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Expansion of Base Station Coverage Area Based on Sector Expansion on Lombok Island

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Abstract — Developing telecommunications infrastructure is vital for national advancement, improving connectivity to accelerate information flow and access to public services. Effective base station planning prioritizes maximizing network coverage in densely populated areas. However, traditional visualization methods often fall short in identifying regions with the highest population density. This study addresses this gap by applying a sector expansion algorithm to select optimal base station locations within the most densely populated sectors, achieving more balanced network coverage. Using Indonesia's population data and administrative boundaries, optimal base station locations are determined with DBSCAN and K-Means clustering algorithms. The network's reach is then enhanced through sector expansion to increase coverage in areas with high population density by selecting new base station locations based on the densest sector around a primary station. The candidate station is positioned at a distance of three-quarters of twice the radius of the primary station, optimizing coverage while remaining close to existing network resources. The evaluation compares population coverage before and after sector expansion, assessing connectivity between base stations and distribution efficiency. Results show that sector expansion increased population coverage on Lombok Island from 15.94% to 99.14%, with the most populated base station covering up to 34,274 people, enhancing distribution efficiency.

Keywords: Base station, coverage area, sector expansion, telecommunication

I. INTRODUCTION

The development of telecommunication infrastructure is essential for national progress, as it provides connectivity that accelerates information dissemination, supports the digital economy, and enhances access to education, healthcare, and other public services (Imasheva & Kramin, 2020; Kurniawati, 2022; Maneejuk & Yamaka, 2020; Olivia Theophilia & Riko Setya Wijaya, 2023). A strong telecommunications network enhances connectivity across economic sectors, enabling cross-regional and international collaboration while creating new job and business opportunities. (Ma et al., 2020). Additionally, this infrastructure assists the government in managing territories more effectively and supports national security through reliable and rapid communication (Anggara Putra, 2021; Hamid et al., 2024; Mufti Prasetiyo et al., 2024; Syahputra et al., 2024).

According to a survey by Indonesian Internet Service Providers Association (Asosiasi Penyelenggara Jasa Internet Indonesia, APJII), internet penetration in Indonesia in 2024 is projected to reach 79.50% (Asosiasi Penyelenggara Jasa Internet Indonesia, 2024). However, this national average masks significant regional disparities across the archipelago. For instance, Nusa Tenggara Barat (NTB) demonstrates a penetration rate of only 66.11%, substantially lower than the national average. This gap highlights the uneven distribution of internet accessibility and infrastructure, which may stem from geographical challenges, limited digital literacy, or differing socioeconomic conditions in NTB compared to more developed regions such as Java or Bali. Specifically, on Lombok Island, many rural areas still lack adequate connectivity, further exacerbating the digital divide within the province (Pratama Chrisna Putra & Djunita Pasaribu, 2023).

In planning the construction of base stations, the primary objective is to maximize coverage so that services can reach as many users as possible with an efficient amount of infrastructure (Isabona et al., 2023; Muharram & Suyanto, 2020). Each base station is designed for optimal range and to minimize unnecessary overlap with nearby stations to ensure that signal distribution is even, providing adequate service throughout the target area (Farej & Al-Najafi, 2020; Ryu & Jung Joon-Young, 2020). However, certain overlap areas are necessary to facilitate handover, allowing users to move seamlessly between networks without losing connectivity as they travel across coverage areas (Umar et al., n.d.).

Mobile operators often rely on manual visualization methods through simulators to determine potential base station locations. However, this approach has significant limitations in terms of time and accuracy. The process requires engineers to manually place points, which often fails to optimally account for population distribution. As a result, potential base station locations may be designated in areas with low population density, making network coverage less effective in serving the needs of densely populated areas.

A proposed solution for determining potential base station locations is to implement a sector expansion algorithm aimed at increasing network coverage in areas with high population density. This approach uses an algorithm to select new base station locations by identifying the sector with the highest population concentration around a primary base station. Each sector is analyzed to determine the one with the densest population. Once the optimal sector is identified, the candidate base station is placed at a distance of three-quarters of twice the radius of the primary station. This positioning keeps the candidate station close to the resources of the primary network while optimizing coverage in areas with high network demand.

Several prior studies have explored optimization techniques for base transceiver station (BTS) placement, such as the firefly algorithm and genetic algorithms. Muharram and Suyanto (2020) (Afuzagani & Suyanto, 2020; Muharram & Suyanto, 2020) applied the firefly algorithm to optimize LTE BTS placement, while Isabona et al. (2023) (Isabona et al., 2023) used a multi-objective genetic algorithm to balance network coverage, capacity, and power consumption in 4G LTE networks.

This research aims to develop a more effective method for identifying potential base station locations by considering population density and network demands in densely populated areas. Unlike prior studies, which primarily focused on network coverage or capacity optimization, this study introduces a sector expansion algorithm that not only enhances network coverage efficiency and optimizes base station placement to maximize service reach without excessive overlap but also ensures seamless connectivity for smooth handovers. The algorithm also takes into account the maximum population within the coverage area, improving network performance and meeting regional demands more effectively.

This approach is expected to provide significant practical benefits, particularly in operational cost savings. Through more efficient BTS placement optimization and reduced coverage overlap, network operators can save more than twice the cost compared to traditional planning methods. By maximizing network reach and capacity in densely populated areas without the need for additional BTS construction, both investment and maintenance costs can be minimized. This not only enhances operational efficiency but also enables more precise resource allocation to support the broader development of network infrastructure, fostering digital economic growth and improving public service access.

II. METHOD

This research adopts a data-driven approach to plan base station placements by considering the population distribution and spatial aspects of the service area. Various spatial data analysis and clustering techniques are used to identify optimal locations for base stations. The planning process begins with collecting population data and administrative boundaries within Indonesia, which are then processed using clustering algorithms to determine initial base station locations based on the highest potential service coverage. Subsequently, a base station placement model is developed using a sector expansion method to extend coverage reach and ensure optimal connectivity between base stations. The research outcomes are evaluated and analyzed to assess improvements in population coverage, inter-base station connectivity, and the population reached by each base station. Figure 1 illustrates the block diagram for the methodology used in this study.

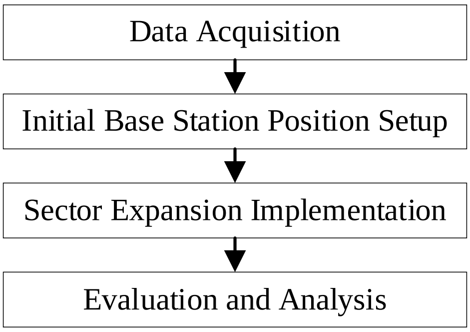

Figure 1. Method block diagram

A. *Data Acquisition*

The data used in the base station planning system includes two main types of data: population data (Aiken et al., 2022) and spatial administrative boundary data (Pratesi et al., 2021). Both are sourced from the Humanitarian Data Exchange (HDX) platform managed by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA).

1. Population Data: The population data is provided in CSV format and includes information on longitude, latitude coordinates, and population numbers at each point across Indonesia. This data offers a detailed view of population distribution across various regions, which is crucial for determining coverage and planning the effective placement of base stations.
2. Spatial Administrative Boundary Data: This data is available in Shapefile format and includes administrative boundaries up to level 4 (village or subdistrict) in Indonesia. Each administrative region is represented with geometry in the form of POLYGON or MULTIPOLYGON (Warnier et al., 2020), defining the boundaries of each area. This data is used to delineate and group regions to be served by base stations.

Both datasets are spatially merged using the `sjoin()` function to determine the population within each administrative boundary (McClain, 2023). The data can then be filtered by administrative level, such as province, district/city, subdistrict, or village, to generate recommendations for optimal base station placement. Figure 2 shows the population filter for the Lombok region.

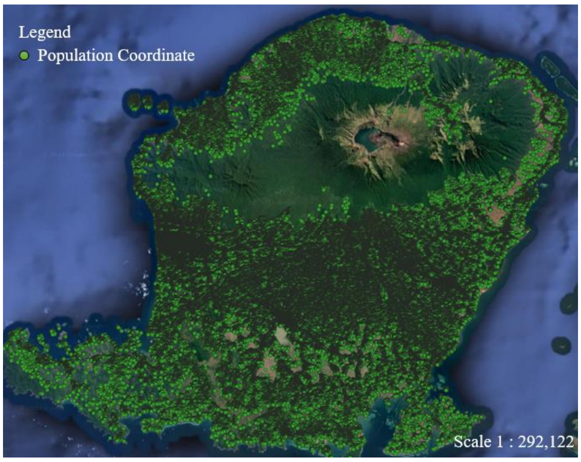

Figure 2. Population filter applied to the Lombok region

B. *Base Station Position Initialization Using DBSCAN and K-Means Algorithms*

In this study, the existing base station data is unavailable, so the initial placement of base stations begins by clustering population data to identify densely populated areas suitable for base station locations. First, the Density-Based Spatial Clustering of Applications with Noise (DBSCAN) algorithm (Tu et al., 2022) is applied with an epsilon of 250 meters to identify areas with high population density, resulting in clusters relevant for base station placement. Figure 3 illustrates the population clustering using DBSCAN before being refined by K-Means clustering.

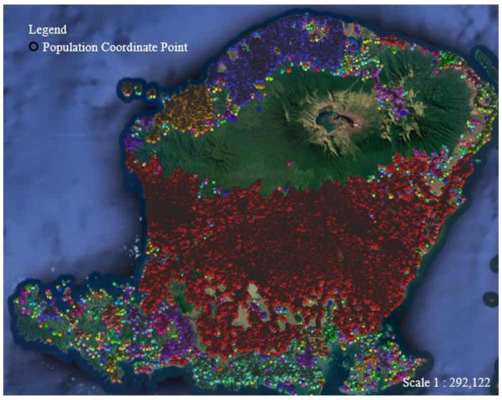

Figure 3. Population clustering using DBSCAN before refinement by K-Means clustering.

The selection of an epsilon value of 250 meters in the DBSCAN algorithm is based on testing various epsilon values ranging from 200 meters to 1000 meters with a step size of 50 meters. In the epsilon range of 200 to 250 meters, the clusters formed are small and well-separated, but at an epsilon value of 250 meters, the clustering becomes more optimal, encompassing relevant points without merging points that are too far apart, while minimizing noise. On the other hand, epsilon values larger than 250 meters, such as 300 to 1000 meters, start to form overly large clusters that are less representative, blurring the distinctions between different population areas. Therefore, epsilon 250 meters was chosen as the most effective value, providing the right balance between accurate clustering and noise avoidance.

After the initial clusters are formed, each DBSCAN cluster is further divided using the K-Means algorithm to ensure that the area of each cluster does not exceed 100 km² (Li et al., 2023). This division allows for more base stations to be formed in larger clusters, improving service coverage. K-Means groups the points within the DBSCAN clusters based on geographical distribution, ensuring each sub-cluster has appropriate population density and area size for effective base station functionality., while Figure 4 shows the result of the DBSCAN clusters after refinement by K-Means clustering.

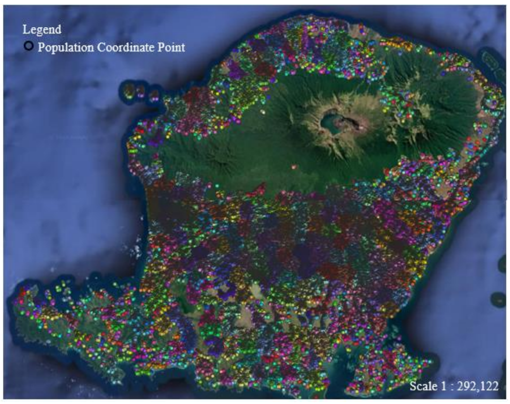

Figure 4. Population clustering after DBSCAN refinement with K-Means clustering.

After applying the K-Means algorithm to refine each DBSCAN cluster, a centroid is assigned to the center of each refined cluster. This centroid represents the geographical center of the cluster after it has been divided into smaller, more manageable sub-clusters. The centroid is recalculated based on the spatial distribution of the points within each refined cluster, ensuring that it accurately reflects the optimal location for a potential base station. These centroids serve as the potential base station locations, chosen for their ability to best serve the surrounding population while maintaining an efficient area size for effective coverage.

To evaluate potential overlap between base station centers, a buffer zone with a radius of 1000 meters (Onidare et al., 2020) is created around each base station. If the buffer zones of two or more base stations overlap with the center of a base station, the less populated base station is removed from consideration to minimize overlap. This process continues iteratively, removing the least populated base stations, until no buffer zones overlap with any base station center. This ensures that the remaining base stations are optimally spaced, with minimal interference, and located in areas of higher population density.

To ensure optimal network connectivity, each base station must be positioned such that it has at least one neighboring base station within a specified maximum distance, ideally sharing a side of their respective hexagonal coverage areas. This approach creates a seamless network where base stations are strategically placed in proximity, minimizing coverage gaps and maximizing signal strength. If a base station does not share its hexagon side with any neighboring base station, it becomes isolated and risks reduced connectivity and network efficiency. In such cases, these isolated base stations shoul d be excluded from the network plan to maintain overall coverage quality.

C. Expansion of Base Station Coverage Area Based on Sector Expansion

The use of DBSCAN and K-Means clustering methods for base station placement indicates that the coverage area is insufficient. Therefore, a coverage expansion strategy is implemented by adding new base stations through a sector expansion method. In this approach, each existing base station is divided into small sectors with a 5-degree angle, resulting in a total of 72 sectors per base station. Each sector has its radius expanded to twice the initial base station radius, serving as potential locations for new base station placements.

To create a 5-degree sector, a central point is defined using its latitude and longitude coordinates, along with a specified radius. The sector is formed by determining two points on the circle's perimeter, calculated using trigonometric functions or geodesic computations for spherical geometry. These points correspond to the start and end angles of the sector, which are spaced 5 degrees apart. The sector is then represented as a polygon, with the centroid as one vertex and the two calculated perimeter points forming the other vertices.

These small sectors are then combined to form possible sectors with a 65-degree angle. The population within each sector combination is calculated by merging the sector geometry with population data using the `sjoin()` function from the geospatial library. From this merge, the total population for each sector is computed, enabling the selection of sectors with the highest population as targets for new base station placements to expand coverage.

To generate consecutive sectors with a 65-degree span, sectors are grouped into combinations of 13, each covering 5 degrees, ensuring a total span of 65 degrees for each group. Circular logic is applied to handle wrap-around at 360 degrees, allowing seamless group selection even when sectors are near the angular boundary (e.g., from 350° to 55°). For each group, the central azimuth of the combined sectors is calculated using circular averaging, which accounts for angular wrap-around to provide an accurate representation. The geometries of all sectors within a group are merged into a single polygon to represent the coverage area of the 65-degree span.

These combined geometries are spatially joined with population data to compute the total population within each group's coverage. The group with the highest population is then identified for each unique location. This result includes essential information such as the azimuth, geometry, and centroid coordinates of the most populated sector group. Longitude and latitude values are extracted for visualization or further analysis, ensuring the approach focuses on areas with the highest population density while maintaining consistent azimuthal spans across all groups.

Once the sector with the highest population is identified, a new point is created at three-quarters of the distance from the center of the original base station. This point serves as the potential location for a new base station. A buffer is then created around this point with a radius equal to the original base station’s radius (1000 meters) (Onidare et al., 2020), representing the coverage area of the new base station. At this stage, it is checked whether the new base station’s buffer intersects with the center of any nearby base station. Figure 5 illustrates the creation of a new potential base station resulting from the expansion of an existing sector.

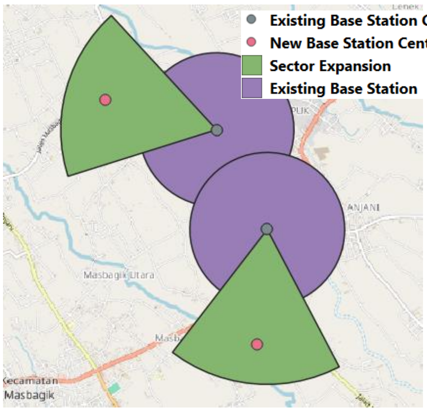

Figure 5. Potential new base station created through sector expansion

To create a centroid representing a base station at 3/4 of the sector's radius from the original eNodeB centroid, the process begins by converting the radius from meters to degrees (R) using the conversion factor (1 degree ≈ 111,320 meters). Then, the azimuth angle (θ), provided for each sector, is used to calculate the offset in both the x (longitude) and y (latitude) directions using trigonometric functions. Equation 1 and Equation 2 are trigonometric functions used to calculate the offsets in both the x and y directions.

$$X_{offset} = \frac{3}{4} \times R \times \sin\theta \tag{1}$$

$$Y_{offset} = \frac{3}{4} \times R \times \cos\theta \tag{2}$$

The resulting offset is added to the original eNodeB's coordinates, creating a new point at the desired location. A buffer is then applied around this new centroid using the `buffer` function, which represents the coverage area. The buffer function creates a circular area around the new centroid with a radius equal to the sector's radius. Spatial joins are then performed to check for intersections with other centroids. Any overlapping buffers are removed to ensure proper sector placement, avoiding conflicts between adjacent sectors.

New base stations whose buffer areas overlap with the center of the nearest base station are eliminated. Additionally, if two or more new base stations have overlapping buffers, the one with the smallest buffer area is removed first until there is no more overlap (Sumathi et al., 2022). This process ensures that each base station’s coverage remains effective and does not interfere with others.

This process is repeated for the population data that remains outside the coverage of existing base station buffers. New base stations that pass the selection are then merged with the original base station data using the `concat()` function, becoming part of the base station data and treated as new base stations. This step is repeated until all population data is covered by existing or new base stations, or until no more base stations can be added.

D. Evaluation and Analysis

Before applying the sector expansion method, the coverage area of existing base stations is calculated to determine the total population reached. Then, the sector expansion method is applied to extend the coverage area and add more base stations as needed to reach the unserved population. The change in population coverage is compared as a percentage between the conditions before and after the sector expansion method is applied. This comparison measures the effectiveness of the method based on the increase in population coverage.

Each iteration of the sector expansion method records the cumulative number of base stations formed and the additional population reached. This data reflects the success of the sector expansion method in expanding population coverage during each iteration. With this tracking, the impact of each expansion stage on coverage can be analyzed, and the rate at which coverage improves over time can be assessed.

To ensure good connectivity between installed base stations, clustering is performed on all base stations. In this analysis, base stations that are connected to one another are considered part of the same cluster. This process aims to assess network unity and estimate the connectivity between base stations in the network. After clustering, the number of base stations in each cluster is recorded, allowing for analysis of how many clusters are formed and how many base stations are in each cluster.

The results of this clustering analysis are visualized in a bar graph to show the distribution of base stations per cluster. Additionally, the average population reached per base station is calculated for each cluster. The distribution of population per base station helps determine whether each base station is optimally placed to serve the local population. Thus, this analysis not only evaluates overall population coverage but also assesses the connectivity between base stations and the efficiency of network deployment.

III. RESULTS

The final results show the initial placement of base stations on Lombok Island, which was determined using population clustering with the DBSCAN and K-Means algorithms. These base stations, positioned prior to any sector expansion, represent the foundational network setup aimed at reaching as much of the population as possible with the available infrastructure. Figure 6 illustrates this initial distribution of base stations across Lombok Island, based on the clustering approach, highlighting the areas of coverage achieved before implementing sector expansion to enhance network reach further.

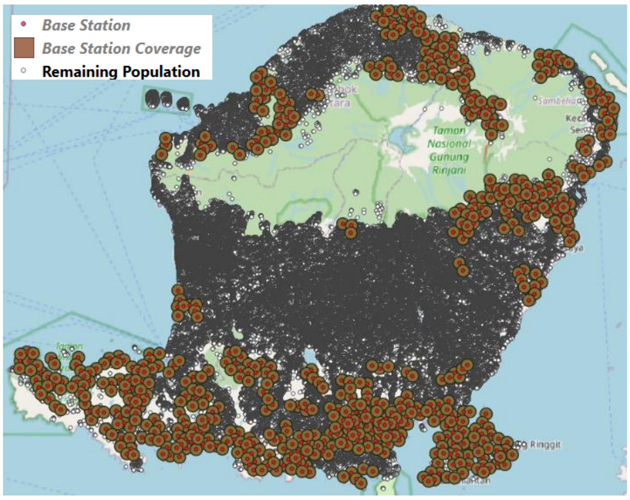

Figure 6. Base stations on Lombok Island before sector expansion

The results also demonstrate a significant increase in the number of base stations following the implementation of sector expansion. Sector expansion allowed each existing base station to expand its service radius and create additional points of coverage, resulting in improved population reach and network density. Figure 7 shows the distribution of base stations on Lombok Island after applying the sector expansion method.

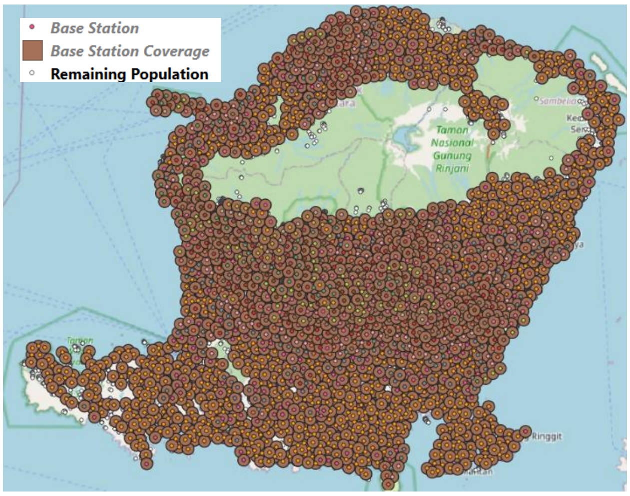

Figure 7. Base stations on Lombok Island after sector expansion

IV. DISCUSSION

This study utilizes population data from 2020, which may affect the accuracy of the results due to potential discrepancies in population distribution or density in subsequent years. Changes such as urbanization, migration, or demographic shifts after 2020 could lead to differences between the modeled predictions and current realities, highlighting the need for cautious interpretation and consideration of updated data for future analyses.

The result in Figure 6 show, that the initial placement of base stations on Lombok Island, based on population clustering using the DBSCAN and K-Means algorithms, resulted in 628 base stations that can serve 571,466 individuals, or approximately 15.94% of Lombok Island's total population of 3,584,810. The results also indicate that 50% of the total base stations serve populations ranging from 570 to 1,902 individuals per station, with an average of 1,383 individuals per base station, and the base station serving the largest population covers up to 7,801 individuals.

The initial coverage area was then expanded using the sector expansion method, which successfully increased the number of base stations to 1,220, a 194.27% increase. By applying this method, the total base stations on Lombok Island grew substantially, from the initial setup to a larger network aimed at optimizing population coverage. Population coverage also grew, reaching 3,553,866 individuals, or approximately 99.14% of the total population, with a 521.89% increase in coverage. The data shows that 50% of the base stations cover populations ranging from 875 to 4,318 individuals per station, with an average of 3,125 individuals per base station, and the base station with the highest coverage serves up to 34,274 individuals. Thus, the sector expansion method increased the average number of individuals served per base station by 125.95%. Additionally, only one cluster of base stations was formed on Lombok Island, indicating that all base stations are interconnected.

Table 1 shows the development of the number of base stations and the population covered in each iteration of the telecommunications infrastructure expansion plan. In the initial iteration, there were 628 base stations covering 15.94% of the population, with an average of 1,383 individuals per base station. As the number of base stations increased in each iteration, the population coverage grew significantly, reaching 99.14% by the 16th iteration with 1,848 base stations. At each stage, the population per base station and the overall coverage percentage increased, reflecting the expected network coverage expansion.

Table 1. Number of Base Stations
and Population Covered in Each Iteration

Iteration	Number of base stations	Population covered (people)	Percentage
existing	628	571,466	15.94%
1	812	906,666	25.29%
2	970	1,187,519	33.13%
3	1,113	1,481,588	41.33%

Iteration	Number of base stations	Population covered (people)	Percentage
4	1,221	1,748,063	48.76%
5	1,325	2,061,729	57.51%
6	1,416	2,383,209	66.48%
7	1,507	2,677,121	74.68%
8	1,587	2,957,260	82.49%
9	1,652	3,163,867	88.26%
10	1,705	3,315,082	92.48%
11	1,754	3,424,958	95.54%
12	1,790	3,497,319	97.56%
13	1,813	3,522,915	98.27%
14	1,837	3,550,996	99.06%
15	1,843	3,552,558	99.10%
16	1,848	3,553,866	99.14%

Additionally, Table 2 shows the distribution of the population served by the base stations through the interquartile range (IQR), which continuously increases with each iteration. In the initial iteration, the IQR ranged from 570 to 1,902 individuals, then increased to 878 to 4,318 individuals by the 16th iteration. This total range covers 50% of the population served by each base station, and the increase indicates a growing population within the coverage of half of the base stations, reflecting not only a broader reach but also an increase in capacity and service access for the covered population.

Table 2. Number of Base Stations,
Population Covered, and Per Base Station in Each Iteration

Iteration	Population per base station (people)	Maximum population per base station	Interquartile range
existing	1,383	7,801	570 – 1,902
1	1,630	9,634	599 – 2,221
2	1,799	12,991	654 – 4,402
3	1,237	27,441	687 – 2,645
4	2,147	31,745	706 – 2,797
5	2,362	33,168	741 – 3,011
6	2,565	34,274	770 – 3,204
7	2,727	34,274	802 – 3,497
8	3,793	34,274	822 – 3,793
9	2,965	34,274	829 – 3,980
10	3,042	34,274	867 – 4,143
11	3,089	34,274	875 – 4,218
12	3,124	34,274	877 – 4,282
13	3,120	34,274	875 – 4,275
14	3,130	34,274	875 – 4,314
15	3,128	34,274	878 – 4,321
16	3,119	34,274	878 – 4,318

The coverage increase from 15.94% to 99.14% has the potential to improve cost efficiency by 155.66%. This is based on a comparison of the population per existing base station, which is 1,383, with the population per base station after the implementation of the sector expansion method, which reaches 3,119. By optimizing the placement and coverage of base stations, the sector expansion method significantly enhances network efficiency and cost-effectiveness.

Table 3 presents the coverage percentages of different methods used for base station optimization. The results indicate that the sector expansion method achieves the highest coverage at 99.14%, outperforming the other methods listed. The firefly algorithm and the hybrid evolutionary firefly algorithm provide coverage of 97.73% and 98.62%, respectively, with references to studies by (Afuzagani & Suyanto, 2020; Muharram & Suyanto, 2020). The Multi-objective Genetic Algorithm, cited by (Isabona et al., 2023), shows the lowest coverage at 96.08%. This comparison demonstrates that the Sector Expansion method provides the best coverage, offering an optimal solution for base station optimization in terms of coverage area.

Table 3. Coverage Percentage of
Different Methods for Base Station Optimization

Method	Coverage Percentage (%)	Reference
Sector Expansion	99.14	This Study
Firefly Algorithm	97.73	(Muharram & Suyanto, 2020)
Hybrid Evolutionary Firefly Algorithm	98.62	(Afuzagani & Suyanto, 2020)
Multi-objective Genetic Algorithm	96.08	(Isabona et al., 2023)

V. CONCLUSION

The conclusion of this study indicates that the application of population clustering methods using the DBSCAN and K-Means algorithms for base station placement in Lombok Island successfully increased population coverage significantly. In the initial iteration, 628 base stations covered 15.94% of the total population, with an average of 1,383 individuals per base station. After implementing the sector expansion method, the number of base stations increased to 1,220, covering 99.14% of the population, with an average of 3,119 individuals per base station. The sector expansion method provides the highest coverage percentage compared to the other methods evaluated, making it the most effective for base station optimization.

The sector expansion method also successfully enhanced the capacity of base stations to serve the population, with the largest base station covering up to 34,274 individuals. The iterative process demonstrated a significant increase in the population covered and service capacity, reflecting the success of telecommunication infrastructure planning in meeting population needs more evenly and efficiently. The results show a potential increase in cost efficiency of 155.66% by comparing the existing population per base station with the final result of the sector expansion method. The algorithm can be directly utilized by telecommunications operators to optimize site placement and improve network efficiency in underserved regions.

This study demonstrates that the sector expansion method increases the population coverage of base transceiver stations (BTS), but it does not address service quality. Future research could examine signal strength parameters and external factors such as terrain type, building density, and signal interference from nearby objects, all of which affect service quality. Additionally, considering population movement or migration patterns that influence base station distribution is crucial.

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