scitation.org/journal/apc

AIP Conference Proceedings

Volume 2542

The 4th International Conference on Science and Science Education (IConSSE 2021)

Integrating Rapid Technology and Whole Person Education in Science and Science Education to Encounter the New Normal Era

Salatiga, Indonesia • 7–8 September 2021

Editors • Didit Budi Nugroho, Andreas Setiawan, Nur Aji Wibowo, Cucun Alep Riyanto and November Rianto Aminu

AIP Publishing

Optimizing WLAN access point placement using geospatial technique

Cite as: AIP Conference Proceedings **2542**, 040005 (2022); https://doi.org/10.1063/5.0103208
Published Online: 10 November 2022

Agustinus Bayu Primawan

Optimizing WLAN Access Point Placement using Geospatial Technique

Agustinus Bayu Primawan[a)]

Electrical Engineering Department, Universitas Sanata Dharma Yogyakarta
Kampus III-USD, Paingan, Maguwoharjo, Depok, Sleman, Yogyakarta, Indonesia

[a)]Corresponding author: bayu@dosen.usd.ac.id

Abstract: Designing network deployment requires a selected skill to perform effective planning. Within the study of wireless networking, nowadays, design-and-adjustment approach has replaced experience-based approach. Applying optimization technique on network planning will reduce cost and time consumed in comparison with trial-and-error technique. GIS spatial analysis are going to be useful to perform prediction of coverage and signal strength. Integrating spatial data analysis and programming technique can then cause improvement of wireless network design. Combining priority location solution and evolutionary algorithm will provide an answer for optimum access point location. This system of access point placement was successfully implemented. Signal prediction technique supported empirical model was found to be better than log- distance and cost231 Hatta model. However, cost231Hatta gives the simplest solution for the location problem. The optimization result from the proposed solution gives maximum coverage area with minimum number of access point.

INTRODUCTION

Deploying wireless LAN (Local Area Network) enables users to access network applications and resources anytime and anywhere. Wireless access point nowadays is often found publicly service buildings, campus areas, etc. Digital campus network is that the most appropriate option to provide internet access to the whole campus area, just in case an outsized number of access points are needed, and a few extra works are required to design access point deployment for an outsized area. Optimization of placement point has been proposed using different methods and models. Some optimization techniques use path-loss, while others use grid location because the objective function.

The usual approach used for designing access point placement is best-guess approach during which a design is developed supported experience by placing access points within the desired coverage area. This design scenario is typically followed by a site survey to make sure the connectivity of the network. It is then followed by a labor-intensive procedure to regulate the access point location, i.e., moving or deploying the access point to a replacement location to hide blank spot areas or to scale back overlay coverage. The full process consumes plenty of time and price [1]. This approach may produce a viable network design for a little area, but it will fail to create a network for a bigger area, which is more complicated [2]. Thus, the approach used for solving wireless access point placement problem nowadays has shifted from an intuitive approach to design-and-adjustment approach.

A model for coverage mapping and prediction is required to explore and investigate a far better design. Additionally, site survey helps define the contour of frequency coverage during a particular facility or a specific area. Some propagation models from site survey are proposed for signal strength prediction [3]. One among the models is Geospatial Kriging Analysis, which is an analysis in geospatial that uses spatial interpolation. Spatial interpolation may be a way of estimating the worth of un-sampled properties from an unknown location supported observed values at known locations. The interpolation methods that have been developed are inverse distance weighted, spline, natural neighbors, Kriging, etc. Signal strength can then be displayed within the sort of filled contour or other types.

Several GIS analyses are proposed to develop signal coverage visualization and calculation [4, 5]. Methods like neural network prediction and Kriging prediction are wont to predict the worth of received signal strength [6].

The 4th International Conference on Science and Science Education (IConSSE 2021)
AIP Conf. Proc. 2542, 040005-1–040005-11; https://doi.org/10.1063/5.0103208
Published by AIP Publishing. 978-0-7354-4259-7/$30.00

Meanwhile, nearest distance analysis is employed to display receiving point to access point connection in terms of the coverage radius. The result of nearest distance analysis is displayed in a table showing receiving points that are located within the coverage area of every access point. Furthermore, combining spatial analysis and optimization to develop a network design remains needed so as to assess whether GIS-based electromagnetic analysis has been performed by [5] and its implementation in sensor network coverage by [7]. Whether, suitability location as so to seek priority location has been proposed in ecotourism [8] and hospital [9]. It might be adopted into priority location for access point placement problem.

The GIS-based optimization is additionally proposed during a specific network [10]. Some simulation and design coverage signal analyses even have been implemented in several previous studies [11, 12]. The analyses are needed to enhance design effectiveness. Implementation of systems integration is important so as to accommodate the dynamic changes of the network and therefore the environment information to urge the minimum number of AP with the optimum coverage area.

This paper discusses the optimization of deployment of access point placement supported location distance and coverage analysis of the signal strength. The optimum number of access point and signal strength coverage gives the simplest result for the specified location and priority placement area. Furthermore, a comparison of field measurement and computation gives a particular result when designing the network. This method will provide a reproducible approach to research wireless access point coverage also as techniques for predicting signal strength with propagation model.

MATERIAL AND METHOD

The Study Areas

The study areas of this experiment are the student dormitory area and the academic area within Asian Institute of Technology campus. The campus is in Pathumthani Province of Thailand, which falls into geographical projection coordinate system UTM WGS 1984 N47. The size of the study area is 1,311,147.811588 square meters or around 131 hectares that consists of academic building, laboratories, administrative building, student dormitory, student residence and open space areas. The access point locations in the study area are deployed to give internet access as the campus facility to the academic community. The location was chosen because the existing access point placement is very dense, too close to one another. Within the existing access points' location, the optimization process tries to deploy an alternative placement to cover the area with a minimum number of access points and a maximum coverage area.

Methodology

The research was conducted by following procedures like device requirement, field data collection, network optimization, that resulted in data map development. Within the beginning, network device specifications were defined, i.e., the utmost power output of the Access Point of 100mW, which suggest a maximum coverage radius of 100m and coverage signal direction of omni-directional. Furthermore, field data collection was performed to urge the RSSI (Received Signal Strength Indication) field strength from several RP (Received Point) locations to a specific AP that was being assessed. This measured field strength is going to be wont to develop coverage prediction of the network strength based on the receive point testbed.

GIS modeling for interconnection of RPs and APs was developed to calculate the Euclidean distance, followed by analyzing priority locations supported analytical hierarchy process. Optimum AP locations were determined based on distance and signal strength. Subsequent step was to develop an output of coverage map of field strength with geospatial analysis. Within the analysis, Kriging prediction was employed to predict the worth of the whole area supported a known value. Data collected from the RSSI within the sample of RPs were then wont to find the coverage signal of the study area. Furthermore, deterministic coverage area was calculated with the classical model of the path loss equation which consists of: $L_{0,dbm}$ is RSSI from the received signal during which the distance d_0 adequate to 1 m, n is that the correction factor of the environment that is interpolated from the measured signal strength which is defined as 2, d is that the distance between RP and AP location. Finally, a comparison between calculation and field measurement and propagation model was performed to gauge the coverage area.

Database of APs and RPs provides information about location and measured RSSI for every RP location from each connected AP. This database includes Location of Access Point (Longitude and Latitude in UTM), Location of

Received Point (Longitude and Latitude in UTM), calculated distance between APs and RPs covered, measured field strength of the RP to the assessed APs in a certain location of each covered area, MAC Address of the accessed APs, and therefore the Location name of each assessed AP.

Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a well-known tool in a multi-criteria decision making. This tool was first proposed in 1977 by T.L. Saaty. AHP has been utilized by some researchers to solve complex decision problems. This device uses multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. Pairwise comparison is used to derive the pertinent data. These comparisons are then used to get the important weight of the variables [13]. The relative performance will measure its alternatives in terms of each individual decision criteria. This also provides a mechanism to improve the consistency of the criteria.

In AHP, pairwise comparison in a judgment matrix is adequately consistent if the corresponding consistency ratio (CR) is less than 10%. Furthermore, the CR is calculated by estimating the consistency index (CI) first. Then, the CI will be divided by the Random Consistency Index (RCI) that has been given.

FIGURE 1. Desired Location Footprint of APs

The footprint of the desired location to perform AHP is displayed in Fig. 1. This footprint was defined as the desired potential locations for access point placement. The potential locations include academic building, administrative building, student-residences, and recreational places. The footprint database consists of location names, score of priority in terms of building type, location, and user access number. The data collection was performed by gathering information from the Office of Asset Management of AIT, IT Infrastructure Management Unit of AIT and field data collection.

TABLE 1. Criterion data.

1st	2nd	Score
Building Type	Recreational	1
	Staff Residential, Administrative	2
	Laboratory	2
	Academic, Student Resident	3
Location	Inside building	1
	Outside building	2
Number of Users	<30	1
	30–60	2
	>60	3

The criteria for AHP process are building, location and user access number. The building criteria are differentiated into recreational, residential, and academic. However, location is a placement location which can be inside the building (indoor) or outside the building (outdoor). The user access number can be differentiated into less than 30, between 30 to 60, and more than 60 users. Complete criteria and their scores can be seen in Table 1.

Based on experience and expertise, feedback on the relative importance of the criteria that were calculated in pair-wise calculation matrix was obtained; the matrix is displayed in Table 2. From this comparison matrix, it can be concluded that user access is more important than building type and location, while location is more important than building type. The number of user access will be strongly important due to customer-experience quality. Meanwhile, building type is considerably less important than location placement category.

Table 2. Pairwise comparisons matrix.

	User	**Building**	**Location**
User	1.00	7.00	3.00
Building	0.14	1.00	0.33
Location	0.33	3.00	1.00
Σ	1.48	11.00	4.33

Optimization of Location Allocation Problem

The coverage optimization method, which is adopted from an "Island-based Algorithm" [14] that was also implemented in radio networking [15]. The model can be seen in Fig. 2. This method assumes to cover the area of the transmitter which is defined as the surface covered by a set of transmitters [16]. A geographical location is said to be covered when it can receive the signal from the transmitter with maximum distance threshold. Minimizing operation is finding the minimum distance by comparing the total distance from node *i* to node *j*. The optimum solution is the minimum total distance of each location to another location. It can be derived as:

$$\text{Minimize } d_{i,j} = \sum_{i=1}^{N} \sum_{j=i+1}^{N} \sqrt{\left(M_{X_j} - L_{X_i}\right)^2 + \left(M_{y_j} - L_{y_i}\right)^2} \quad (1)$$

$$\text{Subject to}$$
$$x, y \in R$$
$$d_{ij} \leq \text{radius}, \forall_{ij} = 1, \dots, N$$

The parameters used in this optimization modeling can be described as follows.

- x is the node coordinate of longitude in *X-Y* plane
- y is the node coordinate of latitude in *X-Y* plane
- i is the starting node
- j is the end node
- d is the Euclidean distance between node *i* and node *j*
- M is the transmitter group
- L is the receiver group
- N is the number of interconnection between transmitted point and received point

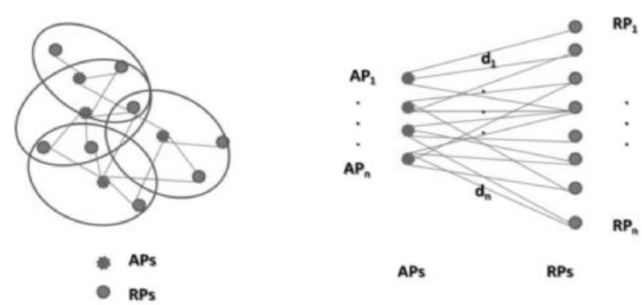

FIGURE 2. Island-based algorithm model for optimization of AP placement.

Optimizing Signal Strength

In WLAN deployment, the free space propagation model is usually used to predict the signal strength at a receiver where there is no obstruction or attenuation between the AP and RP. In terms of receiving signal power, the optimization of the RSSI calculation is given by

$$\text{Maximize } \sum_{i=1}^{N} \sum_{j=i+1}^{N} L_{ij} \quad \text{Subject to } i, j \in R \tag{2}$$

in which

$$L_{ij\,(dBm)} = L_{0(dBm)} - 10n\log_{10}(d_{ij}) \tag{3}$$

where
- d is the Euclidean distance between node i and node j
- i is the starting node
- j is the end node
- L_0 is the RSSI within distance 1 meter

$L_{ij\,(dBm)}$ is the path loss obtained at 1 meter distance from the AP, d is the distance from RP to the AP and n is an experimental result by using interpolation [17]. This model is a classical propagation model and is widely used in a large number of environments, including industrial and wide area network. Another predicted model can be derived from a log-distance model to perform predicted signal received level. This model is called the empirical predicted model. Empirical predicted model can be performed as:

$$L_{ij\,(dBm)} = L_{0(dBm)} - 10n\log_{10}(d_{ij}) - EF \tag{4}$$

EF is an environmental factor that is calculated from the received signal strength difference among the propagations with and without environment attenuation. Defining the empirical factor for empirical signal strength is conducted by performing and calculating the difference of value of measured signal strength between non-obstacle and obstacle. This empirical outdoor signal level with environment factor was obtained from the difference of signal level between LOS without environment attenuation and LOS with environment attenuation. This value is an average of the difference in volt that is converted from dBm. The predicted received signal level can be obtained as follows.

$$L_{ij\,(dBm)} = L_0 - 10n\log_{10}(d_{ij}) - 7.20 \tag{5}$$

This model was used to accommodate the environment attenuation that has impacts on the signal quality of the receiver. Some models have been proposed with different conditions [1] and another empirical model that has been formulated to simplify calculation of path loss is the Hatta Model [18]. This formula is to be used in the frequency band from 500 MHz to 2000 MHz. It is also known as COST-231 Hatta model, which is formulated as

$$L_{ij\,(dBm)} = L_0 - PL \tag{6}$$

$$PL = 46.3 + 33.9\log_{10}(f) - 13.83\ \log_{10}(h_b) - a(h_m) + (44.9 - 6.55\ \log_{10}(h_b))\log_{10}(d) + c_m \tag{7}$$

where
- f is the frequency in MHz,
- d is the distance between AP and RP in km,
- h_b is the AP antenna which is high above the ground level in m,
- c_m is defined as 0 dB for suburban or open environments and 3 dB for urban environment,
- $a(h_m)$ is defined for urban environment as

and

$$a(h_m) = 3.20\left(\log_{10}(11.75h_r)\right)^2 - 4.97 \text{ for urban and } f > 400 \text{ MHz} \tag{8}$$

or

$$a(h_m) = (1.1\log_{10}(f) - 0.7)h_r - (1.156\log_{10}(f) - 0.8) \text{ for suburban and rural} \quad (9)$$

where h_r is the RP antenna high above the ground level in m.

RESULTS AND DISCUSSION

Priority Location of Access Point Placement

The experiment has been conducted by performing models and programming optimization tools based on python programming language with Geographic Information System applications and analytical tools such as AHP for priority placement and Krigging interpolation. The analysis of priority location of the desired location was performed by weighted calculation of the pair-wise matrix in Table 2. After that, it computed the weighted value of each criterion. The complete computation is displayed in Table 3. The best criterion for access point allocation is the number of user access, followed by the location, which is then followed by type of building. The consistency of each criterion can be seen in Table 4. The random consistency index for all three criteria is 0.058, while the consistency ratio obtained is 0.061, which is acceptable as it is less than 0.1.

TABLE 3. Weighted criteria for first criteria.

	User	**Building**	**Location**	**Σ**	**Weight**	**Percentage**
User	0.68	0.64	0.69	2.01	0.669	66.87
Building	0.10	0.09	0.08	0.26	0.088	8.82
Location	0.23	0.27	0.23	0.73	0.243	24.31
Σ	1.00	1.00	1.00	3.00	1.000	100.00

TABLE 4. Consistency calculation for first criteria.

	User	**Building**	**Location**	**Σ**	**Eigen Value**
User	1.00	7.00	3.00	2.01	3.01
Building	0.14	1.00	0.33	0.26	3.00
Location	0.33	3.00	1.00	0.73	3.01
Σ	1.48	11.00	4.33	3.00	
				CI	0.004
				RI	0.058
				CR	0.061

Similarly, for the second level criteria or sub-criteria, calculation of weights and consistency ratio was done. However, because the location criteria only have two sub-criteria, weighted value was not calculated. The complete weighted sub-criteria are displayed in Table 5 and Table 6. It is shown that the consistency ratios were calculated as 0.083 and 0.079. The Access Point Priority Index (APPI) result for priority location of access point placement for all numbers of data is given as follows:

$$\text{APPI} = 0.669U + 0.243L + 0.008B. \quad (10)$$

TABLE 5. Consistency calculation for second criteria of building type.

	Recrea.	Staff. Res, Admin.	Lab.	Acad., Stud.Res.	Σ	Weight	Percent	Eigen Value
Recrea.	0.083	0.040	0.103	0.095	0.322	0.081	8%	4.16
Staff. Res, Admin.	0.250	0.120	0.069	0.143	0.582	0.145	15%	4.12
Lab.	0.167	0.360	0.207	0.190	0.924	0.231	23%	4.37
Acad., Stud.Res.	0.500	0.480	0.621	0.571	2.172	0.543	54%	4.24
Σ	1.000	1.000	1.000	1.000	4.000			
							CI	0.074
							RI	0.900
							CR	0.083

TABLE 6. Consistency calculation for second criteria of number of user.

	<30	30-60	>60	Σ	Weight	Percent	Eigen Value
<30	0.17	0.14	0.18	0.49	0.16	16%	3.00
30–60	0.33	0.29	0.27	0.89	0.30	30%	3.01
>60	0.50	0.57	0.55	1.62	0.54	54%	3.01
Σ	1.00	1.00	1.00	3.00			
						CI	0.005
						RI	0.058
						CR	0.079

The final scores were classified into three classes, i.e. low, medium and high priority. The result of priority location was performed by a raster data calculation process. Firstly, the feature data set of building type, location and user access number were reclassified based on the scoring table. Furthermore, the reclassified featured data set was then converted to raster data set, and then finally calculated by multiplication based on its weighted value of APPI result. The results of raster data calculation were then reclassified into three classes, i.e. low, medium, and high priority. The priority classification uses natural breaks in which all data subsets were divided into three intervals. This method gives an interval value of a subset. This statistical computation shows that the break values are 1.41, 2.08, and 2.75 as an interval of the priority criterion (low, medium, and high priority areas). The high priority access point locations are student dormitory, most of the student village and main academic building. The medium priority areas are parts of the student village, field of study academic building and hotel area. The lowest priority areas are the administrative building and faculty housing area. Figure 3 displays the results of the priority location which were calculated from the criteria score and its weight to get the final score.

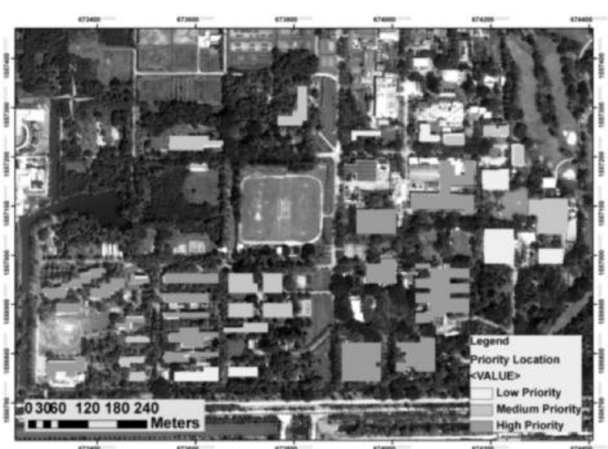

FIGURE 3. Access point priority location map.

Considering the priority locations, random access point candidates were placed into desired locations. Furthermore, it defines the access point candidate locations that will be optimized to get a solution that can be proposed to cover the areas of highest priority. These proposed AP locations will be used to calculate the distance to each covered RP. Building a connection between APs and covered RPs can be done by running an interconnection model of Fig. 4. This model has two input data, i.e., Access Points Location Table and Received Points Location Table. These two data will be connected based on a 100-meter radius of receiving points to the access points. By using nearest distance analysis, *XY* to line interconnection map could be produced. The database result was stored in an interconnection shape file. By using this shape file, the optimization process could be performed to find the optimum locations.

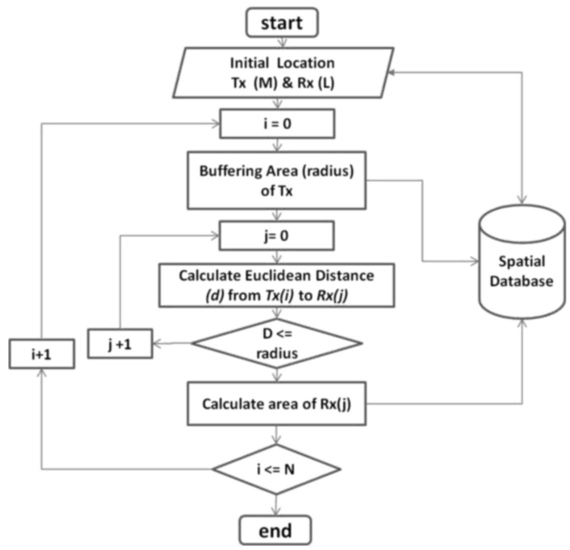

FIGURE 4. GIS model for interconnection and distance between APs and RPs.

Signal Strength Prediction

Signal strength prediction analysis is very important to find the best prediction model. Furthermore, an appropriate signal strength prediction model will give a better solution for optimum location. The measured field strength from one meter distance is known as L_0 and from the distance of received point as L_d. Coverage map is a map that shows RSSI values in a certain coverage area of all access points. These coverage maps consist of measured coverage and calculated coverage. Accuracy of the predicted signal with empirical model is better than log-distance or cost231 Hatta [19]. The empirical method more accurate than log-distance model in the case of non-environment attenuation or without obstacle, as the error of the predicted value is the smallest compared to others (see Table 7).

The result shows that the coverage area of the predicted empirical method can achieve better signal than the measured one. Using this empirical method, the design of access point placement can be used effectively [20]. This method is as effective as the other model which was previously proposed in [18].

TABLE 7. Root mean square error of the predicted RSSI to measured RSSI.

M-LD	M-E	M-C	(w/ obstacle)
14.71	11.31	12.16	

M-LD	M-E	M-C	(w/o obstacle)
9.95	7.68	10.79	

Note: M-LD is Log distance predicted to measured RSSI
M-E is Empirical predicted to measured RSSI
MC is Cost231 Hatta predicted to measured RSSI

The measured coverage map was developed from Kriging interpolation with measured RSSI data from each RP. Otherwise, the calculated coverage map comes from calculated RSSI field strength from each received point distance. This distance comes from the deterministic calculation of the signal strength equation. The coverage prediction of measured RSSI and predicted RSSI from empirical method is displayed in Fig. 5. This existing coverage signal strength was performed to receive signal level of the existing access point. These data were collected by site survey of the entire study area.

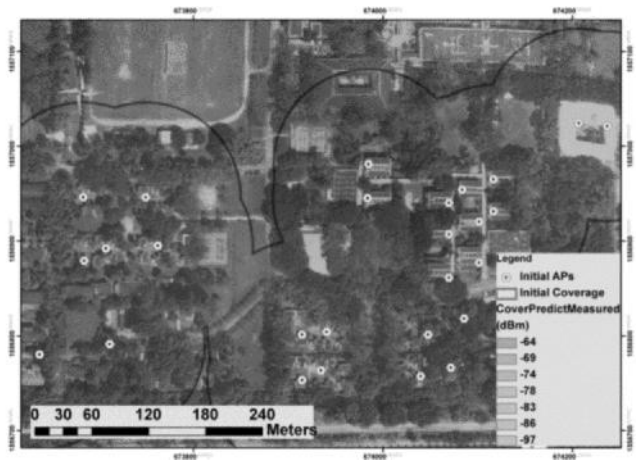

FIGURE 5. Initial coverage signal strength in the study area.

Access Point Optimization

The optimization algorithm refers to the flow chart in Fig. 6. The best AP locations use connectivity matrix access point and receive point as a basis. If a location of the access point relates to some received point locations, the signal will look for the minimum value of the distance between the access point and received point; on the other hand, if a location of the received point is connected to multiple locations of access point, the minimum distance will be calculated to determine the best location of the access point. The coverage area is calculated based on the number of receiving point locations that are connected to an access point location. If a site has a small number of received point locations, it can be said that this access point location is not necessary. Similarly, the process is done repeatedly until a true user's received point location of access point is detected to cover all locations. Basic calculation of the extent of the coverage is the value of the minimum distance and maximum signal strength.

The optimization model was developed using genetic algorithm. This algorithm has been calculated in a different number of generations. The percentage of the different optimal access point number and coverage is optimum at 1,000 generations [16]. The optimum number of generations gives the best percentage of number of access points and coverage area.

Although the empirical method gives values that are closer to the measured strength, the optimization process remains following cost231Hatta prediction model. This prediction model results in minimum number of access point with a maximum coverage area. While performing optimization with the existing scenario, log-distance prediction model gives the best coverage result; however, the number of access points needed is higher than cost231Hatta. Therefore, cost231Hatta prediction model gives the optimum solution for the placement problem.

Optimization result from the study area is shown in Fig. 7. It can be identified that 27 access points can cover most of the area of high priority locations. The predicted signal strength for the optimum access point location is shown in Fig. 8. A comparison of the optimization result with the existing access point placement shows that it can cover most of the study areas. This is very encouraging as it offers visualization of coverage quality and extent. This technique offers a solution for access point, which is suitable placement to cover maximum area. This method has provided scientific geospatial approach to overcome the problem of placing access point at one place, while some places only have few APs and weaker signal strength.

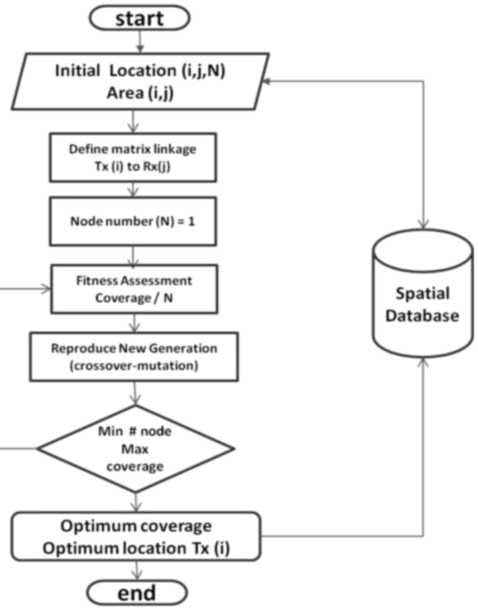

Figure 6. Optimization algorithm.

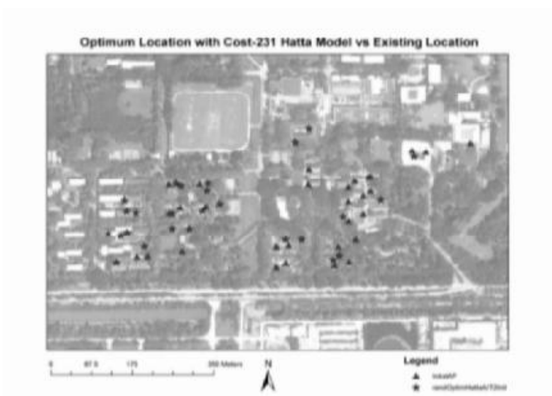

FIGURE 7. Optimum access point location.

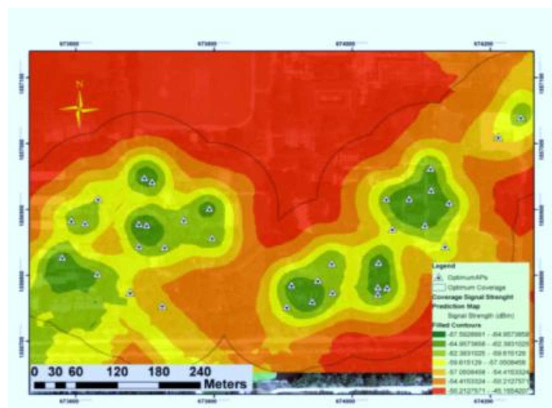

FIGURE 8. Optimum coverage signal strength of the optimum location.

CONCLUSION

In this study, deployment wireless access point placement was performed by using design and simulation scenario instead of intuitive and trial-error. An optimization technique in access point placement problem has been successfully implemented. This study reveals that combining GIS analysis and software programming gives an appropriate method in wireless access deployment design.

A coverage model based on the empirical environment method can be performed in the deployment of access point for dense areas. The proposed geospatial technique to deploy access point placement solution combines an analytical hierarchy process and island-based genetic algorithm. The signal strength and distance constraints were used to obtain the maximum coverage area and minimum number of access point.

Implementation of this proposed method by using GIS application and analysis has been found to be very useful. This proposed methodology can be implemented to design access point placement, especially for wireless device placement into desired location. For further experiments, this method can still be improved for better alternatives and solutions in wireless network design.

REFERENCES

1. A. Mc Gibney, M. Klepal, D. Pesch, "A wireless local area network modeling tool for scalable indoor access point placement optimization," in Proceedings of the 2010 Spring Simulation Multiconference (Society for Computer Simulation International, San Diego, 2010), pp. 1–8 .
2. J. Blanford and D. Renfroe, "Network Computing," available at http://www.networkcomputing.com/wireless-infrastructure/review-wireless-lan-analysis-tools/d/d-id/1215071?page_number=1
3. C. Phillips, D. Sicker, D. Grunwald D, "A survey of wireless path loss prediction and coverage mapping methods," in IEEE Communications Surveys & Tutorials (IEEE, 2013), Vol. 15, No. 1, pp. 255–270.
4. W. Muttitanon, N. K. Tripathi, and M. Souris, J. Comput. Sci. **3**, 907–913 (2007).
5. V. Barrile, G. Bilotta, F. Di, "GIS for calculating electromagnetic field," in Proceedings of the 2nd WSEAS International Conference on URBAN PLANNING and TRANSPORTATION (WSEAS Press, 2009), pp. 117–124.
6. H. Mehmood and N. K. Tripathi, Int. J. Digit Earth **6**, 158–184 (2013).
7. M. Argany, M. A. Mostafavi, F. Karimipour, and C. Gagné, Trans. Comput. Sci. **XIV**, 151–172 (2011).
8. K. M. Ullah and R. Hafiz, Geocarto Int. **29**, 256–267 (2014).
9. S. Abdullahi, A. R. bin Mahmud, and B. Pradhan, Geocarto Int. **29**, 164–184 (2014).
10. E. A. Baltas and M. A. Mimikou, Int. J. Digital Earth **2**, 171–185 (2009).
11. Q. Hou and L. Gao, Procedia Eng. **15**, 5525–5530 (2011).
12. L. Arya and S. C. Sharma, "Coverage and analysis of obstructed indoor WLAN using simulation software and optimization technique 1," in *Conference on Advances in Communication and Control System* (Atlantis Press, Dehradun, 2013), pp. 631–637.
13. E. Triantaphyllou and S. H. Mann, Int. J. Ind. Eng. Theory: Appl. Pract. **2**, 35–44 (1995).
14. P. Calegari, F. Guidec, P. Kuonen, and D. Kobler, J. Parallel Distrib. Comput. **47**, 86–90 (1997).
15. E. Alba, "Evolutionary algorithm for optimal placement of antennea in radio network design," in *18th International Parallel and Distribution Processing Symposium* (IEEE, 2004), pp. 1–8.
16. A. B. Primawan, Int. J. Sci. Res. Eng. Technol. **7**, 348–353(2018).
17. C. B. Andrade, R. Pierre, and F. Hoefel, "IEEE 802.11 WLANS: A comparison on indoor coverage models," in *23rd Canadian Conference on Electrical and Computer Engineering* (IEEE, 2010), pp. 1–6.
18. P. K. Sharma and R. K. Singh, Int. J. Electron. Commun. Eng. **4**, 225–32 (2011).
19. A. B. Primawan, "GIS-based optimization framework for WLAN access point placement using multi-objective genetic algorithm," Ph.D. thesis, Asian Institute of Technology, Bangkok, 2017.
20. A. B. Primawan and N. K. Tripathi, Int. J. Inf. Commun. Technol. **13**, 439–453 (2018).

Faculty of Science and Mathematics
Universitas Kristen Satya Wacana

Certificate

Award to:

Dr. Augustinus Bayu Primawan

as Presenter

at the 4th International Conference on Science and Science Education (IConSSE) 2021
organized by Faculty of Science and Mathematics-Universitas Kristen Satya Wacana

Salatiga, September 7-8, 2021

Dr. Adi Setiawan, M.Sc.
Dean-Faculty of Science and Mathematics

Dr. Adita Sutresno, M.Sc.
Chairman-The 4th IConSSE 2021