure 2: “GA Pseudo Code” [11]

1. **Creation of Initial Population**: The population consists of individuals representing potential base station placements. Each individual can be represented as a series or vector of different base station locations. Typically, this initial population is created with randomly selected placements.

2. **Fitness Evaluation**: A fitness function is used to measure the effectiveness of each placement arrangement. This function evaluates the ability to cover all demand points on the map. The width of the coverage area is the primary metric determining the performance of the placement arrangement.

3. **Selection**: Individuals with the best performing placement arrangements are selected for future generations. This ensures the preservation and improvement of placements with the highest coverage areas.

4. **Crossover**: A crossover process is conducted among the selected individuals. This process creates new and potentially more effective placement arrangements by combining different placement patterns.

5. **Mutation**: Random changes are made in newly created placement arrangements. This increases the diversity of solutions and prevents the algorithm from getting stuck in local optima.

6. **Generation of New Individuals**: The next generation, consisting of new individuals, replaces the previous one. This process continues until a certain stopping criterion is met, such as reaching a specific fitness level or a certain number of generations.

Effectiveness of GA in Base Station Allocation Problem:

GA is an effective tool for the base station allocation problem because:

- **Diverse Solution Space**: GA efficiently explores and evaluates numerous potential placement patterns for base stations.
- **Handling Complex Constraints**: GA can flexibly address complex problems, including geographical and cost constraints.
- **Global and Local Search**: The crossover and mutation mechanisms of GA provide both global and local search capabilities, leading to generally better solutions.
- **Flexibility and Adaptation**: GA can easily adapt to different scenarios and varying conditions, making it suitable for dynamic problems like base station allocation.

3.3 Performance Metrics and Evaluation

In this part of our project, we define the detailed metrics and evaluation methods for assessing the performance of our base station allocation and emergency call routing system comprehensively. This evaluation will be based on the three types of nodes defined on the map: demand nodes, possible base station locations, and emergency call nodes.

Detailed Performance Metrics:

1. **Coverage Rate and Quality of Demand Nodes**: Each demand node represents the need for a base station in a specific location. Our performance will be measured by how effectively these nodes are covered, considering the following criteria:
   - **Demand Quantity**: The demand amount defined for each node determines the capacity and coverage requirements of the base stations.
   - **Geographical Difficulty**: Classified into low, medium, and high levels, these difficulties determine the challenges and costs of placing base stations in various locations, reflecting the impact of different geographical structures like mountainous areas or dense city centers on coverage.
2. **Response Time to Emergency Call Nodes**: The speed of response to emergency calls is a critical indicator of the system's emergency management capacity. This metric will include:
   - **Response Speed**: The time elapsed from receiving an emergency call to processing it.
   - **Effective Routing**: Determining the shortest and most effective routes to process emergency calls at designated base stations.
3. **Total Cost and Efficiency of the Network**: Evaluating the cost of the network involves considering the characteristics of the possible base station locations nodes:
   - **Type and Cost of Base Stations**: The costs of different types of base stations used in Turkey and their suitability according to geographical conditions and regional demand.
   - **Total Cost Assessment**: The total cost of the created network will be analyzed to determine the most cost-effective combinations of different base station placements and types.

Comprehensive Evaluation Methods:

1. **Scenario-Based Simulations**: We will create scenarios with different geographical difficulties and demand patterns to test our system's flexibility and adaptability to various conditions. These scenarios will assess how our system performs under variable demands and geographical structures.
2. **Analysis of Routing Algorithm Efficiency**: The impact of the routing algorithm developed for emergency calls on the speed and efficiency of processing these calls will be analyzed. This will test how the algorithm operates under different scenarios and levels of demand and assess its emergency management capacity.
3. **Cost and Efficiency Evaluation**: We will analyze the cost of the created network to determine the most cost-effective base station placements and types. The cost analysis will evaluate the budget efficiency and economic sustainability of the project, while also considering the overall performance of the network.

These detailed performance metrics and evaluation methods are designed in line with our project's core objectives and ensure a comprehensive evaluation of every aspect of the system. These metrics and analyses are critical for measuring the success of our project, making continuous improvements, and establishing an effective base station allocation and emergency call routing system.

3.4 Dataset or Benchmarks

This section discusses the dataset derived from real-world locations within the selected regions, utilized to test the core algorithm of our project, as well as the comparative reference points (benchmarks) used for performance evaluation.

Dataset Creation Process and Selection Criteria

In our project, the regions of Reşadiye, Tepeüstü, and Başibüyük were carefully selected to accurately reflect real-world scenarios. Demographic information such as population density and age distribution for each region was mapped using the Python Folium library. The low population density and expansive area of Reşadiye, the higher density and complex urban structure of Başibüyük, and the proximity to the city center and high density of Tepeüstü provide ideal conditions for testing different base station placement strategies.

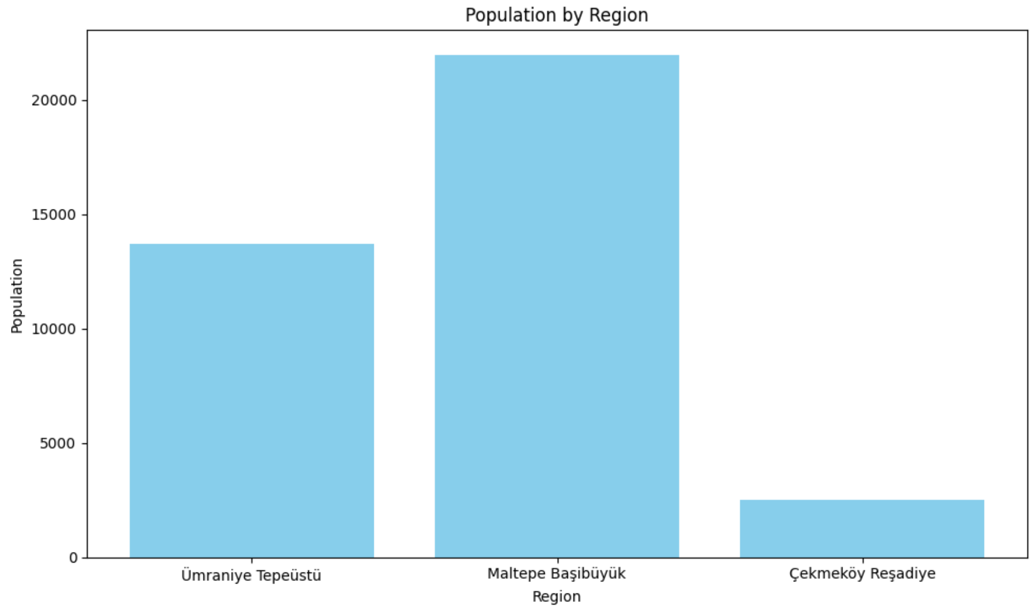

Figure 3: “Population information of the data set”

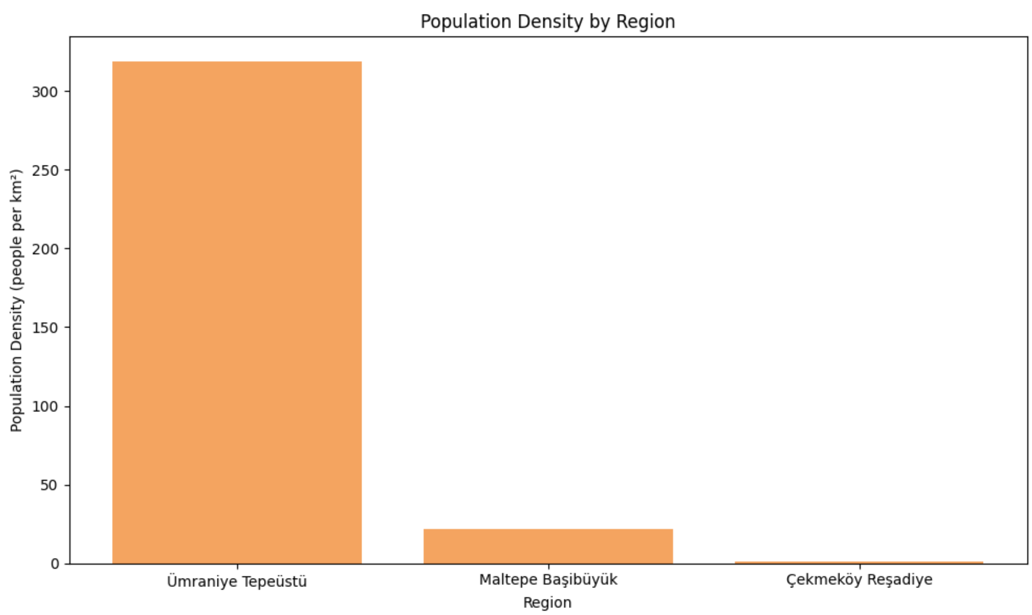

Figure 4: “Population density information of the data set”

Specifically, Reşadiye has been determined to have a low population density of 1.29 persons/km² over an area of 4.69 km², while Tepeüstü has a high population density of 318.61 persons/km², and Başibüyük is represented with a density of 21.71 persons/km² [5]. This demographic and geographical diversity plays a critical role in the design of our dataset and in evaluating the effectiveness of the genetic algorithm.

Creating Benchmarks for Comparative Analysis

To assess the performance of the Genetic Algorithm (GA) used in the project, we were inspired by instance generators mentioned in similar studies [1], but instead of using them directly, we created our own simulated test problems. This allowed us to create a dataset with unique demographic and geographical features. This unique dataset, grounded in real-world data points, enhances the realism and applicability of our model.

We will juxtapose our results against similar models mentioned in the literature, showcasing the innovations and advantages our GA-based solution approach brings to the existing problems. This comparative analysis will document not only the theoretical but also the practical contributions of our project.

4. System Architecture

The system architecture of our project relies on a central optimization engine using a genetic algorithm (GA) to generate optimal base station placement plans based on defined requirements. This section provides a detailed explanation of the algorithm's data flow, processing workflow, and overall structure.

Optimization Process and Control Flow

The Genetic Algorithm utilizes user-provided data points enriched with geographic information to determine the optimal placement of base stations and network configuration. The algorithm conducts iterations across various populations with the goal of finding the most cost-effective and efficient network structure, aided by a predefined fitness function. In each iteration, individuals within the current population are selected, paired, and subjected to mutations to achieve the best placement. Termination of the algorithm occurs when a specific cost/efficiency threshold is reached or when the algorithm can no longer make further improvements, typically identified by reaching a certain number of iterations or no improvement in fitness value.

Data Flow and Processing

In our system, users define demand points and potential base station locations by specifying demographic and geographic parameters. These data points serve as input for the algorithm and are continuously processed and updated throughout the optimization process of the GA. The results obtained are visualized and presented to the user through the system interface.

System Performance and Evaluation

The performance of our system is continuously monitored and evaluated using various metrics such as coverage area, emergency call routing speed, and cost-effectiveness of the generated network. These performance metrics are of critical importance to understand how effectively the GA operates under different scenarios and parameters.

Technological Infrastructure

Python programming language has been preferred for implementing the algorithm due to its extensive library support and data processing capabilities. The Folium library allows users to easily manipulate geographic data and supports the accurate and efficient provision of inputs for the algorithm.

5. Experimental Study

This section outlines the planned experimental setup, anticipated results, and the expected discussions for the future experiments in our project.

5.1 Experimental Setup

Our future experimental setup is designed to evaluate the effectiveness of Genetic Algorithm in optimizing base station locations for emergency call routing. The proposed experiments will be conducted in a controlled simulation environment that closely mimics real-world conditions.

- **Simulation Environment:** We plan to develop a virtual network environment simulating various urban and rural landscapes.
- **Data Set:** The experiments will utilize synthetic datasets, encompassing geographic locations, potential base station sites, and simulated emergency call data.
- **Algorithms to be Tested:** We aim to test nature-inspired algorithm which is Genetic Algorithm (GA), tailored for the base station allocation problem.
- **Performance Metrics:** Our evaluation will focus on metrics such as coverage area, signal quality, cost-efficiency, and response time to emergency calls.

5.2 Expected Experimental Results

We expect to observe varying performance strengths when using the Genetic Algorithm.

- **Genetic Algorithm (GA):** GA is anticipated to excel in evolving optimal base station positions, focusing on coverage and cost.

A comparative analysis will be done against baseline algorithms currently documented in the literature.

Discussions on Expected Outcomes

The upcoming experiments are expected to shed light on:

- **Algorithmic Efficiency:** How well do nature-inspired algorithms perform in dynamic and complex scenarios compared to traditional methods?
- **Adaptability and Cost-Efficiency:** Assessing the adaptability of these algorithms to various environmental constraints and their effectiveness in reducing operational costs.
- **Response Time:** Evaluating the responsiveness of the algorithms, which is critical for emergency call routing.

Through these future experiments, we aim to contribute novel insights into the optimization of base station locations using nature-inspired algorithms, potentially offering more adaptable, cost-effective, and efficient solutions for emergency communication networks.

6. Tasks Accomplished

6.1 Current state of the Project

We collect data about base station locations.

We are about to finish the dataset part.

As soon as the dataset part is finished, we start the implementation.

6.2 Task Log

Meetings	Date	Location	Period	Attendees	Objectives	Decisions and Notes
Meeting#1	6.10.2023	Marmara University	1 Hours	All group members	Conducting a basic research on the algorithms to be implemented in the project	The scope of our project has been determined.
Meeting#2	13.10.2023	Marmara University	1 Hours	All group members	Simple research about the algorithms that will be used in the project	Our project scope has been decided
Meeting#3	20.10.2023	Marmara University	1 Hours	All group members	Showcasing related studies and works.	We have determined the methodology and baseline algorithms for our study
Meeting#4	27.10.2023	Zoom	1 Hours	All group members	Showcasing related studies and works.	The presentation of related works has been completed.
Meeting#5	10.10.2023	Marmara University	1 Hours	All group members	Refining the methodology and technical approach	We discussed our current methodology and identified areas that need improvement.
Meeting#6	10.11.2023	Marmara University	1 Hours	All group members	The meeting concluded with a commitment to begin the dataset search process, utilizing the strategies and criteria discussed.	Our team decided to initiate a comprehensive dataset search using identified strategies and criteria to find datasets that align with our project's requirements.
Meeting#7	17.11.2023	Marmara University	1 Hours	All group members	The main objective of the meeting was to discuss and finalize the strategy for creating a comprehensive dataset that accurately mirrors real-world complexities for our project.	Decided to use Simple Distribution, Raster-Based Distribution, and Real-World Coordinates.
Meeting#8	24.11.2023	Marmara University	1 Hours	All group members	Enhancements will be made to the PSD document.	We discussed the draft version of the PSD document.
Meeting#9	1.12.2023	Marmara University	1 Hours	All group members	We reviewed the initial draft of the PSD document.	The final version of the PSD document was scrutinized.
Meeting#10	24.01.2024	Zoom	1 Hours	All group members	We discussed the strengths and weaknesses of our PSD presentation.	Some parts of the presentation will be corrected

Figure 5: “Meeting Task Logs During the Semester”

6.3 Task Plan with Milestones

- **Milestone 1:** Algorithm Customization and Theoretical Model Development phases are completed

- **Milestone 2:** Algorithm Testing and Refinement is finished on prepared data-set.

- **Milestone 3:** Performance Evaluation, Analysis and documentation preparation is finished.

Phases

1. **Initial Setup and Algorithm Customization** - The first phase involves adapting nature-inspired algorithm which is Genetic Algorithm (GA) to our specific project needs. This customization ensures that the algorithm can efficiently address the problem of optimal base station placement for effective coverage and emergency response.
2. **Theoretical Model Development** - In the second phase, we create theoretical models for each algorithm. These models help us predict how the algorithm may perform in the real world and lay the groundwork for the performance metrics that will be used later in the evaluation process.
3. **Simulation Model Building** - Once we have our theoretical models, we construct simulation models that mimic real-world conditions as closely as possible. This allows us to test our algorithms without the real-world consequences, ensuring that they are robust and reliable.
4. **Data Set Creation** - We then develop a comprehensive dataset that includes information on emergency calls and potential base station locations, organized in a way that allows us to run various placement scenarios effectively.
5. **Algorithm Testing and Refinement** - With our dataset ready, we begin testing the algorithms. The results from these simulations are used to optimize the algorithm, ensuring they can handle the complex task of base station placement.
6. **Performance Evaluation and Analysis** - After testing, we analyze the results using the established performance metrics. This analysis helps us understand our algorithm's performance and pinpoint areas for improvement.

7. **Documentation and Reporting** - The final phase involves documenting everything, including test results, theoretical and simulation models, and algorithm customizations. We prepare reports that summarize our research findings and potential implications.

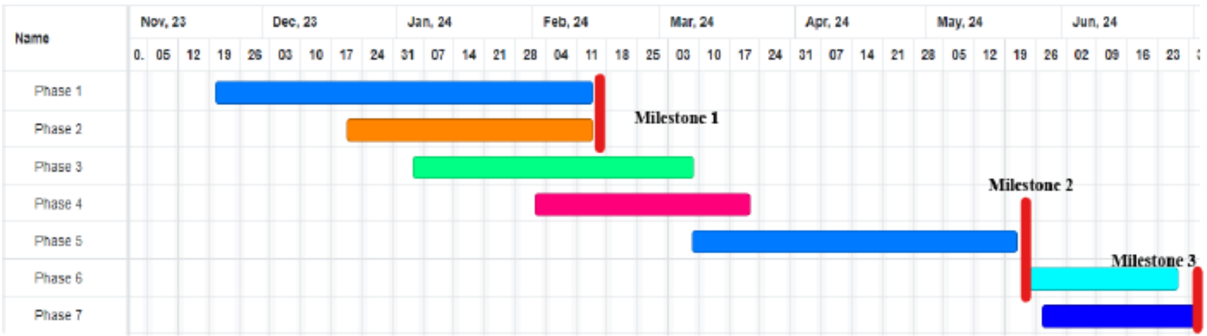

Figure 6: “Milestones of the Project”

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