Location-Allocation Optimization of Wi-Fi Access Points at Gaziantep University Campus

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Abstract

The internet plays a very vital role in the education sector. Having a good internet connection in an educational institution such as a university campus is a must-have. For a campus network, the university installs WLAN Access Points (AP) in certain areas. Users can access the internet using their devices in these certain areas covered by the APs signal. This study is applied to the Gaziantep University campus in order to find the optimal locations of outdoor access points that satisfy demand points. To do so, first of all, geographic information of 17 current and 14 new potential locations of outdoor access points, and 25 demand points were gathered using their GPS coordinates. Second, two of the location-allocation models were used; one of them is the Set-Covering model which was used to find the minimum number of outdoor APs to cover all campus areas within a specific distance. The other one is the maximal-coverage location problem (MCLP) model which tries to maximize the demand to be covered, served by a fixed number of Wi-Fi APs. Distances between the total 31 potential locations and 25 demand points were taken using the Euclidean Distance Algorithm. Then, the models were solved using GAMS, software for mathematical optimization. The results obtained were compared with the current system and showed approximately 30% improvements in some aspects.

Keywords
Campus network, Wi-Fi, WLAN, Access point, Set-covering, Maximal-coverage, Euclidean distance.

1. Introduction
In today's world, the Internet is one of the most indispensable technologies. And since the emergence of the Internet, it has become an important medium of communication as well as a research and leisure tool. The reason is that it provides many opportunities to many people around the world in many different ways. The internet serves nearly 5.07 billion people worldwide (63.5% of the population). The role of the internet is observable not only in statistics but also more visibly in everyday life: in social interactions, entertainment, business, science, and especially in education

The internet plays a very vital role in the education sector. And having a good internet connection in an educational institution such as a university campus is a must-have. A university campus network is far more than just a physical infrastructure, and planning and having full coverage of a good internet connection in a university campus means developing an entirely new information environment that will have a profound impact on almost every aspect of campus life such as full access to information in any place at any time, enhanced communication between students/faculties/staffs in the campus and increasing their welfare.

A campus network is a set of interconnected Local Area Networks (LAN). And a Local Area Network (LAN) is a group of computers and peripheral devices that share a common communications line or wireless link to a server that connects multiple sites or buildings, within a distinct geographic area. When two or more devices use wireless communication, they form a Wireless Local Area Network (WLAN). A WLAN uses Wi-Fi technology to connect devices wirelessly and transmit data over radio frequencies, allowing users to move around within the area and remain connected to the network.

A Wi-Fi or (Wireless Fidelity) is a wireless protocol that uses 802.11 standards created by the Institute of Electrical and Electronics Engineers (IEEE). These standards operate in different frequencies and other distinct features making up the different types of WLANs.

Wi-Fi is achieved with a wireless base station, called an access point (AP). An access point (AP) provides access to the network (LAN) wirelessly (WLAN). It broadcast a Wi-Fi signal to devices such as laptops, mobile phones, and tablets so that these devices can connect wirelessly to the internet network.

1.1 Problem Statement and Objectives

The campus of Gaziantep University is considered our study area. Gaziantep University covers a very large physical area, with 20 faculties, 2 high institutes, 11 vocational schools, 5 institutes, 28 research and application centers, and 5 units affiliated to the Rectorate distributed over an area of 3,113,084 m2 serving more than 46,000 population including students, administrative and academic staff.

In this paper, our aim is to enhance the communication environment and the accessibility to the internet network of the Gaziantep University campus.

Our study is focused on areas inside the main campus where students and staff visit more often. The area of study is shown in Figure 1 and it is 562,000 m2.

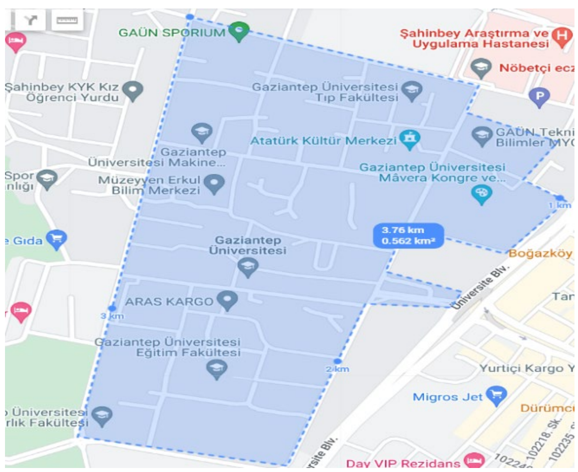

Figure 1. Gaziantep University Campus Study Area

The area of study was determined according to higher population density. Therefore, areas such as forests will be neglected. However, the selected area contains all of the faculties and buildings inside our campus. Gaziantep University's main campus internet network is provided by a total of 648 access points, which are a combination of 631 indoor APs and 17 outdoor APs. Indoor APs are access points that are suitable to be installed inside a building. On the other hand, outdoor APs are access points that are more suitable to be installed outside the building. The Huawei AP8030DN outdoor access point is used in the campus currently. In our study, the 17 of AP8030DN outdoor access points will be our main focus. As can be noticed there is a large physical area with only 17 APs to cover it. Thus, a study of improvement must be considered.

2. Literature Review

In this section, we give a brief review only of the most relevant references and the latest ones on location-allocation models for Wi-Fi coverage and similar studies, alongside a review of Wi-Fi network analysis.

2.1 Location-allocation models

Location allocation models are well-known in the literature. They are mathematical models used to determine optimal locations of facilities based on a set of defined variables (Forsey 2014). For the latest studies where location-allocation models were applied in different sectors and purposes, Forsey (2014), Özceylan et al. (2017), Arifin (2010), and Brangers (2019) can be examined. Mete et al. (2018) gave the concepts of set-covering and MCLP models; which were used in our paper. For Wi-Fi coverage, Rengarajan & de Veciana (2008), Primawan (2018), and Kouhbor et al. (2006) can be examined.

2.2 Wi-Fi network analysis

Understanding wireless networks is playing a vital role in achieving optimal network performance. In order to get information and to understand campus wireless network structure, Becker (2005); explained wireless networking and showed detailed visualization and mapping providing information about signal propagation from wireless networks. In their work, Schwab and Bunt (2005), and Easha et al.(2020) described the concepts of a campus wireless network. In this paper, by taking into consideration the understanding of a campus Wi-Fi network behavior, location-allocation models were used to improve the coverage of Gaziantep University campus network.

3. Methods

If a university has an unlimited budget, then it can install APs in many places as needed to cover the whole campus area. However, due to limited budgets, a university must place APs in locations with high connection demand. But not only budget is the whole concern, bad location is also as much worse. A bad location of any facility has a negative effect to provide services to the beneficiary. Distance between the area of supply and the area of demand should be optimal. Our aim in this paper is to find the optimal locations of access points that will satisfy the demand points with the limited available resources. To do so, the Set-Covering location-allocation model will be used to find the minimum number of facilities – in our case the APs – to cover a specified number of demand points within a specific distance. Thus, the current outdoor APs inside the main campus will be identified. Then accordingly, potential locations, coverage range, as well as demand points and distances will be determined. After that, the model will be solved using GAMS studio 40 software. The maximal-covering location problem (MCLP) model will be used as well. (MCLP) tries to cover the maximum amount of demand within a specific distance. Again, the parameters mentioned previously, plus demand weights will all be considered, and the model will be solved.

4. Data Collection

4.1 Campus Current Network Analysis

After gathering some data about the current locations of each outdoor AP inside the campus which are located on a map are illustrated in Figure 2. An important parameter, which is the distance an AP8030DN access point can cover, will be determined by investigating the signal broadcasted by each AP.

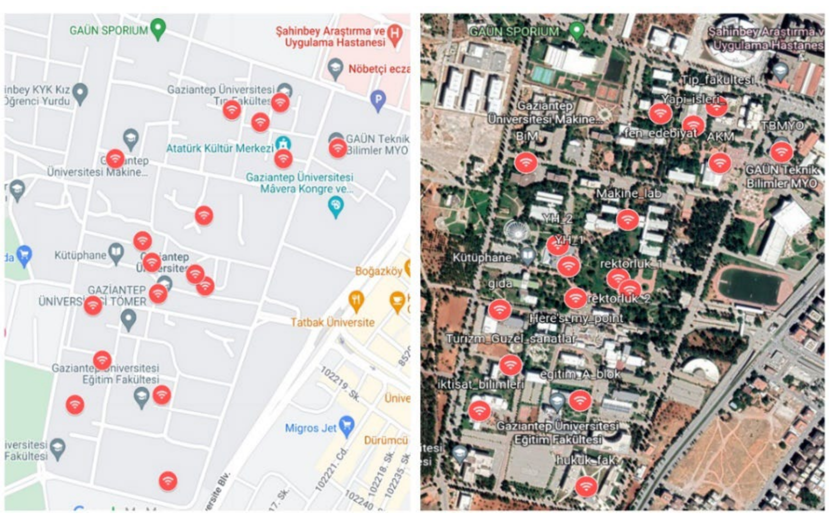

Figure 2. Current locations of Wi-Fi APs inside the campus

Wi-Fi scanning is the process of identifying wireless networks by looking for these signals that are in the range of a Wi-Fi adapter. The coverage area is primarily determined by the power that the signals are transmitted at. Wi-Fi signals data can be obtained by Wi-Fi scanning applications. These applications gather information about access points on wireless networks and display it in an easy-to-understand, visually accessible way.

4.1.1 Wi-Fi Analyzer application

Wi-Fi analyzer is a useful scanning tool whose purpose is to provide a wealth of information about wireless networks, including their signal strength, names, location of the Wi-Fi adapter, and security configuration. Using the Wi-Fi analyzer application, the coverage distance was determined in meters as a radius value. While opening the application and walking down a street, a weak signal might be seen from an access point. Then, by observing the signal, it gets stronger by approaching the actual location of the access point. At some point, the more we approach the access point the more the signal strength will reach a maximum, and then it will start declining as moving farther away, with the application giving the distance between the mobile phone and the access point being detected as shown in Figure 3. As it is seen from Figure 3, there are several networks listed on the list. In Figure 3 there are several networks having the name such as, GAUNNET network, the reason is that every network is broadcasted in different locations thus, to differentiate between each network, every network is assigned a MAC address.

A MAC or a media access control address is a unique identifier assigned to a network interface controller for use as a network address in communications within a network segment. As shown in Figure 3, the first GAUNNET network in the list with a MAC: f0:2f:a7:8e:e5:30 is the network broadcasted by the AP8030DN that is located in the Student Affairs Department. Alongside the MAC: f0:2f:a7:8e:e5:30 there is a (1m) parameter. 1m indicates that right now the mobile device detecting this network using the analyzer application is 1 meter away from the AP8030DN access point located in the student affairs department. To make sure that this information is correct, it can be seen from Figure 3 that the network signal strength is very high in the green area indicating that we are very close to the access point. On the signal meter, the meter normally ranges between -40 dBm to -100 dBm. The larger the number the stronger the network signal will be. In Figure 4, GUANNET (MAC: f0:2f:a7:8e:e5:30) is found to be the last on the list and our mobile device is 54m away from the access point broadcasting this network. At that point, the indicator now was pointing to -100 dBm in the grey area saying that the signal is lost now and is no longer connected to that network anymore.

Figure 3. List of available internet access points in a distinguished area (left-side), alongside a signal strength meter (right-side).

Figure 4. Internet connection signal loss of GUANNET (MAC: f0:2f:a7:8e:e5:30) network

4.1.2 Coverage distance

Several trials at different days for different locations were done using the Wi-Fi Analyzer application in order to get more accurate information about the coverage distance. According to the results obtained by the Wi-Fi analyzer, the coverage distance of the AP8030DN access point was found to be 50 meters radius. This result is found as an average value due to some factors that may affect the signal strength such as bad weather conditions, technical problems and some physical obstructions such as (walls, trees, ceilings, metal doors, etc.).

4.1.3 Demand Points and Potential Locations

In this paper, 25 demand points and 31 potential locations were determined. The GPS information of each demand point and potential location were found via Google Maps.

The demand of our study is the internet users, which in this case are considered to be students and staff of the campus. The location of each demand point accompanied by the building/area name that our demand exists in, longitude and latitude are all listed in Figure 6. The demand points were identified first after analyzing the current locations of Wi-Fi APs inside the campus and discovering the uncovered areas that need to be covered. In addition, demand points were also determined based on the idea that these points are the most visited, as well as being the most demanded locations where all of the staff and students are demanding an internet connection in it. After that, each demand point is assigned a value or a weight that indicates the importance of each demand point. The number of students and staff visiting the demand points in the campus is given in Table 1. In Table 1, the demand points, their areas names, and the number of students/staff that are passing by these areas in rush hours between 12:00-2:00 PM are all given.

Demand Point	Longitude	Latitude
D1. Mavera Center	37.03755	37.31706
D2. Sporium (Sport center)	37.04114	37.31298
D3. Student Dining Hall 1	37.03638	37.31311
D4. Library	37.03617	37.3123
D5. Market	37.03476	37.31341
D6. Central Classroom MD	37.03736	37.31376
D7. Electric.E.E café	37.03737	37.31275
D8. Faculty of Economy	37.03306	37.31118
D9. Faculty of Fine Arts	37.03447	37.31188
D10. TBMYO institute	37.03888	37.31766
D11. Faculty of Medicine	37.0393	37.3161
D12. Faculty of Theology	37.03307	37.31386
D13. Atatürk Culture Center	37.03822	37.31677
D14. Civil Engineering	37.03879	37.31173
D15. Conservatory	37.03825	37.31516
D16. Faculty of Education	37.03327	37.31328
D17. Student Affairs	37.03564	37.31291
D18. Food Engineering	37.0355	37.31137
D19. Rectorate	37.03551	37.31457
D20. Enterance	37.03505	37.31643
D21. Fac. of Architectures	37.03222	37.31135
D22. Kitap Café (Fac. of Law)	37.03203	37.31342
D23. Fac. of Arts and Sciences	37.03948	37.31448
D24. Sporium 2	37.04021	37.31362
D25. Student Dining Hall 2	37.03682	37.3131

Figure 6. Demand points and spatial locations using Longitude and latitude

The potential locations were all determined based on demand points and the availability of installing the APs in such locations. These potential locations include the 17 currently used locations of the APs as well as 14 new locations we identified ourselves. As a result, we found 31 potential locations in total. The area name of each potential location, its longitude and latitude, and its spatial locations are all given in Figure 7. There were some areas, after analyzing them were found to be unsuitable to install the APs due to lack of demand, unavailable infrastructures for the APs installation. These areas are areas such as forests, areas under construction and sports playgrounds. Thus, we did not consider these areas as potential locations.

Table 1. Demand points with user population during rush hours

DEMAND POINT	BUILDING NAME	POPULATION
D1	Mavera Center	275
D2	Sporium (Sport center)	430
D3	Student Dining Hall 1	685
D4	Library	500
D5	Market	620
D6	Central Classroom MD	400
D7	Electric.E.E café	480
D8	Faculty of Economy	175
D9	Faculty of Fine Arts	490
D10	TBMYO institute	200
D11	Faculty of Medicine	325
D12	Faculty of Theology	175
D13	Atatürk Culture Center	200
D14	Civil Engineering	375
D15	Conservatory of Turkish music	175
D16	Faculty of Education	230
D17	Student Affairs	550
D18	Food Engineering	250
D19	Rectorate	530
D20	Entrance	600
D21	Fac. Of Architectures	175
D22	Kitap Café (Fac. Of Law)	350
D23	Faculty of Arts and Sciences	300
D24	Sporium 2	385
D25	Student Dining Hall 2	600
TOTAL		9475

AP POTENTIAL LOCATION	Longitude	Latitude
S1. Data Processing Center (BIM)	37.03842	37.3118
S2. Student Dining Hall 2	37.0367	37.31256
S3. Student Dining Hall 1	37.03626	37.31282
S4. Food Engineering	37.03535	37.31117
S5. Faculty of Fine Arts	37.0342	37.31143
S6. Faculty of Economics	37.03325	37.31069
S7. Faculty of Law B Block	37.03167	37.31325
S8. Student Affairs Department	37.03559	37.31299
S9. Rectorate 1	37.03576	37.31429
S10. Rectorate 2	37.036	37.31401
S11. Mechanical Eng. Lab	37.03723	37.31424
S12. Fac. of Education A Block	37.03346	37.3131
S13. Atatürk Culture Center	37.03842	37.31646
S14.TBMYO Institute	37.03864	37.31795
S15. Faculty of Medicine	37.03961	37.31638
S16. Construction Works (Yapı işleri)	37.0392	37.31582
S17. Fac. of Arts and Sciences	37.03945	37.31502
S18. Mavera Congress Center	37.03742	37.31679
S19. Entrance 2 (near to Atatürk status)	37.03548	37.3151
S20. Entrance Door 1	37.035	37.31681
S21. Physics Engineering	37.03412	37.31379
S22. Textile Engineering	37.03367	37.31396
S23. 75.yil Department	37.03444	37.31266
S24. Biology	37.03459	37.3135
S25. Faculty of Architectures	37.03199	37.31114
S26. Red Crescent Center (kızılay)	37.03718	37.31331
S27. Engineering Dean's Office	37.03859	37.3129
S28. Sporium Sports Center	37.04085	37.31352
S29. Electrical and Electronics Engineering	37.03767	37.31267
S30. Faculty of Theology	37.03307	37.31361
S31. Conservatory of Turkish Music	37.03806	37.31558

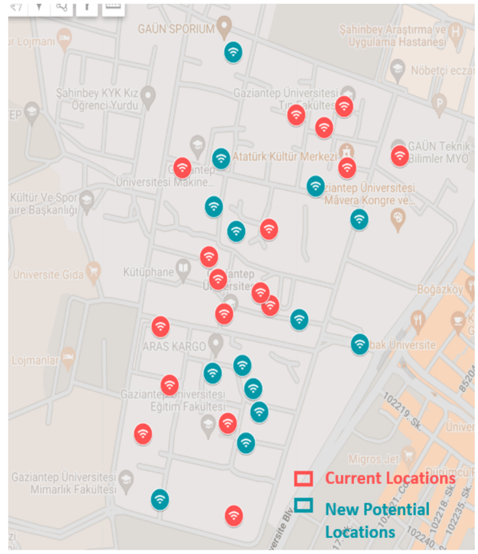

Figure 7. APs Potential Spatial Locations Using Longitude and Latitude information

4.2 Location- Allocation Models

In this part, two main location-allocation models were implemented. The models are the Set-Covering and the Maximal coverage Location Problem models.

4.2.1 Set-Covering Problem

The set-covering problem is identified as a facility location selection problem in a way to reach every cluster at least once in a predetermined time/distance on a network. As all networks consist of N nodes and A edges**;** the nodes were considered either as a demand point I or as a potential location K. Set-covering model formulation is given as follows:

Decision variables:
$y_k = 1$, if potential location k is selected to install an AP ($\forall k \in K$);
0, otherwise
Objective function:

$$\text{Min } Z = \sum_{k \in K} y_k \tag{1}$$

s.t.

$$\sum_{k \in K} a_{ik} y_k \geq 1 \qquad \forall i \in I \tag{2}$$

$$y_k \in \{0, 1\} \qquad \forall k \in K \tag{3}$$

The objective function (1) is to minimize the number of APs to be installed. Constraint (2) is to provide service from at least one installed AP to every demand points within the predetermined distance. Constraint (3) is the integrality constraint of the decision variable. Here, a_{ik} is 1, in a case can be reached from k to i in a predetermined distance; 0, otherwise.

4.2.2 Maximal Coverage Location Problem

The MCLP seeks to satisfy the maximum population which can be served within a stated service distance or time, given a limited number of facilities. The MCLP model is defined on a network of nodes N, consisting of an index and set of demand I, and an index and set of potential locations K. The formulation of MCLP is:

Decision variables:
$x_i = 1$, if demand point at i is covered ($\forall i \in I$);
0, otherwise
$y_k = 1$, if potential location k is selected to install an AP ($\forall k \in K$);
0, otherwise

Objective function:

$$\text{Max } Z = \sum_{i \in I} w_i x_i \quad (4)$$

s.t.

$$\sum_{k \in N_i} y_k \geq x_i \quad \text{for all } i \in I \quad (5)$$

$$\sum_{k \in K} y_k = P \quad (6)$$

$$x_i \in \{0, 1\} \quad \text{for all } i \in I \quad (7)$$

$$y_k \in \{0, 1\} \quad \text{for all } k \in K \quad (8)$$

The objective function (4) is to maximize the number of students served or "covered" within the desired service distance where demand population is represented by w_i. Constraint (5) allows the demand point x_i to equal 1 only when one or more potential locations are established at sites in the set N_i (that is, one or more potential locations are located within S distance units of demand point i). The number of facilities allocated is restricted to equal P in constraint (6). Constraints (7) and (8) are the integrality constraints of the decision variable.

4.2.3 Distances Measuring and Computations

Measuring the distances between the potential location points and the demand points is one of the essential steps of studying and implementing this project. The distances between the 31 potential location points and the 25 demand points were calculated using the **Euclidean Distance Algorithm**. The Euclidean distance is defined as the distance measured along the straight-line path between two points. All calculations are done via Microsoft Excel to get the distance matrix in Table 2.

5. Results and Discussion

In this section, GAMS was used to find the optimal solution to the problem. GAMS software is a high-level modeling system for mathematical programming and optimization. A heat map was created as well using PyCharm software with a Python 3.8 version programming language. The heat map is just a rough visualization tool that was used to represent the propagation of Wi-Fi signals to give more clear insights about the results obtained. In the heat map, the strongest signal is illustrated by the red color, and the weaker the signal becomes the more the colors move to the blue range.

Table 2. Distances (m) between demand points and potential locations of APs.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	533	296	242	230	399	222	141	539	395	587	438	573	497	37	336	535	299	295	401	572	621	659	288	255	206
2	457	445	636	59	211	136	69	389	233	554	432	385	447	224	302	350	111	169	233	420	464	474	337	366	50
3	443	488	31	50	161	144	111	359	202	550	447	335	440	275	307	302	62	163	190	380	429	427	362	403	62
4	628	606	219	139	231	327	256	229	113	738	631	352	629	348	493	296	176	25	340	526	313	401	529	544	242
5	655	711	275	215	205	392	343	116	10	779	691	267	668	460	550	207	206	130	340	507	198	294	609	639	310
6	768	821	395	333	311	513	460	40	170	895	811	317	785	563	670	259	326	235	449	601	122	299	729	755	430
7	700	947	471	459	309	571	572	249	311	845	814	152	743	728	685	160	398	426	406	464	197	39	790	854	515
8	451	555	79	90	93	193	179	311	157	571	484	266	460	343	343	233	5	162	158	348	374	358	416	466	123
9	329	553	133	203	133	168	222	411	273	459	397	272	349	396	263	268	138	293	37	225	460	383	372	450	159
10	342	524	97	171	137	138	186	408	262	464	390	293	354	360	252	282	115	268	74	260	462	401	351	422	122
11	283	410	141	221	260	49	149	517	363	379	278	417	271	295	137	407	207	335	175	309	578	526	226	304	121
12	569	768	292	282	133	395	392	196	158	708	656	85	601	550	521	26	218	267	252	369	214	146	617	677	336
13	105	441	392	472	476	290	385	752	604	128	95	594	36	474	131	605	450	586	347	337	803	707	224	335	372
14	140	556	534	616	597	438	535	877	736	37	196	691	125	622	281	711	586	729	460	389	920	801	357	460	518
15	216	372	459	533	568	345	426	836	683	147	41	700	144	472	182	705	527	648	448	456	893	813	190	282	430
16	206	343	391	464	505	276	357	769	615	186	29	643	136	411	115	645	459	578	389	419	828	756	136	242	361
17	278	264	361	426	495	244	307	745	588	270	109	648	213	335	120	642	435	537	396	462	810	759	50	159	325
18	29	532	382	466	430	303	404	710	572	169	200	524	80	524	182	543	426	575	292	239	752	635	309	422	373
19	285	604	218	288	183	230	301	460	337	425	394	271	320	472	277	286	219	373	50	139	496	383	404	495	240
20	256	723	394	465	340	385	470	595	495	397	435	352	322	633	364	393	395	546	229	38	612	450	505	610	413
21	473	706	236	253	74	324	341	281	194	613	567	105	506	510	435	99	175	278	159	279	309	212	540	609	278
22	496	753	284	300	122	369	389	284	222	639	602	60	534	558	473	78	223	317	193	282	298	172	583	654	326
23	538	670	199	176	81	312	293	202	78	668	595	182	558	444	455	132	122	167	218	381	257	252	535	584	242
24	462	657	183	198	19	278	287	277	162	597	537	156	488	455	401	133	120	231	141	296	320	256	498	562	226
25	812	933	481	433	358	597	561	107	258	948	883	292	839	682	744	249	405	351	491	611	31	228	820	858	521
26	376	397	82	142	242	48	59	463	306	467	350	414	361	225	213	391	159	256	209	377	533	515	258	304	41
27	428	255	221	249	386	150	122	579	424	476	327	560	388	118	228	533	295	344	350	499	655	658	181	177	178
28	483	50	448	483	609	349	356	813	658	458	300	778	418	272	307	758	524	576	544	648	889	882	167	50	405
29	439	348	136	154	300	113	31	484	329	513	379	475	413	146	255	444	204	253	287	458	560	569	256	271	95
30	565	809	334	336	170	429	438	243	222	708	670	25	604	602	540	38	266	330	262	344	241	105	646	714	378
31	156	403	298	378	394	194	291	666	515	223	134	527	120	391	46	531	360	492	274	312	721	640	179	290	277

5.1 Numerical Results

5.1.1 GAMS Set-Covering Model Results

According to the solution obtained by GAMS, the total minimum number of APs to ensure full coverage in all of the areas chosen inside of the campus was found to be 21 APs. 12 out of the 21 locations – around 57.1% – are current locations used by the university. The remaining 9 are new locations as shown in Table 3.

5.1.2 GAMS MCLP Model Results

According to GAMS, the maximum number of satisfied demands of the MCLP model was found to be 8750 users. This number of users is satisfied during rush hours between 12:00-2:00 PM using the same number of APs that are used in our campus which are 17 APs where 10 access points (58.8%) are at their same current location while the remaining 7 are at new locations. The results were all listed in Table 3, showing the 17 optimal locations that satisfy the maximum amount of demand in the campus.

5.3 Proposed Improvements

The signal provided by an access point is broadcasted in a circular shape, and as we have mentioned previously, walls and insulating building materials weaken or cancel the Wi-Fi signal. Thus, in order to ensure that no part of the signal is lost in vain we recommend the access points to be placed on top of a medium-height pole with a stable power supply such as utility poles and surveillance poles, not on walls -as it's currently placed in the campus- so that we can fully benefit from access point coverage.

5.3.1 Set-Covering Model

The Set-Covering problem's solution (Figure 8) costs more than current system since it requires a greater number of APs to obtain a wider coverage range. But on the other hand, let us not forget the fact that with this solution all of the demand points are satisfied. Thus, campus's welfare and internet service quality are significantly increased.

5.3.2 Maximal Coverage Model

The total summation of the demand weights that we assigned to each demand point in our study was 9475 users during rush hours as was mentioned before in Table 1. According to the results obtained by GAMS, the maximum demand covered was found to be 8750 users. Which corresponds to a 92.34% demand satisfaction as a percentage? Using the same demand weights data, the campus's current system demand coverage was found to be 6210 users which are 62.5% of the total demand. As it can be seen, our maximal coverage study shows a 29.84% increase in demand coverage with the same 17 APs but in different locations, indicating an improvement in user satisfaction in the campus. Figure 9, visualizes the difference between the distribution of the current network system and the solution of the MCLP. It can be observed that our results are distributed approximately in most of the places in the campus taking into consideration the most crowded areas such as the entrance door, campus market, and the Sporium center. These mentioned places are places and locations that the campus's current AP distribution doesn't cover.

6. Conclusion

In this study, the current environment of the network on the campus of Gaziantep University was investigated. Based on the quest to develop and improve it, two of the Location-Allocation models, the Set-Covering and the Maximal Coverage Location Models were represented and their solutions were reviewed. Our results guided our planning by telling us two important things: (1) which areas need more wireless coverage and (2) which demand points need more focus. Table 3 showed the optimal locations found for both models using GAMS where current locations, as well as the new locations, are all illustrated in Table 3. The results obtained by the MCLP model showed a 29.84% improvement in terms of user satisfaction by covering areas with a higher user population using the same number of APs currently used in the campus but with some of them at new different locations as it can be visualized in Figure 9 compared with the current system. Eventually, implementing the Set-Covering model to cover the entire campus (Figure 8), should take into account the proposals presented in the study, or perhaps choosing Wi-Fi devices with higher efficiency in terms of coverage range, the maximum number of users, and signal strength depending on the budget, as always there must be trade-offs.

Table 3. Optimal locations according to GAMS solution of set-covering (left-side) & MCLP (right-side)

Potential locations	Chosen Location	
S1. Data Processing Center (BIM)	✓	**(current)**
S2. Student Dining Hall 2		
S3. Student Dining Hall 1	✓	**(current)**
S4. Food Engineering	✓	**(current)**
S5. Faculty of Fine Arts	✓	**(current)**
S6. Faculty of Economics	✓	**(current)**
S7. Faculty of Law B Block	✓	**(current)**
S8. Students Affairs Department	✓	**(current)**
S9. Rectorate 1	✓	**(current)**
S10. Rectorate 2		
S11. Mechanical Eng. Lab		
S12. Faculty of Education A Block		
S13. Atatürk Culture Center	✓	**(current)**
S14. TBMYO Institute	✓	**(current)**
S15. Faculty of Medicine	✓	**(current)**
S16. Construction Works (yapı işleri)		
S17. Fac. of Arts and Sciences	✓	**(current)**
S18. Mavera Congress Center	✓	
S19. Entrance 2 (near to Atatürk statue)		
S20. Entrance Door 1	✓	
S21. Physics Engineering		
S22. Textile Engineering		
S23. 75.yil Department		
S24. Biology	✓	
S25. Faculty of Architectures	✓	
S26. Red Crescent Center (kızılay)	✓	
S27. Engineering Dean's office		
S28. Sporium Sport Center	✓	
S29. Electrical and Elec. Engineering	✓	
S30. Faculty of Theology	✓	
S31. Conservatory of Turkish Music	✓	

Potential locations	Chosen Location	
S1. Data Processing Center (BIM)	✓	**(current)**
S2. Student Dining Hall 2		
S3. Student Dining Hall 1	✓	**(current)**
S4. Food Engineering	✓	**(current)**
S5. Faculty of Fine Arts	✓	**(current)**
S6. Faculty of Economics		
S7. Faculty of Law B Block	✓	**(current)**
S8. Students Affairs Department	✓	**(current)**
S9. Rectorate 1	✓	**(current)**
S10. Rectorate 2		
S11. Mechanical Eng. Lab		
S12. Faculty of Education A Block		
S13. Atatürk Culture Center		
S14. TBMYO Institute	✓	**(current)**
S15. Faculty of Medicine	✓	**(current)**
S16. Construction Works (yapı işleri)		
S17. Fac. of Arts and Sciences	✓	**(current)**
S18. Mavera Congress Center	✓	
S19. Entrance 2 (near to Atatürk statue)		
S20. Entrance Door 1	✓	
S21. Physics Engineering		
S22. Textile Engineering		
S23. 75.yil Department		
S24. Biology	✓	
S25. Faculty of Architectures		
S26. Red Crescent Center (kızılay)	✓	
S27. Engineering Dean's office		
S28. Sporium Sport Center	✓	
S29. Electrical and Elec. Engineering	✓	
S30. Faculty of Theology	✓	
S31. Conservatory of Turkish Music		

Figure 8. Heat map of set-covering model (left-side) vs. the current campus network (right-side)

Figure 9. Heat map of MCLP (left-side) vs. the current campus network (right-side)

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Biography

Ola Khanji is an Industrial Engineering student at Gaziantep University in Gaziantep, Turkey. A Syrian. She was born in 2001 in Aleppo. She studied primary school there before moving to Turkey in 2012, and now she is based in Gaziantep. She started her undergraduate journey in 2019 as an Industrial Engineering student in order to achieve her goal of transferring this knowledge to her country upon her return.

Lana Manla Ali is an Industrial Engineering student at Gaziantep University in Gaziantep, Turkey. She was born in Aleppo, Syria. She will be graduating in 2023, and currently planning to combine the theoretical education infrastructure she obtained during the course of her education with practical knowledge in her internship period. She also intends to apply to graduate school to further her knowledge and passion in industrial engineering and progress toward a career as a researcher.

Eren Özceylan is an associated professor in Industrial Engineering Department, Gaziantep University, Gaziantep, Turkey. He received his Ph.D. from Selçuk University, Computer Engineering in 2013. His research focuses on logistics and supply chain management. In particular, he focuses on supply chain network design, environmental conscious production/distribution, GIS-based multi-criteria decision-making and fuzzy logic.